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The effects of m-learning on motivation, achievement and well-being: A Self-Determination Theory approach

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Abstract

From the lens of Self-Determination Theory, this study investigated the effects of a mobile application tool for identifying species on biology students' achievement and well-being. It was hypothesized that the mobile application, compared to a textbook, would enhance feelings of competence and autonomy and, in turn, intrinsic motivation, positive affect and achievement, because the mobile application's built-in functions provide students with choice and volition, informational feedback, and optimal challenges. Fifty-eight second-year students were randomly assigned to use either the mobile application or a textbook for a learning task. Well-being was assessed before and after the learning task, and intrinsic motivation, perceived competence, perceived autonomy and achievement were assessed after the task. Results indicated that the mobile application, relative to the textbook, produced higher levels of students' perceived competence, perceived autonomy and intrinsic motivation. Further, the mobile application had indirect effects on positive affect through autonomy, competence and intrinsic motivation, and on achievement through competence.

Introduction

Technological tools have become widespread among youth, with computers and smartphones being the most common. In Norway, 92% of the students have some form of Information and Communication Technology (ICT) in their homes (OECD, 2015). Specifically, 97% of young adults (16–25 years) have access to smartphones (Slettemeås and Kjørstad, 2016). Importantly, mobile-learning (m-learning), which is defined as "learning across multiple contexts, through

Practitioner Notes

What is already known about this topic

- Mobile learning has become widespread and a necessity in today's society, and thus an important tool to consider in both formal and informal learning contexts
- Mobile learning can impact students' learning and motivation through extending the learning space, facilitating collaboration and interacting with course content.
- Research generally show that mobile learning contributes to student retention and satisfaction with learning content.

What this paper adds

- Employs the prominent motivational theory Self-Determination Theory to understand how and why mobile learning might facilitate student motivation and achievement.
- Investigates psychological well-being aspects of using mobile learning in a learning situation.

Implications for practices and/or policy

- Teachers and instructors needs to understand the underlying need supportive elements of identification tools to facilitate students' intrinsic motivation, perceived competence, achievement and psychological well-being.
- Intrinsic motivation, perceived competence, and psychological well-being are important factors to consider in order to maintain student engagement and motivation throughout a learning situation.

social and content interactions, using personal electronic devices" (eg, smartphone, PDA, tablet; Crompton, 2013, p. 4), affords learning opportunities beyond the traditional methods used in classrooms, such as the ability to extend the learning space from a formal context (classroom) to an informal context (social network, augmented reality, location awareness). Furthermore, m-learning may have additional benefits such as increasing students' mastery with learning tasks, providing prompt feedback, facilitating faster learning by offering efficient ways to access information, affording opportunities to interact with the course content (Hashemi, Azizinezhad, Najafi, and Nesari, 2011) and enhancing intrinsic motivation (ie, engaging in activities because of the inherent interest and enjoyment of the activity; Jeno, Grytnes, and Vandvik, 2017).

The intrinsic motivational pull of m-learning tools is especially valuable, given that students report low levels of intrinsic motivation in traditional classroom contexts (Brahm, Jenert, and Wagner, 2016). However, it is less clear how m-learning impacts achievement and well-being, as research on m-learning and motivation in science education is still in its infancy and thus represents an exciting new area for discovery (Zydney and Warner, 2016). The goal of our research, therefore, was to investigate the effect of m-learning tool via a mobile application on students' achievement and well-being, from the lens of the prominent theory of human motivation and wellness, Self-Determination Theory (SDT; Ryan and Deci, 2017). In addition, we examine potential underlying mechanisms of these effects, namely basic psychological need satisfaction and intrinsic motivation.

Self-determination theory

SDT is a macro-theory of human motivation and wellness that focuses largely on how environments support or thwart people's basic psychological needs for autonomy (experiencing volition and self-endorsement), competence (feeling effective and capable) and relatedness (having a sense of social connection and belongingness). When people's basic psychological needs are satisfied rather than frustrated, SDT predicts that people will display enhanced motivation, performance and well-being.

SDT is comprised of six mini-theories addressing different elements of human motivation and wellness, such as goal contents, regulatory processes, interpersonal relationships, individual differences in motivational styles and the universality of basic psychological needs. One mini-theory, Cognitive Evaluation Theory (CET), is particularly pertinent to the current research on mobile application, as CET focuses on how environments, such as learning activities, can support the mechanisms of need satisfaction and intrinsic motivation (Ryan and Deci, 2017). Specifically, CET suggests that the need for autonomy is satisfied in learning tasks when individuals experience meaningful choices and volition, and the need for competence is satisfied when individuals are provided with optimal challenges and effectance-relevant feedback. Moreover, CET posits that learning tasks that satisfy and support the needs for autonomy and competence will, in turn, enhance intrinsic motivation, performance (eg, achievement) and well-being (eg, having high positive affect and low negative affect; Deci and Ryan, 2000). Assessing the motivational pulls of a mobile application for learning from the lens of CET is especially useful for several reasons. First, CET has specific hypotheses on how features within a mobile applications can support students' experiences of autonomy and competence and in turn enhance their intrinsic motivation for learning (Ryan and Deci, 2017). Second, within the technology field research has shown that consistent with CET, virtual environments that are the most intrinsically motivating and engaging are those that satisfy the basic needs for autonomy and competence (Rigby and Ryan, 2017). Last, in addition to increased intrinsic motivation, CET postulates that the satisfaction of autonomy and competence within virtual environments, should also enhance positive affect and vitality (Ryan, Rigby, and Przybylski, 2006). Thus, we ground the current research in CET, by examining whether experiences of competence and autonomy explain the effects of a mobile application on enhancing student's intrinsic motivation, achievement and well-being.

Mobile application tools, achievement and basic psychological needs

Several studies have found that mobile application tools and technology positively contribute to learning and achievement (Archer *et al.*, 2014; Wu *et al.*, 2012). For instance, mobile application have had positive effects on students' achievement in a variety of domains such as learning to identify birds (Chen, Kao, and Sheu, 2003), statistics (Ling, Harnish, and Shehab, 2014) and physiotherapy (Noguera, Jiménez, and Osuna-Pérez, 2013). Contrary to these studies, however, Thomas and Fellowes (2016) found no significant difference between the use of a mobile application and a standard textbook on achievement scores for students. Clearly, further research is needed to investigate the effects of these m-learning tools on students' educational outcomes.

SDT-based research in other tangentially related areas of the technology field offer support for our hypotheses. For instance, in a recent content analysis of 175 smoking cessation applications, Choi, Noh, and Park (2014) found that only 10.3% of the applications contained components of basic need satisfaction. However, of the four top-ranked applications, all contained components of psychological need satisfaction, suggesting that applications that support users' psychological needs are more effective in facilitating smoking cessation. In addition, several studies have demonstrated that need satisfaction enhances intrinsic motivation and well-being in the context of video games (Adachi and Willoughby, 2017; Przybylski, Rigby, and Ryan, 2010; Ryan *et al.*, 2006), language learning (Fathali and Okada, 2017) and in simulation learning (Koh *et al.*, 2010).

To our knowledge, only one study has explicitly investigated how a mobile application support students' basic psychological needs and intrinsic motivation. Jeno *et al.* (2017) examined how a mobile application tool for species identification, relative to a traditional textbook, affects students' intrinsic motivation, perceived competence and achievement. The results showed that the mobile application tool versus textbook led to higher levels of perceived competence, intrinsic motivation and achievement. Furthermore, the results of a structural equation model showed a significant indirect effect of the mobile application on achievement through intrinsic motivation. Yet, it is unclear whether this mobile application also enhanced students' perceived autonomy, in line with CET. Furthermore, if the mobile application is more need satisfying than a textbook, it may also produce elevations in students' well-being; however, no measures of wellness were included in Jeno *et al.* (2017). In addition, given that this work is quite recent, it has yet to be replicated, and thus the reliability of these effects is unclear. Hence, research is needed to address each of these questions.

The present research

The goals of the current study were threefold. First, we aimed to replicate Jeno *et al.*'s (2017) findings on mobile application in a SDT perspective. Thus, our first hypothesis was that the mobile application (versus textbook) would produce higher levels of perceived competence, intrinsic motivation and achievement. Given the strong emphasis on replication in the social sciences (Open Science Collaboration, 2015) and the increased use of mobile application tools in education, is important to examine the reliability of these findings via replication before recommending the use of mobile application tools to practitioners.

Second, we extend Jeno *et al.*'s (2017) work by examining the effects of the mobile application tool versus textbook on perceived autonomy and well-being, representing an important contribution to our understanding of mobile applications. In particular, we hypothesized that the mobile application versus the textbook would lead to higher levels of perceived autonomy, because the mobile application may provide students with more opportunities to make self-directed choices about the learning strategies they used, the order in which they learned the different sections of information and how they checked errors (hypothesis 2a). Furthermore, we hypothesized that the mobile application would enhance well-being compared to using the textbook, given that it is hypothesized to be more need-satisfying (hypothesis 2b).

Finally, we examined whether perceived competence, perceived autonomy and intrinsic motivation are mechanisms underlying the effects of the mobile application (versus textbook) on achievement and well-being. Consistent with CET, we hypothesized that the mobile application (versus textbook) would enhance perceived competence, perceived autonomy and intrinsic motivation because of its need supportive elements, which, in turn, would predict higher levels of achievement and well-being (hypothesis 3).

Methods

Participants

Participants were 58 second-year undergraduate students in Biology (63.8% females), with a mean age of 21.7 years ($SD = 2.09$). The participants were recruited during a week-long mandatory field course. In this field course, the students learn about species and ecology, and were trained to identify a broad range of animal and plant species, including sedges.

The students were asked to participate in the present experiment after a general introduction to species identification and the tools used for this identification process. In this introduction, the students were introduced to and were allowed to work with two identification tools, the traditional textbook identification tool Norsk Flora and the mobile application identification tool

ArtsApp. The species targeted in the present study were the sedge genus (Latin: *Carex*). Pilot studies have revealed that sedges are often challenging for undergraduate students to identify. Specifically, they have a relatively narrow range of morphological and colour variations that make it commonly perceived as less interesting and at the same time more difficult to identify than more colourful, charismatic or morphologically diverse species.

Materials

The traditional method of identifying and learning about species is done through using flora textbooks (systematic descriptions of species). The Norwegian textbook "Norsk Flora" (Lid and Lid, 2005) uses dichotomous keys (ie, a series of sequential questions with only two possible answers at each step) in the identification process. When using the flora textbook, students start at a high taxonomic level and answer more general questions about the species' characteristics to help distinguish different groups. Students then gradually move on to more specific questions at the lower taxonomic level. Importantly, this hierarchical process requires the students to correctly answer all of the questions in the keys at each step to be able to correctly identify the species, and thus requires a high level of content knowledge. Furthermore, the voluminous nature of the textbook often makes it time-consuming.

As an alternative to this traditional method, we used the mobile application tool "ArtsApp" (bioCEED, 2017), which is freely available in Norwegian and English at Google Play (Google, 2016). ArtsApp offers unique learning opportunities and support, such as (1) embedded links to drawings and explanations for all of the different traits mentioned in the key to support students' deeper learning and comprehension; (2) a dynamic identification process—that is, students can choose to start the identification process in any order they want, so they can start with the traits they know or questions they feel competent with; (3) a geographic filter that enables students to exclude species that have not previously been recorded in their specific geographic area; (4) informational feedback that is given to students after each question about how many species they have left to identify in their region and how many have been excluded, thus providing them with an overview of how they are proceeding through the identification process. Furthermore, due to constant maintenance and unlimited storage abilities, the biological diversity and flora is updated and contains pictures for the users to see (Figure 1).

Procedure

A research assistant unaware of the study hypotheses randomly assigned the participants to one of two conditions; an experimental condition ($n = 29$: mobile application—ArtsApp) or the control condition ($n = 29$: textbook—Lids Flora). The students were seated in a classroom and presented with an envelope. All participants were provided with the following information: "In front of you there are three documents. The first is a short preliminary questionnaire. The second contains the questions about identifying species. The third one is a final questionnaire. Kindly start with the first questionnaire. When you are done, you can move on to the second part, the identification questions." Then, participants assigned to the experimental condition where provided with the following instructions: "Kindly answer all questions by using a smartphone or tablet with the application ArtsApp." Participants assigned to the control condition were provided with the following instructions: "Kindly answer all the questions by using the textbook Lids Flora." Both the experimental and control conditions where then given the following and final information. "You can use as much time as you want. If you are not able to answer a question, simply move to the next. When you are done with the questions, you can start with the final questionnaire. Kindly answer all the items on the questionnaire and be as sincere as possible." All students in the control condition were provided with the traditional textbook. Students in the experimental condition who did not have a smartphone were provided with a tablet during the experiment.

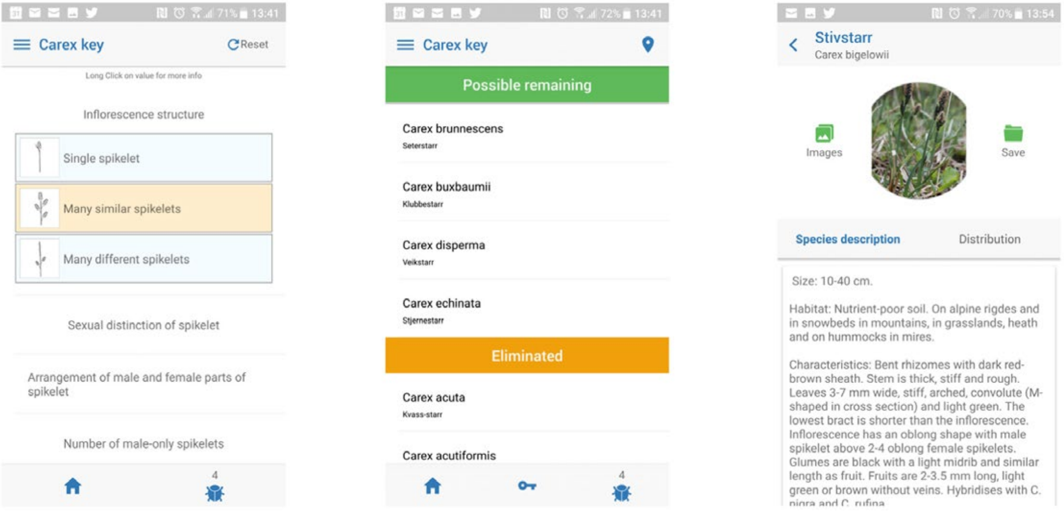

Figure 1: Screenshots depicting (a) the dynamic identification process with several different questions that can be answered in any order, and with supporting drawings to aid the decision making, (b) feedback on remaining and eliminated species, (c) information about a particular species with information on traits, species distribution in the area, and color pictures

The present study received ethical approval from the Norwegian Centre for Research Data (NSD). All the participants were ensured that participation was completely anonymous and voluntary, and that they could withdraw from the study at any time without any consequences. Participants who requested further debriefing or had any questions were asked to contact the first author for more information. No participant withdrew from the study, requested any additional information or reported any inconvenience as a result of participating in the study. Participants were given the possibility to win movie tickets.

Measures

Well-being

Two subscales within the PANAS-X were employed as pre- and post-test measures of general positive affect (11 items) and general negative affect (10 items; Watson and Clark, 1999). The respondents were asked to rate the items on a scale ranging from 1 (very slightly/not at all) to 5 (extremely) before and after the learning task. A sample item from the general negative subscale is “please rate how irritable you feel at this moment,” and a sample item from the general positive subscale is “please rate how alert you feel right at this moment.” The pre-test measure for the general negative affect scale obtained a Cronbach’s alpha of .67, while the post-test measure obtained an alpha of .85. The pre-test measure of the general positive affect scale obtained an alpha of .87, while the post-test measure obtained an alpha of .94 (see Appendix 1 for a complete list of items for each measure).

Intrinsic motivation

To measure levels of intrinsic motivation, the interest/enjoyment subscale within the Intrinsic Motivation Inventory (IMI) was used (McAurley, Duncan, and Tammen, 1989). The scale consists of seven items where the students responded on a 7-point scale ranging from 1 (not at all true) to 7 (very true). A sample item is “I enjoyed identifying species through ArtsApp/Lids Flora” ($\alpha = .96$).

Perceived competence

Five items from the perceived competence subscale within the Intrinsic Motivation Inventory scale (McAurley *et al*., 1989) were employed. A sample item for perceived competence is “I think I am pretty good at identifying species” ($\alpha = .87$). Participants were asked to answer on a 7-point scale ranging from 1 (not at all true) to 7 (very true).

Perceived autonomy

The perception of within app/textbook autonomy was adapted from the autonomy subscale used in Ryan *et al*. (2006). Participants responded on a 7-point scale ranging from 1 (not at all) to 7 (very true). A sample item is “This identification tool provides me with interesting options and choices” ($\alpha = .92$).

Achievement

Participants were given a test developed by an expert in floristics. The test consisted of nine questions: six multiple-choice questions about the characteristics of sedges and three questions in which students had to identify different sedges either using the mobile application or the textbook, depending on the experimental condition that they were assigned. The sedges were picked by a research assistant unaware of the study hypotheses and were the same for both of the experimental conditions. All the results from the test were assessed by a biologist blind to the research hypotheses. A total achievement composite score was calculated, and scores ranged from 0 (lowest possible score) to 26 (highest possible score).

Results

Preliminary analyses

According to Little’s MCAR test, the small amount of missing values were missing completely at random ($p = .44$; Little, 1988). Full information maximum likelihood estimation in Mplus was used to handle the missing data. To test whether gender and age were potential confounding variables, we examined whether there were mean differences in the study variables between males and females or whether age predicted these variables. We found no significant gender differences (all p’s > .05) and age did not significantly predict any of the study variables (all p’s > .05). We thus collapsed across gender and age for all variables. In addition, all of the variables were within the acceptable range in terms of normality (Table 1). The large range and standard deviation of the achievement variable indicated differences in students’ knowledge levels and ability to identify species. The correlations between all variables were in the expected directions.

Primary analyses

Main effects of study variables

A MANOVA was conducted to examine the mean differences in the study variables between the mobile application versus textbook (hypothesis 1 and 2a). The omnibus test was significant, $V = .783$, $F(4, 52) = 46.91$, $p < .001$, partial $\eta^2 = 0.78$. Follow-up analyses revealed that the students using the mobile application had higher perceived autonomy, perceived competence and intrinsic motivation, relative to the textbook condition, consistent with our hypotheses (Table 2). All three measures had large effect sizes. There was also a tendency for the mobile application students to have higher achievement, although this effect was not significant, $p = .15$.

Table 1: Descriptive analyses of the means and standard deviations of the study variables along with skewness, kurtosis, range

Measure	M (SD)	Unit (range)	Skew.	Kurt.	1	2	3	4
1. Perceived autonomy	4.7 (1.9)	1–7 (6.0)	–.38	–1.1	–			
2. Perceived competence	2.9 (1.2)	1–7 (5.2)	.26	–.44	.54**	–		
3. Intrinsic motivation	4.4 (1.9)	1–7 (5.7)	–.21	–1.4	.87**	.62**	–	
4. Achievement	8.7 (3.9)	0–26 (15.0)	.05	–1.0	.10	.32*	.23	–

Note: ** p < 01, * p < .05. n = 58 for all measures except for autonomy (n=57).

Table 2: Mean comparison between the study conditions along with standard deviations, F-values and effect sizes (Cohen's d)

	Mobile application (n=29)	Textbook (n = 29)		
	M (SD)	*M (SD)*	*F(1,57)*	*D*
Perceived autonomy	6.14 (0.92)	3.22 (1.41)	86.87***	2.45
Perceived competence	3.58 (1.07)	2.23 (1.0)	24.62***	1.30
Intrinsic motivation	6.05 (0.69)	2.65 (1.08)	202.54***	3.75
Achievement	9.48 (3.42)	8.0 (4.37)	2.06	0.38

Note: ***sig p < .001.

Well-being

To examine the effects of mobile application versus textbook on positive and negative affect (hypothesis 2b), we conducted a 2 (condition: mobile application versus textbook) × 2 (time: pre-species identification versus post-species identification) × 2 (affect: positive versus negative) RMANOVA, with time and affect as the within-subjects variables and condition as the between-subjects variable. The main effects and interactions were qualified by a significant three-way interaction between condition, time, and affect, $F(1, 47) = 21.40$, $p < .001$, partial η^2= 0.31. Follow-up analyses revealed that participants reported a decrease in negative affect and no significant change in positive affect after using the mobile application (Figure 2). Of interest, participants who used the textbook reported an increase in negative affect and a decrease in positive affect.

Indirect effects

To investigate our hypothesis that perceived competence, perceived autonomy and intrinsic motivation would be mechanisms underlying the effects of the mobile application (versus textbook) on achievement and well-being (hypothesis 3), we estimated a path model in Mplus using bias-corrected bootstrapping (bootstrap samples = 2000; see Figure 3). To predict change in positive and negative affect from pre to post-test, we calculated standardized residual change scores by regressing the post-affect scores on the pre-affect scores. These standardized residual change scores were included in the model as dependent variables. Consistent with SDT, we specified paths from condition (textbook versus mobile application) to perceived competence, perceived autonomy and intrinsic motivation, from perceived competence and perceived autonomy

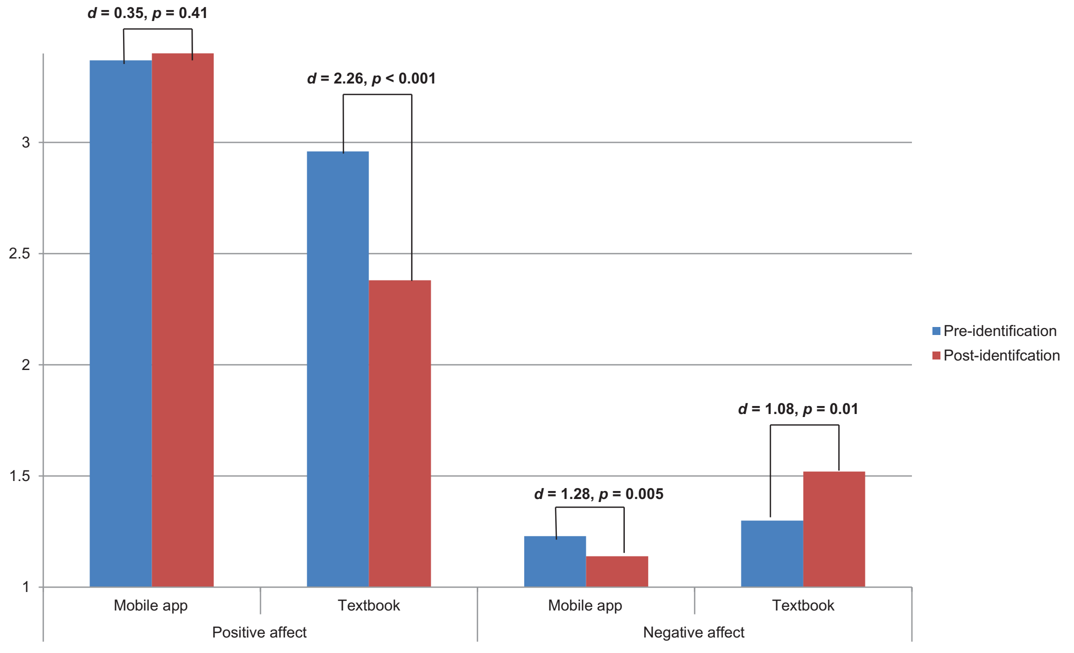

Figure 2: Pre- and post-positive and negative affect in the mobile application and textbook conditions

to intrinsic motivation, and from perceived competence, perceived autonomy and intrinsic motivation to positive affect (residual change), negative affect (residual change) and achievement. Model fit was excellent, $\chi^2(3) = 2.33$, $p = .51$, CFI = 1.0, RMSEA = .00 (0.000 – .201), SRMR = .01.

In terms of direct paths, the results revealed that condition (textbook versus mobile application) significantly predicted perceived competence, perceived autonomy and intrinsic motivation. Perceived autonomy significantly predicted intrinsic motivation, and perceived competence significantly predicted intrinsic motivation and achievement. Finally, intrinsic motivation significantly predicted positive affect. The model as a whole accounted for 17% of the variance in negative affect, 36% of the variance in positive affect and 13% of the variance in achievement.

Consistent with our hypothesis, there were also several indirect effects. There was a significant indirect effect from condition to intrinsic motivation to positive affect ($\beta = .26$, $p = .04$, 95% CI [.02, .50]), suggesting that using the mobile application (versus textbook) predicted higher levels of intrinsic motivation, which, in turn, predicted higher levels of positive affect. Further, a significant indirect effect was found from condition to perceived autonomy to intrinsic motivation to positive affect ($\beta = .14$, $p = .03$, 95% CI [.01, .27]). This indirect effect suggests that participants who used the mobile application (versus textbook) experienced higher levels of perceived autonomy, which, in turn, predicted higher levels of intrinsic motivation, which, in turn, predicted higher levels of positive affect. There was also a trend from condition to achievement through perceived competence ($\beta = .16$, $p = .066$, 95% CI [–.01, 0.33]), indicating that using the mobile application (versus textbook) predicted higher levels of perceived competence, which in turn predicted higher levels of achievement (Figure 3).

Discussion

The main objectives of the present experiment were to examine the effects of a mobile application versus a traditional textbook for biology students identifying species on achievement and

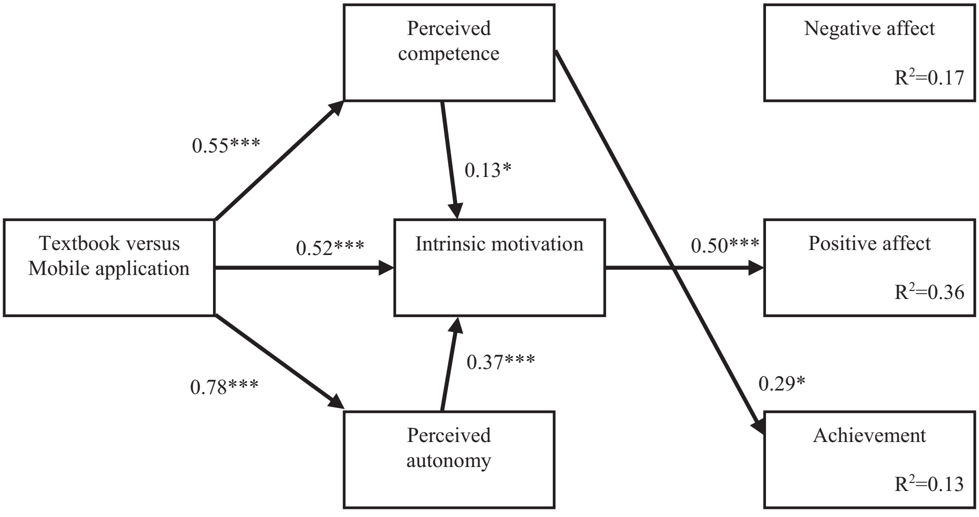

*Figure 3: Path-model assessing the indirect effects of condition on well-being and achievement through perceived competence, perceived autonomy and intrinsic motivation. Notes: *** significant at p < .001, *significant at p < .05. For clarity, only significant paths are shown. Textbook coded=0, mobile application coded=1. Positive and negative affect are standardized residual change variables*

well-being. We took an SDT-based approach to examine whether the basic psychological needs of competence and autonomy, as well as intrinsic motivation, were underlying mechanisms of these effects.

First, consistent with our hypothesis, we found that students who used the mobile application (versus textbook) reported significantly higher levels of perceived competence, perceived autonomy and intrinsic motivation, and these effects were large in magnitude. These findings are consistent with the work of Jeno *et al*. (2017), and thus offer support for the reliability of these effects. The results are also in line with SDT's tenet that tasks that provide support for the psychological needs of competence and autonomy facilitate intrinsic motivation (Ryan and Deci, 2017). We suggest that the observed differences in need satisfaction and intrinsic motivation between the conditions may be at least in part due to the need-supportive elements of the mobile application, compared to the rigidness of the textbook. For example, the feedback generating function in the mobile application tool supports students' perceived competence because students can constantly monitor their success in the identification process and then make necessary modifications to their strategy. In addition, the mobile application supports a dynamic learning process by providing opportunities for choice and modification, which can facilitate feelings of volition that satisfy the inherent need for autonomy. The textbook, on the other hand, has a hierarchical identification process that is more static, affording less choice and more regulation from external forces.

In contrast with our hypothesis, we found no significant difference in achievement scores between the study conditions. However, students in the mobile application condition on average scored 1.48 points higher on the achievement test (and the standard deviation was smaller) than students using the textbook, although the difference did not reach statistical significance. One explanation is that the current study had a smaller sample size thus limiting the ability to detect a difference between the conditions. Given that the effect size of this difference was small, a larger sample may be needed in future research to have sufficient power to detect the significance of this effect.

In terms of the effect of the mobile application tool versus textbook on students' well-being, the results showed that students using the mobile application reported a significant decrease in negative affect from pre- to post-test, whereas positive affect was unchanged, offering partial support for the hypothesis that the mobile application could enhance well-being. In contrast, students using the textbook had a decrease in positive affect from pre-test to post-test, and an increase in negative affect. The magnitudes of these differences were strong. Thus, the results suggest that using the mobile application somewhat enhanced students' well-being, whereas using the textbook actually diminished it. In addition, the mobile application versus textbook indirectly predicted positive affect through need satisfaction and intrinsic motivation, consistent with SDT. These findings suggest that the mobile application may be more need satisfying and intrinsically motivating than the textbook, and may enhance student's well-being, rather than diminish it. There was also some evidence of an indirect effect on achievement scores through perceived competence, although this was a trend.

Limitations and directions for future research

Of course, the study is not without limitations. First, due to the time and schedule constraints of the field course, the experiment took place shortly after the initial presentation of both the identification process and the introduction to the sedges. Thus, the students were new to this process and information, which could explain the lower mean achievement scores across the study conditions. To compliment the results of the current experiment, future research could use a longitudinal design to compare achievement outcomes over time between the mobile application versus textbook conditions.

Second, the present study had a relatively small sample size. Although researchers suggest that small sample sizes may be unstable when assessing model fit in SEM models (eg, Wolf, Harrington, Clark, and Miller, 2013), MacCallum and Austin (2000) argue that it is problematic to provide guidelines for sample size in SEM due to context specific factors in different studies. For example, large sample sizes in SEM models are important when the expected effects are vague, and measures included are unreliable, whereas smaller samples of 50–100 participants may suffice for models with stronger effects and reliable measures, such as those in the current study (Iacobucci, 2010). Furthermore, O'Rourke and Hatcher (2013) argue that the existing guidelines for determining sample size in SEM models pertain primarily to the use of latent variables, rather than models with manifest variables, which were used in our study. Importantly, Preacher and Hayes (2008) suggest the use of bootstrapping when conducting multiple indirect effect models with sample sizes that are small or medium, and thus we estimated 2000 bootstrap samples when assessing indirect effects. Nonetheless, future research on this topic could benefit from using larger samples.

Third, while the current study found that the mobile application predicted higher levels of intrinsic motivation, SDT postulates that there are several different types of motivation that range from more autonomous (eg, engaging in an activity out of interest or personal value) to more controlled motivation (eg, engaging in an activity because of external or internal pressure; Ryan and Deci, 2017). Furthermore, whereas autonomous motivation has been shown to be associated with well-being, controlled motivation is often related to ill-being. Given that we found that using the textbook produced decreases in well-being, it would be interesting to examine whether the textbook is conducive to more controlled motivation. Simply put, future research should examine whether using a mobile application versus a textbook for a learning task can elicit different types of motivations.

In addition, future studies should expand upon our work and investigate the effects of mobile application on motivation, achievement, well-being and psychological need satisfaction among different age groups (eg, children, adolescents). For example, mobile applications may be perceived as more intrinsically motivating for children since they may promote "game-like" elements such as curiosity, fantasy and challenge (Lepper and Gurtner, 1989). Furthermore, given that intrinsic motivation tends to decrease as students get older (Lepper, Corpus, and Iyengar, 2005), investigating whether mobile applications can combat this decrease for adolescents is of critical importance. Finally, it will be important to investigate the generalizability of these findings to other areas in education beyond biology, by examining how mobile applications with need-supportive features impacts motivation, achievement and well-being in other fields.

Implications and conclusion

Overall, the current research suggests that using a mobile application was more need satisfying and intrinsically motivating than using a textbook, which, in turn, predicted higher levels of well-being and achievement. In addition, compared to the textbook, the mobile application tool used in the present study is more suitable to take into the field (ie, to identify species in nature) due to its small size and compactness. The mobile application (versus textbook) may also allow students to identify species more quickly and accurately, which are important benefits for field work that often has time-constraints. Furthermore, the finding that the mobile application led to increased well-being, whereas the textbook decreased well-being, suggests that mobile applications may positively impact students' subjective learning experience, which may have positive implications for fostering students' long-term persistence in a variety of learning contexts. Thus, it might be useful for teachers to incorporate mobile applications into their classrooms to the extent that they provide choice in the learning strategy used, prompt informational feedback, optimal challenges and the ability to monitor one's progress and learning. The importance of this implication is further highlighted by the fact that students have reported low levels of intrinsic motivation in traditional classroom settings (Brahm *et al*., 2016). Mobile applications that support students' basic psychological needs, therefore, may offer an engaging solution to increase students' intrinsic motivation for learning tasks.

Statements on open data, ethics and conflict of interest

a. Data is available upon request from first author. The data is not openly available elsewhere.
b. The present research received research approval by the Norwegian Centre for Research Data (NSD). Furthermore, all participants were given the possibility to withdraw from the study, and told that participation was voluntary.
c. The authors report no conflict of interest.

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Appendix A

Pre-test and Post-test measures

Well-being: Positive affect

Use the scale (ranging from 1 to 5) to answer the items below to describe how you feel right now:

- Active
- Alert
- Attentive
- Enthusiastic
- Excited
- Inspired
- Interested
- Proud
- Strong
- Determined
- Concentrating

Well-being: Negative affect

Use the scale (ranging from 1 to 5) to answer the items below to describe how you feel right now:

- Afraid
- Scared
- Nervous
- Jittery

- Guilty
- Ashamed
- Irritable
- Hostile
- Upset
- Distressed

POST-TEST MEASURES

Intrinsic motivation

- I enjoyed identifying species
- Identifying species was fun
- Identifying species was boring (R)
- Identifying species did not hold my attention at all (R)
- I would describe identifying species as interesting
- I thought identifying species was quite enjoyable
- While I was using this identification tool, I was thinking about how much I enjoyed it

Perceived competence

- I think I am pretty good at identifying species
- I think I did pretty well at identifying species compared to other students
- After identifying species for a while, I felt pretty competent
- I am satisfied with my performance at this task
- I was pretty skilled at identifying species

Perceived autonomy

- I experienced a lot of freedom in this identification tool
- I can find something interesting to do in this identification tool
- This identification tool provides me with interesting options and choices

Achievement

- How many species of sedges (Carex) are there in Norway?
- In sedges with unequal spikelets is the male spikelet on top or below?
- What do we find inside the perigynium?
- Where do we find the (inflorescence) bract in a sedge?
- Which of the following characteristics are important for identifying a sedge species? A) Number of stigmas, B) If the node is hairy or not hairy, C) Breadth of the petals, D) If the spikelets are stalked or not stalked
- Which sedge is in the plastic bag number 1?
- Which sedge is in the plastic bag number 2?
- Which sedge is in the plastic bag number 3?
- What characterizes a sedge?