Tablets, Plants, and Primary School Students: A Study

Emmanuel Fokides, Penelope Atsikpasi & Dorothea Karageorgou

Technology, Knowledge and Learning

ISSN 2211-1662
Volume 25
Number 3

Tech Know Learn (2020) 25:621-649
DOI 10.1007/s10758-020-09445-7

Technology, Knowledge and Learning (2020) 25:621–649
https://doi.org/10.1007/s10758-020-09445-7

ORIGINAL RESEARCH

Tablets, Plants, and Primary School Students: A Study

Emmanuel Fokides[1] · **Penelope Atsikpasi**[1] · **Dorothea Karageorgou**[1]

Published online: 15 April 2020

Abstract
Primary school students have trouble grasping concepts related to plants. Their misconceptions are also notable. On the other hand, mobile devices (such as tablets) and their apps, are considered effective educational tools. For examining whether the same holds true in relation to plants, we carried out a project, having as a target-group 263 students aged 11–12, divided into five groups. Two were taught using printed material, one using laptops and webpages, while the last two were taught using tablets (one with a commercial app and one with a tailor-made one). We chose Bybee's 5Es as the teaching framework for all groups except the first, in which lecturing was applied. Six two-hour sessions were allocated in each group. We collected data through evaluation sheets and a questionnaire. The results suggested that students in the tablets groups established a solid base of declarative and procedural knowledge regarding plants. Their misconceptions were eased, at least when compared with the groups that used printed material. We also observed a positive impact on motivation and enjoyment. On the basis of the findings, we recommend the active involvement of teachers in the development of apps and the corresponding learning material, so as to be able to gain valuable insights on how mobile learning is implemented. We also propose a teaching framework that would allow the full exploitation of mobile devices' advantages.

Keywords Misconceptions · Plants · Primary school students · Tablets

1 Introduction

Tablets and other mobile devices are among the technological innovations believed to enhance the teaching/learning process. Indeed, a rather significant number of research projects examined mobile devices' educational value (Kearney et al. 2015); together with Augmented Reality (AR) applications are considered as invaluable tools in a

✉ Emmanuel Fokides
fokides@aegean.gr

Penelope Atsikpasi
pred17015@aegean.gr

Dorothea Karageorgou
fkaragewrgou@gmail.com

[1] Department of Primary Education, University of the Aegean, Dimokratias Str., Rhodes, Greece

technology-assisted education (Özdemir 2017) and, more specifically, in science learning (Metz 2014). Actually, as mobile devices allow learners to seamlessly access educational resources without any temporal and spatial restrictions, led to the formation of a new type of pedagogy called "mobile learning/m-learning" (Sharples et al. 2009). M-learning, by exploiting mobile devices' unique features (e.g., portability, touch screens, and wireless network connectivity), provides greater flexibility and new affordances to learners, the most important ones being personalization, customization, and contextualization of the learning experience (Crompton 2013).

Subjects related to natural sciences are challenging for both primary school students and teachers. A learning domain in which students face quite a significant number of problems is plants. In fact, besides having trouble in understanding basic concepts (e.g., plant parts, nutrition, and reproduction) their misconceptions are significant as well (Barman et al. 2006). Despite that, plants are superficially taught in primary school (Lally et al. 2007), using ineffective conventional teaching methods (Osborne and Dillon 2008). Teachers' problems are also notable, as they lack knowledge and understanding of natural phenomena (Kilty and Burrows 2019). Interestingly enough, their own misconceptions are not negligible, exposing students to the risk of wrongful knowledge acquisition (Grossman and Thompson 2004).

Although the literature regarding the educational uses of tablets is extensive, it seems that, in relation to plants, it is rather slim (Fokides and Atsikpasi 2017). Furthermore, mobile technologies are introduced in education in an unsystematic way and without having a thorough empirical understanding of the intricate relationship between them and instructional frameworks that underpin learning (Bano et al. 2018). In this respect, it is important to have more evidence for the effectiveness of this technology and of mobile learning pedagogies in general. In the light of the above, we designed and implemented a project, seeking to explore the effects of tablets and their apps on primary school students' knowledge and misconceptions about plants, in the context of a constructivist teaching framework. As we will detail in the coming sections, in order to reach a deeper understanding of the issues we sought to examine, we compared the results of multiple groups, each using a different tool.

2 Problems Related to the Teaching of Plants

Although young children find plants interesting, as they grow older this interest is lost (Wandersee and Schussler 2001). Several reasons lead to this situation. With the exception of ones with unusual characteristics, plants are not "exciting" (Strgar 2007). The limited knowledge about them and limited contact with the natural world also contribute. For example, in a study, students could name just a few of the plants they routinely encounter (Lindemann-Matthies 2002). Lack of appreciation for plants' importance in the ecosystem was also noted (Lindemann-Matthies 2005). Adults and children alike, consider animals far more interesting (Strgar 2007). Not only that, but animals are considered superior to plants, as humans belong to the animal kingdom and as it is easier to recognize the features of something that moves and makes sounds (Fančovičová and Prokop 2010).

Quite aptly, Wandersee and Schussler (2001) coined the term "plant blindness" for describing students' limited knowledge about plants. It is true that many students find it difficult to understand the vocabulary involved (e.g. photosynthesis) (Dass 2001), leading them to classify the related subjects as "difficult" ones (Bates 2019). On the other hand, their main problem seems to be their several misconceptions about plants. In fact, they are introduced at early ages (Barman et al. 2006) and they persist even after teaching (Marmaroti and Galanopoulou 2006). Student misconceptions may be related to their inability to comprehend plants' basic characteristics and functions, while others derive from the tendency to anthropomorphize them (Anderson et al. 2014; Strgar 2007). In the following paragraphs, we will present the most important ones classified in broad categories.

2.1 General Problems

- Research has demonstrated that children cannot attach to plants some of the characteristics of life (movement, respiration, sensitivity, reproduction, secretion, development, and nutrition) (Özay and Öztaş 2003). As a result, although all students know that plants grow, few understand that they are living organisms.
- Students consider an organism to be a plant only if it has flowers (Bell 1981). For instance, McNair and Stein (2001) found that children and adults alike when asked to draw a plant, most came up with a flowering one.
- Bell (1981) indicated that some children believed that trees are not plants.
- Another study demonstrated that students classified plants on the basis of easily identifiable features (e.g., being green and developing in the soil) and parts (e.g., strain, leaves, and flowers) (Ryman 1974). Yet, half mistakenly classified a mushroom as being a plant, because its stem resembles that of a plant.

2.2 Plant Reproduction

- Problems related to plant reproduction are not widely studied (Barman et al. 2006). Then again, there is evidence that the different types of reproduction are not easily understood. For example, students were unable to cite an apparent mechanism for sexual reproduction (Lewis and Wood-Robinson 2000).
- Also, they cannot understand the connection between flowers and fruits or that sexual reproduction is related to pollination (Schussler and Winslow 2007).
- Fertilization is often confused with pollination. Moreover, students expressed the view that pollination depends exclusively on insects and animals (Hershey 2004).

2.3 Plant Nutrition

- Students can understand the needs of plants that are "obvious" and can be accommodated by humans. They can recognize that plants need water because we water them. They also recognize the need for light because we place them in bright spots or the need for nutrients because they are planted in soil. On the other hand, they find it difficult to identify the air as being one of their basic needs (National Research Council 1996).
- Most students can understand plants' need for energy and that this energy is taken from their "food". Yet, difficulties occurred when asked to clarify the origin of this food. Most insisted that plants' food is extracted from the soil (Lazarowitz and Penso 1992); the absorbed substances create a "juice" (i.e., sap), which moves through the stem and allows the plants to grow and perform all their functions (Cañal 1999). These perceptions are perhaps the most stable and most commonly detected in students.

- In addition, children believe that plants need "food" just like humans (Smith and Anderson 1984). Therefore, when they hear that "plants make their food", they think of something that is "eaten" (Roth 1984). Moreover, they think that plants ingest -more or less- the same way humans do (Roth 1984).

2.4 Photosynthesis, Respiration, and Transpiration

- Student problems with these concepts are widely studied. In general, photosynthesis is perceived by children as a substance rather than as a process (Amir and Tamir 1994).
- Many students seem to believe that photosynthesis (and the subsequent oxygen production) is something that plants do for the benefit of humans and animals (Simpson and Arnold 1982).
- Although students understand that sunlight is important for the growth of plants, it is viewed as the direct energy source (Simpson and Arnold 1982). The solar energy is also confused with heat, concepts that students often equate. However, they were not able to explain how plants survive in the dark (Barman et al. 2006).
- A common belief is that plants breathe like animals, by inhaling and exhaling air. If they do not do that unceasingly, they suffocate and die, just like humans (Cañal 1999).
- Moreover, students think that plant respiration and photosynthesis do not occur simultaneously (Özay and Öztas 2003).
- Finally, even high-school students do not grasp the nature of plant respiration and its connection with photosynthesis, even though they know that both processes occur in plants' green parts (Anderson et al. 1990).

Though educational interventions, preferably targeting younger ages, could ease these problems, plants take just a fraction of primary school program of study (Lally et al. 2007). To make things even worse, it is not unusual for teachers to superficially teach plants (Sanders 2007). In fact, conventional teaching (lecturing/teacher-centered) seems to be the prevailing teaching framework in science-related subjects, although there is mounting evidence that constructivist methods are more effective (Osborne and Dillon 2008). Teachers' limited knowledge, lack of pedagogical training in science subjects, and lack of understanding of natural phenomena (Antink-Meyer and Meyer 2016; Kilty and Burrows 2019) forces them to use the school textbooks and the related curriculum materials as their only source of information and as guides for their pedagogical decisions (Trundle et al. 2002). As a result, they simply reproduce the textbooks' content (Remillard 2005), with the memorization of facts/terms being their primary goal. What is more, the tools they use for evaluating knowledge acquisition are limited to exams and short evaluation tests (Brossard et al. 2005). Another problem is that teachers do not use ICT tools in the teaching of science-related subjects because they consider them difficult to use (Wilkinson and Barter 2016). Finally, quite alarmingly, it was found that teachers have several misconceptions in science-related subjects, similar to those of students (e.g., Antink-Meyer and Meyer 2016) and there is the risk of conveying them to their students (Grossman and Thompson 2004).

3 The Educational Uses of Tablets and Their Apps

Nowadays, smartphones and tablets are probably the most commonly used electronic devices by minors (Sahin et al. 2015). Inevitably, they drew the attention of researchers who examined their uses in an educational context. While there are studies that found no impact on learning (e.g., Carr 2012) or even negative results (e.g., Doolittle and Mariano 2008), most reported positive outcomes. In fact, several meta-analytic studies (e.g., Bano et al. 2018; Crompton and Burke 2015; Sung et al. 2016) concluded that the results of around 65% to 71% of the studies they examined indicated that, when using mobile devices, participant performance in variables related to cognitive achievements were significantly better compared to those not using them. What is of interest in the context of our study is that mobile devices, when compared with traditional teaching, produced better results in all teaching/learning subjects (Tingir et al. 2017), especially in sciences and maths (e.g., Crompton et al. 2016a, b).

Overall, students hold a positive attitude toward the use of mobile devices in their learning (Kinash et al. 2012). That is because they find them easy to use (e.g., Chen 2013; Fokides and Atsikpasi 2017), offering an interesting (Nguyen et al. 2015), engaging (Diemer et al. 2012), enjoyable (Sloan 2012), and motivating (Furió et al. 2013) learning experience. Researchers argued that mobile devices allowed students to work more efficiently (Nuhoglu Kibar et al. 2019) and that interactions, communication, and collaboration among peers were better (Heinrich 2012). The fostering of independent, personalized, and self-directed learning was also observed (Kearney et al. 2012).

However, we have to note that tablets and smartphones can distract students, hindering the learning process. That is because, during lessons, students can use them for non-educational purposes (Henderson and Yeow 2012). Although the intention of entertaining features is to increase student interest, their excessive use might also pose a problem (Iserbyt et al. 2014). In addition, technical problems (not present in traditional means) might add a layer of unnecessary complexity, which also acts as a distractive factor (Culén and Gasparini 2012).

The questions of how to integrate mobile devices into instruction and of what teaching strategies are the most appropriate were also raised and examined, but the relevant literature is not extensive (Warschauer et al. 2014). It is generally agreed that students' active participation in a learner-centered teaching framework is preferred over a conventional/teacher-centered one (Fisher et al. 2013; Iserbyt et al. 2014), as the effect sizes in quantitative studies were higher in the former case and qualitative studies also reinforced this view (Tamim et al. 2015). Additionally, just relying on digital devices is not enough; it is strongly advised to design educational interventions that seamlessly integrate them into a technology-based instructional framework (Tamim et al. 2015).

We have to stress that mobile devices per se are not educational tools. What renders them as such, are the accompanying applications. An interesting category of mobile apps are the ones employing AR, a technology that bridges reality and virtuality (Akçayir and Akçayir 2017). In short, AR overlays digital media in the real world, providing users with a composite view of both. According to the relevant literature, AR apps allowed students to develop skills easier, acquire more knowledge (e.g., Garzón et al. 2019; Huang et al. 2016), and retain it (Zhang et al. 2014) compared with other educational resources and conventional teaching methods (Özdemir et al. 2018). The above hold true for weak and average students (Allagui 2019), or even for concepts that are considered troublesome (Tarng et al. 2018) and abstract (Wu et al. 2013), as are the concepts belonging to natural sciences. In fact, there is evidence that AR is more effective when the learning subjects are related to natural sciences rather than to social sciences, probably because concepts belonging to the former can be concretized easier in AR (Özdemir et al. 2018).

As with tablets, AR apps positively affected student motivation to learn (Garzón et al. 2019), since they considered them more appealing compared with conventional teaching (Hsiao et al. 2016). Enabling students to practice in environments that seamlessly combine the real world and digital information (Wojciechowski and Cellary 2013), together with the increased levels of interactivity (Chen and Wang 2015) and enjoyment (Chiang et al. 2014), were also considered as contributing factors to the positive learning outcomes. Researchers argued that student autonomy and self-paced learning are key-advantages of AR apps (Ferrer-Torregrosa et al. 2015). At the same time, it was found that collaborative learning was fostered, given that students can interact with both their fellow students and the educational content (Bujak et al. 2013). Finally, AR apps were considered crucial for the creation of blended learning environments which facilitated problem-solving and critical thinking (Dunleavy et al. 2009).

4 The Project's Rationale and Research Questions' Formation

Summarizing the literature review we presented in previous sections, we can note that subjects related to plants are not systematically taught in primary school, resulting in students having incomplete knowledge and several misconceptions. Moreover, teaching in science-related subjects is mostly conventional and based on school textbooks; alternative teaching methods, though strongly advised, are not widely implemented. As far as mobile devices are concerned (tablets included) they are considered effective teaching tools. Then again, there is the need to better understand their impact on student learning, especially in subjects related to plants, as the literature in this specific subject is limited. Finally, there is a need to examine the impact of technology-based teaching frameworks that utilize mobile devices.

The above problems and research gaps provided the initial motivation for the development of our project. What is more, we identified a number of issues which, in our view, had to be resolved. First, a substantial number of studies we reviewed had sample sizes that were not adequate for drawing reliable conclusions. Second, in most studies mobile devices were compared with printed material and/or conventional instruction; far fewer compared them with the use of other ICT tools (e.g., computers), as others pointed out (Nedungadi and Raman 2012). Third, tablets' impact on student misconceptions is not well-studied. Lastly, there is the issue of the apps utilized in previous studies; in some studies, commercial apps were used while in other tailor-made/non-commercial ones, developed specifically for their needs were employed (Bano et al. 2018). Then again, each type of app has different advantages and disadvantages.

Reflecting upon these issues, our first decision was to use tablets, given that their larger screens, compared with other mobile devices, would allow for a better presentation of the learning material. What is more important, we came to the conclusion that, in order to achieve a thorough understanding of the impact of tablets, we had to form five different groups of students, each using a different tool or teaching method. Given that lecturing is the most commonly used teaching method and given that teachers typically use printed material (the school textbooks), one group was taught following both the above and served as the study's control group. Yet, the printed material might prove to be more effective if an appropriate teaching method is applied. Thus, the second group of students used printed material together with a method described in a coming section. As tablets are miniaturized computers, we considered possible that both might yield equal learning outcomes. Consequently, the third group used laptops together with webpages presenting the learning material. The teaching method was the same as in the second group. The last two groups used tablets; one used a commercial app, while the other used a non-commercial one.

One might argue that the teaching method we decided to apply in the control group might pose a problem, given that this group had two major differences compared with the other groups (method and teaching tool). We counter-argue that as this group was taught conventionally and by using printed material, it provided a good reference point for determining how much better (or worse) were the results of the other four groups. Therefore, we set the following research questions:

RQ1 Which combination of tools, apps, and methods can produce the best learning outcomes? In which case knowledge retention is better?
RQ2 Which combination of tools, apps, and methods can ease student misconceptions?

Given that students find tablets easy to use, motivating, and enjoy working with them and given that we had five groups of students using different tools, apps, and methods, we were interested in comparing their views on these matters. Thus, we explored the following research questions:

RQ3 Which combination of tools, apps, and methods students considered as being more motivating, enjoying, and effective in terms of learning? Also, which ICT tools and apps students find easier to use?

5 Method

5.1 Sample Selection and Project Duration

According to the Greek program of study for primary schools, students are taught subjects related to plants during the third (ages 8–9) and sixth (ages 11–12) grades. As the most significant (and difficult) concepts are taught during the sixth grade, we decided our target group to be 11–12 years-old students.

As our study followed a quasi-experimental design, one of our concerns regarding our sample was to achieve an "ordinary" and "typical" one (Creswell and Poth 2017). Thus, we applied the following set of criteria: (1) students to have never before used tablets during their teaching, (2) their overall performance to reflect -more or less- the performance of typical sixth-grade students, (3) the ratio of boys and girls to be close to the one in a typical sixth-grade class, and (4) to attend public primary schools. Another concern was to achieve a sample size that would allow us to draw reliable conclusions. Using G*power (Faul et al. 2007) we calculated that for being able to detect a medium effect size ($f = .25$), with a low error probability ($\alpha = .05$), a satisfactory power ($1 - \beta$ error probability $= .90$), and by having 5 groups, we needed at least 255 students (51 students in each group). Consequently, we contacted the sixth-grade teachers of several public primary schools in Athens, Greece. Out of those who agreed to participate, sixteen satisfied our selection criteria and their classes amounted to 285 students. To each class/teacher we randomly assigned one of the teaching tools and methods described in the "Materials" and "Procedure" sections. We have to note that all teachers (seven females and nine males) had more than 10 years of service each and they were roughly between 40 and 50 years old.

For complying to the rules of conducting research with minors, we took a series of measures: (1) our research was approved by the University's ethical committee, (2) following a parents' briefing, we obtained their written consent for their children's participation, and (3) the school headmasters also approved teachers' participation.

The project had a preliminary phase which applied only to groups that used tablets or laptops, that lasted for eighteen one-teaching-hour sessions (six for each group, three sessions per week) and a main phase that lasted for thirty-two-teaching-hour sessions (six for each group, two sessions per week). As sessions were not conducted simultaneously to all groups, the project lasted from early-March 2019 to mid-May 2019.

5.2 Materials

In the third grade, students were taught, in just five teaching hours, plant structure and classification (depending on how many years they live, stem types, the locations they grow, whether they are evergreen or deciduous, and how they are used by humans). The program of study for the sixth grade dedicates, once again, just five teaching hours, for the teaching of plant structure (in more detail this time), as well as of the processes of photosynthesis, respiration, and transpiration. Given that students were taught (rather superficially) subjects related to plants when they were 8–9 years old, we assumed that their prior knowledge would probably be incomplete and fragmented. Thus, we decided to start with the basics before moving to more complex concepts. We also decided to allocate more teaching hours and to enrich the subjects included in the official textbook. Accordingly, we formed an outline of the learning material and the unit/session arrangement:

- Unit 1, plant structure (session 1). Overview of plant structure (roots, stems, and leaves) and their functions.
- Unit 2, reproduction organs (session 2). The flower structure and organs, fruits and seeds, seed germination.
- Unit 3, pollination, sexual (with/without flowers), and asexual reproduction (session 3).
- Unit 4, plant nutrition and the process of photosynthesis (sessions 4 and 5). As these were the most complex concepts, we considered wise to conduct two sessions.
- Unit 5, the processes of respiration and transpiration (session 6).

A multi-stage process followed which, in essence, was the participating teachers' sole responsibility, as they were the ones who assembled, wrote, and edited all the relevant material (i.e., texts, images, photos, videos, and additional readings). They were also the developers of the project's webpages and non-commercial mobile apps. Because of the teaching method we were planning to apply (as elaborated in the "Procedure" section), we also asked them to develop two worksheets for each session, having comprehension questions, exercises, activities (e.g., students were asked to develop mind maps), and guidelines for experiments (e.g., carbon dioxide and starch detection). After several email exchanges, videoconferences, and face-to-face meetings, the material was finalized and approved by all teachers.

Next, the teachers were split into three groups. Using the finalized material, the first group's task was to produce a handbook, the second developed a website, and the third developed mobile apps (one for each session, because the software we used had file size limitations). The handbook units had two parts; to the main, the bulk of a unit's learning material was included, while additional readings were included to the second. Given that it was not possible to have videos in the printed material, we replaced them with a series of screenshots. The website followed the same logic and structure as the handbook and was developed using Google Sites. For the development of mobile apps, Blippbuilder was used (https://www.blippar.com). This software allows the rapid and relatively easy development of applications for mobile devices with AR features (Fig. 1). Since apps developed using Blippbuilder are image-based (meaning that they are triggered using images), we printed a sufficient amount of the trigger images and we later handed them to students who used these apps. We have to note that: (1) we trained teachers and provided technical assistance in the use of Google Sites and Blippbuilder (2) the handbook, the website, and the mobile apps were reviewed, tested, and approved by all teachers (following comments and suggestions, corrections were made), and (3) to avoid the need of an Internet connection, the webpages (and all the additional files) were downloaded and installed locally to laptops; the same applied for the mobile apps. Finally, the commercial mobile app that we selected was Arloon Plants™ (http://www.arloon.com/apps/arloon-plants/), as it covered all the project's learning subjects and as it was tested with good results in one of our previous projects (Fig. 2).

5.3 Procedure

Prior to the beginning of the project, we gathered all the participating teachers and we explained the teaching methods, described below, by providing detailed guidelines and by

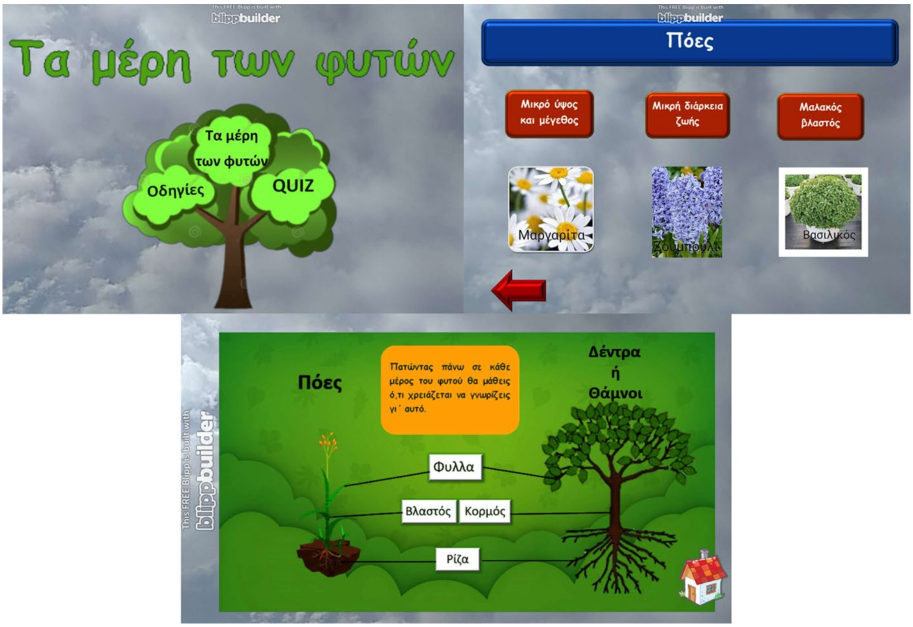

Fig. 1 Screenshots from the non-commercial apps

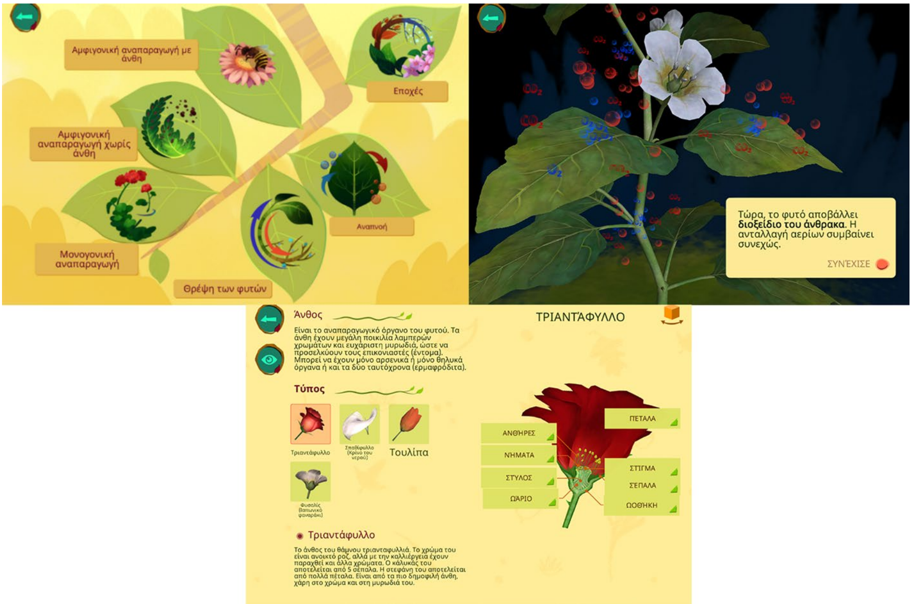

Fig. 2 Screenshots from the commercial app

demonstrating specific scenarios for each teaching unit. We also urged them to strictly follow their designated method. The underlying reason for doing so was because, during our collaboration with them at various stages of the project (e.g., during the development of the learning material), we became aware that none was familiar with this teaching framework. Consequently, there was the risk of teachers not to be able to implement it correctly, or each to implement it differently, or even not to implement it at all, jeopardizing the results' validity.

There is an ongoing debate regarding the student to tablet ratio. A one-to-one setting helps to avoid unnecessary disputes among students, as sometimes they view the shared tablet as their "own" and refuse to share it with their fellow students (Culén and Gasparini 2012). Then again, others suggested that a many-to-one setting allows for better discussions/collaboration among the members of a group (Lin et al. 2012). However, both settings seem to have a positive impact on student performance (Lin et al. 2012). As for the students to laptops ratio, research illustrated that a one-to-one setting significantly increases student performance (Bebell and O'Dwyer 2010). Also, Carr (2012) suggested that access to technology (i.e., tablets and laptops) outside school (i.e., at home) has the potential to improve the learning outcomes. Given the above, we decided to remove students' textbooks for the duration of the project and each to receive, depending on the group he/she belonged to, a copy of the handbook, a laptop with the webpages, a tablet with the commercial app, and a tablet with the non-commercial apps (the ones developed by the teachers). We also decided to allow students to take the handbooks, laptops, and tablets at home, so as to be their primary source for studying plants. We have to note that we uninstalled all the unnecessary applications from both tablets and laptops.

Given that most students are -up to a certain point- familiar with the use of tablets (Cumming et al. 2014), one might consider unnecessary to train them on how to use these devices. On the other hand, researchers suggested that most studies either overlooked this parameter or used novices (Frohberg et al. 2009). Moreover, training sessions can help to overcome problems and ensure that students are comfortable enough with the use of tablets (or laptops) (Fernández-López et al. 2013). Therefore, we allocated six teaching hours to each group that was going to use laptops or tablets for familiarization purposes. For that matter, we used educational websites and apps, but their content was not related to plants.

Coming to the project's main phase, we decided to allocate two teaching-hours for each session. That is because the experiments, the exercises, and the activities, required a substantial amount of time. We also considered it important to provide students with enough time to assimilate the learning material, as some concepts were rather difficult to grasp (e.g., photosynthesis, respiration, and transpiration).

The first group of students used printed material (the handbook). As we already stated, the teaching method in this group was lecturing. At the beginning of each session, the teachers made a short introduction regarding the subject students were about to be taught. Then, they presented the relevant information, pausing, from time to time, for answering students' questions or for addressing questions to the class (the ones included in the first set of worksheets). Following that, students, working individually, studied the related material in the handbook (both the main and additional) and tried to complete the activities and exercises included in the second set of worksheets. Their answers to these activities and exercises were later presented to the whole class and discussed. Discussions among students were allowed but they were controlled and guided by the teachers. Also, if experiments were included in a session, these were conducted by the teachers.

To the other four groups, regardless of the tool they used, we applied a teaching method that was based on constructivist principles and student collaboration. As we presented in a preceding section, the fostering of collaboration is considered one of the tablets' key advantages. Not only that but in science-related subjects, group work is strongly advised (Harlen and Qualter 2014). Thus, students worked in groups of three. Out of the available teaching frameworks, we deemed that Bybee's 5Es (Bybee et al. 2006) was the most suitable for our needs. During the Engage stage, for stimulating student interest, the teachers initiated a first round of discussions among groups related to the session's subject. During the Explore stage, the students used their handbooks, laptops, or tablets and studied the relevant main material. Individual work was discouraged; discussions, exchange of ideas, or even exchange of handbooks, laptops, or tablets were encouraged. If the sessions included experiments, these were conducted in each group by the students (we provided the required tools and materials). At the end of this stage, the group members discussed and collectively recorded their views and answers to the questions in the first set of worksheets. Following that, during the Explain stage, each group presented, discussed, and debated on their recorded views with the rest of the class. We considered the Extend stage as the most important part of the teaching procedure. That is because the purpose of this stage was to allow students to gain procedural knowledge (e.g., to make predictions, to apply what they have learned in different contexts or situations, and try to explain more complex phenomena/conditions). Once again, the participating students used their handbooks, laptops, or tablets for studying the additional material. Then, they conducted the exercises and activities in the second set of worksheets. If included, they also conducted supplementary experiments. As previously, students collectively recorded their views, presented, and discussed them with the other groups. During the final stage (Evaluation) the teachers presented problems or asked questions related to the unit's subject and, following group discussions, students presented their ideas.

Teachers' role during the above stages was that of the learning process facilitator. The objective was to avoid giving direct answers or imposing their views on students and to allow them to "discover" knowledge by themselves. Thus, the teachers joined in students' conversations, debated, and indirectly guided them (i.e., by drawing students' attention to what was significant and by providing hints).

5.4 Instruments

For collecting data on the learning outcomes and for answering RQ1 and RQ2, we asked teachers to collectively devise evaluation sheets/tests (two pre-tests, one for each teaching unit-six in total, and two delayed post-tests), following a multi-stage process similar to the one for developing the teaching material. One pre-test examined prior knowledge in subjects related to plants, so as to determine the initial knowledge level. The second pre-test examined student misconceptions regarding plants. We administered the delayed post-tests 3 weeks after the end of all sessions; one examined knowledge retention (in all subjects), while the objective of the second was to examine changes in student misconceptions. Students completed the rest of the evaluation sheets right after the end of a session.

Frohberg et al. (2009), in their analysis, concluded that most studies in mobile learning examined the acquisition of lower-level knowledge. Having that in mind, we decided to check whether students acquired not only declarative but procedural knowledge as well and whether there was an impact on their misconceptions. To achieve this, the evaluation sheets, with the exception of the two tests examining misconceptions, had the same structure: (1) besides multiple-choice and yes–no questions, they also had open-ended ones, (2) in most cases students had to justify their answers, and (3) questions examining declarative knowledge (e.g., term/concept definitions) were about a third of the total questions, most questions' objective was to examine procedural knowledge; for that matter, they required attention to details, critical thinking, asked students to give examples, and to apply what they have learned to different situation/conditions. For example, in a question, two images of cacti were presented (one that grows in deserts and one that grows in rainforests). Students were asked to name their morphological differences and resemblances (actually, the rainforest cacti do not have the easily recognized characteristics of their desert relatives), but also to explain why they differed (many rainforest cacti do not have thorns as there is an abundance of water and they are unable to withstand the desert harsh conditions).

Researchers suggested that three- or four-tier tests can accurately measure misconceptions in science-related subjects (e.g., Gurel et al. 2015). Therefore, each of the two tests regarding misconceptions consisted of 25 four-tier multiple-choice questions. Hershey's (2004) comprehensive list of plant misconceptions, provided the basis for the questions' formation. For each question, the first tier had three possible answers. The third tier provided a set of three explanations/reasoning for each answer to the first. The second and fourth tiers asked students to give their confidence level (certain/uncertain) for the first and third tier respectively. For instance, a question related to transpiration was as follows:

1. Plant transpiration is more active during (a) day, (b) night, (c) all day
2. I am confident for my answer-I am not so confident for my answer
3. The correct answer is (a) because:

   - When the stomata open for releasing the oxygen produced during photosynthesis, the excessive water also finds its way out.
   - At night all plant functions are minimal and this applies to transpiration too.

   The correct answer is (b) because:

- Photosynthesis uses water. It would be illogical plants to lose water when they need it the most. Therefore, plants transpire at night.
- Plants are more active during the day but water moves slowly through. As a result, the excessive water reaches the leaves at night.
- When the stomata open for absorbing oxygen for respiration, the excessive water also finds its way out.

The correct answer is (c) because:

- Plant transpiration is like our sweating; we sweat all the time.
- It can rain regardless if it is day or night. It can also rain for days. If plants transpired only during day or night, they would be in danger because of the excessive water absorbed by their roots.
- Plants draw water from the soil all the time and all their functions require just a fraction of it. Thus, it is logical to transpire all the time.

4. I am confident for my answer-I am not so confident for my answer

For answering RQ3, we selected four out of the twelve factors included in a validated, modular scale, designed for examining digital educational applications (Fokides et al. 2019). Specifically, we selected fun/enjoyment (6 items), subjective learning effectiveness (6 items), ease of use (6 items), and motivation (3 items). The items were presented in a five-point scale, worded from "strongly disagree" to "strongly agree". Ease of use was not applicable to the groups that used printed material. Therefore, we omitted the corresponding items from their questionnaires. The participating students filled the questionnaire at the end of the last session.

6 Results

As already stated, the initial sample size was 285 students divided into five groups. Then again, we had to remove 22 of them, as they were absent in one or more sessions. As a result, our final sample size was 263 students. Group1 (baseline group, printed material, conventional teaching) comprised of 54 students (28 girls, 26 boys), Group2 (printed material) had 49 (26 girls, 23 boys), Group3 (laptops, webpages) had 52 (27 girls, 25 boys), Group4 (tablets, commercial app) had 55 (28 girls, 27 boys), and Group5 (tablets, non-commercial apps) had 53 (27 girls, 26 boys). We graded all tests and we imputed the resulting data into SPSS 25 for further analysis. Table 1 presents the tests' means per group of participants.

Given that: (1) the groups did not have an equal number of participants, (2) in several cases the data were not normally distributed, and (3) in almost all cases the homogeneity of variances was violated, we carried out a series of Kruskal–Wallis H tests to compare student scores in all tests. We found that there were no statistically significant differences in the two pre-tests [$H(4)_{\text{pre-test knowledge}} = 5.69$, $p = .224$ and $H(4)_{\text{pre-test misconceptions}} = 1.11$, $p = .892$]. Then again, in all the other tests there was strong evidence of a difference between the mean ranks of at least one pair of groups [$H(4)_{ES1} = 73.79$, $p < .001$; $H(4)_{ES2} = 109.65$, $p < .001$; $H(4)_{ES3} = 28.03$, $p < .001$; $H(4)_{ES4} = 78.90$, $p < .001$; $H(4)_{ES5} = 46.24$, $p < .001$; $H(4)_{ES6} = 90.69$, $p < .001$; $H(4)_{\text{delayed post-test knowledge}} = 71.16$, $p < .001$; and $H(4)_{\text{delayed post-test misconceptions}} = 62.77$, $p < .001$].

Table 1 Tests means and standard deviations

Tests	Group1 $n=54$		Group2 $n=49$		Group3 $n=52$		Group4 $n=55$		Group5 $n=53$	
	M	SD	M	SD	M	SD	M	SD	M	SD
Pre-test knowledge	14.69	5.85	13.98	6.22	14.02	7.17	12.80	5.91	12.23	6.73
Pre-test misconceptions	6.13	2.81	5.84	2.99	6.63	4.16	5.80	3.64	6.25	4.22
ES1 (plant structure)	25.94	6.07	30.94	6.22	33.19	9.46	39.16	7.10	35.72	7.82
ES2 (reproduction organs, fruits, seeds)	21.63	10.00	23.88	11.57	31.50	7.91	37.18	7.49	40.40	6.25
ES3 (pollination, asexual reproduction)	25.74	12.01	31.90	8.62	33.02	8.26	35.44	7.75	34.15	7.08
ES4 (plant nutrition, photosynthesis I)	15.43	5.06	20.47	7.48	25.13	6.81	28.44	9.41	26.45	8.24
ES5 (plant nutrition, photosynthesis II)	20.54	8.42	23.04	11.33	24.06	9.04	31.31	7.94	29.77	9.12
ES6 (respiration, transpiration)	22.83	8.01	26.94	6.47	33.79	8.13	38.49	5.89	32.26	9.33
Delayed post-test knowledge	22.26	8.58	27.90	6.90	29.79	7.09	33.93	6.09	34.13	5.46
Delayed post-test misconceptions	12.04	3.42	14.37	2.79	16.38	2.90	17.38	4.19	16.58	3.47

ES evaluation sheet; the maximum score for the ESs was 50 while for the misconceptions tests was 25

A total of 80 Dunn's pairwise post hoc tests (Field 2013) were carried out (6 EVs and 2 delayed post-tests X 10 pairs of groups for each of them) (Table 2). Note that Bonferroni adjusted *p* values are quoted in this table. This procedure adjusts (rather conservatively) the significance level relative to how many repeated analyses are being conducted (Bland and Altman 1995). Moreover, the reported effect sizes (g_{Hedges}) were computed following a procedure identical with d_{Cohen} but with a correction of a positive bias in the pooled standard deviation, given that the groups had different sample sizes (Hedges and Olkin 1985). As with Cohen's *d*, effect sizes around the 0.5 mark are regarded as medium, around 0.8 large, around 1.2 very large, and around 2.0 are considered extremely large (Cohen 2013). Table 3 summarizes the above results. In each cell, the group with the statistically significantly higher score is reported

By observing Tables 2 and 3, we can infer the following:

- In both pre-tests, no differences were found in student scores. Consequently, we can assume that the differences noted in the subsequent tests can be attributed to the different tools each group used.
- There was not a single case in which Group1 (control group) surpassed any other group. Thus, students in this group had the worst results compared with students in the other four groups.
- Students in Group2 (printed material) outperformed only students in Group1 (in 3 out of 6 EVs and in both the delayed post-tests). The effect sizes were mostly medium to large.
- There was not a single case in which students in Group3 (laptops, webpages) were able to achieve better scores compared with students in groups 4 and 5. Then again, they outperformed students in Group1 in almost all cases and the effect sizes were large. Compared with students in Group2, they had better results in 3 out of 6 EVs and in the delayed post-test regarding misconceptions, while the effect sizes were medium to large.
- Students in Group4 (tablets, commercial app) outperformed students in groups 1 and 2 in almost all cases. The effect sizes were mostly very large and, in a couple of cases, the effect sizes were extremely large. Compared with students in Group3, they achieved better scores in 3 out of 6 EVs and in the delayed post-test regarding knowledge. In this case, the effect sizes were mostly medium to large. Then again, we found only one case in which Group4 outperformed Group5 (tablets, non-commercial apps).
- Students in Group5 also outperformed students in groups 1 and 2 in almost all cases. The effect sizes were mostly very large when compared with Group1 and medium to large when compared with Group2. When compared with Group3, we noted three cases (including the delayed post-test) in which they had better results.
- In sum, and for answering RQ1 and RQ2, in terms of knowledge acquisition, the results of groups 4 and 5 did not differ that much, they were slightly better than that of Group3 and better than that of groups 1 and 2. In terms of knowledge retention, groups 4 and 5 had an advantage over Group3, while the rest of the results were the same as in knowledge acquisition. As far as misconceptions are concerned, the results of groups 3, 4, and 5 were the same, but still better than that of groups 1 and 2.

As for the questionnaire, we obtained scores by assigning numerical values to student responses (ranging from 1 for "Strongly Disagree" to 5 for "Strongly Agree"). We followed the same statistical procedures as with student tests. Prior to analyzing the results, we examined the questionnaire's internal consistency using Cronbach's alpha.

Table 2 Evaluation sheets post hoc comparisons

Tests	Pair	Mean ranks pair A–B		*p*	*g*	Pair	Mean ranks pair A–B		*p*	*g*	Pair	Mean ranks pair A–B		*p*	*g*
ES1	1–2	68.51	112.67	.032	0.81	2–3	112.67	134.35	1.000	–	3–4	134.35	185.58	.005	0.72
	1–3	68.51	134.35	< .001	0.92	2–4	112.67	185.58	< .001	1.23	3–5	134.35	156.65	1.000	–
	1–4	68.51	185.58	< .001	2.00	2–5	112.67	156.65	.035	0.67	4–5	185.58	156.65	.480	–
	1–5	68.51	156.65	< .001	1.40										
ES2	1–2	69.36	86.57	1.000	–	2–3	86.57	129.88	.042	0.77	3–4	129.88	172.35	.039	0.74
	1–3	69.36	129.88	< .001	1.09	2–4	86.57	172.35	< .001	1.38	3–5	129.88	198.03	< .001	1.25
	1–4	69.36	172.35	< .001	1.76	2–5	86.57	198.03	< .001	1.80	4–5	172.35	198.03	.793	–
	1–5	69.36	198.03	< .001	2.25										
ES3	1–2	87.04	130.07	.041	0.59	2–3	130.07	137.86	1.000	–	3–4	137.86	159.38	1.000	–
	1–3	87.04	137.86	.006	0.70	2–4	130.07	159.38	.497	–	3–5	137.86	145.43	1.000	–
	1–4	87.04	159.38	< .001	0.96	2–5	130.07	145.43	1.000	–	4–5	159.38	145.43	1.000	–
	1–5	87.04	145.43	.001	0.85										
ES4	1–2	61.60	109.34	.015	0.80	2–3	109.34	153.47	.035	0.65	3–4	153.47	174.29	1.000	–
	1–3	61.60	153.47	< .001	1.62	2–4	109.34	174.29	< .001	0.93	3–5	153.47	159.73	1.000	–
	1–4	61.60	174.29	< .001	1.72	2–5	109.34	159.73	.008	0.76	4–5	174.29	159.73	1.000	–
	1–5	61.60	159.73	< .001	1.62										
ES5	1–2	89.75	113.60	1.000	–	2–3	113.60	118.09	1.000	–	3–4	118.09	173.23	.002	0.85
	1–3	89.75	118.09	.551	–	2–4	113.60	173.23	.001	0.85	3–5	118.09	162.92	.025	0.63
	1–4	89.75	173.23	< .001	1.32	2–5	113.60	162.92	.011	0.66	4–5	173.23	162.92	1.000	–
	1–5	89.75	162.92	< .001	1.05										
ES6	1–2	68.64	97.38	.554	–	2–3	97.38	154.31	.002	0.93	3–4	154.31	194.97	.057	0.67
	1–3	68.64	154.31	< .001	1.36	2–4	97.38	194.97	< .001	1.87	3–5	154.31	141.33	1.000	–
	1–4	68.64	194.97	< .001	2.23	2–5	97.38	141.33	.035	0.66	4–5	194.97	141.33	.002	0.80
	1–5	68.64	141.33	< .001	1.09										

Table 2 (continued)

Tests	Pair	Mean ranks pair A–B		*p*	*g*	Pair	Mean ranks pair A–B		*p*	*g*	Pair	Mean ranks pair A–B		*p*	*g*
Delayed post-test knowledge	1–2	69.53	111.88	.047	0.72	2–3	111.88	130.97	1.000	–	3–4	130.97	172.50	.047	0.63
	1–3	69.53	130.97	< .001	0.96	2–4	111.88	172.50	< .001	0.93	3–5	130.97	173.24	.044	0.69
	1–4	69.53	172.50	< .001	1.57	2–5	111.88	173.24	< .001	1.01	4–5	172.50	173.24	1.000	–
	1–5	69.53	173.24	< .001	1.65										
Delayed post-test misconceptions	1–2	68.91	111.91	.040	0.74	2–3	111.91	155.37	.040	0.71	3–4	155.37	167.62	1.000	–
	1–3	68.91	155.37	< .001	1.37	2–4	111.91	167.62	.002	0.84	3–5	155.37	154.97	1.000	–
	1–4	68.91	167.62	< .001	1.40	2–5	111.91	154.97	.042	0.70	4–5	167.62	154.97	1.000	–
	1–5	68.91	154.97	< .001	1.32										

All p values reported in this table are adjusted using the Bonferroni correction; when using this correction, it is possible to obtain p values equal to or greater than 1.000; g = Hedges's effect size

Table 3 Summary of the evaluation sheets post hoc comparisons

Test	Pair									
	1–2	1–3	1–4	1–5	2–3	2–4	2–5	3–4	3–5	4–5
Pre-test knowledge	–	–	–	–	–	–	–	–	–	–
Pre-test misconceptions	–	–	–	–	–	–	–	–	–	–
EV1	2	3	4	5	–	4	5	4	–	–
EV2	–	3	4	5	3	4	5	4	5	–
EV3	2	3	4	5	–	–	–	–	–	–
EV4	2	3	4	5	3	4	5	–	–	–
EV5	–	–	4	5	–	4	5	4	5	–
EV6	–	3	4	5	3	4	5	–	–	4
Delayed post-test knowledge	2	3	4	5	–	4	5	4	5	–
Delayed post-test misconceptions	2	3	4	5	3	4	5	–	–	–

The overall internal consistency was good ($\alpha = .821$) (DeVellis 2016) and the same applied for the reliability scores of the five constructs ($\alpha = .807$ to $\alpha = .851$). Table 4 presents the factor means per group of participants. The Kruskal–Wallis H tests provided strong evidence of a difference between the mean ranks of at least one pair of groups in all factors [$H(4)_{\text{enjoyment}} = 69.20$, $p < .001$; $H(4)_{\text{learning effectiveness}} = 70.49$, $p < .001$; $H(4)_{\text{AV adequacy}} = 48.84$, $p < .001$; $H(4)_{\text{ease of use}} = 44.92$, $p < .001$; and $H(4)_{\text{motivation}} = 100.81$, $p < .001$]. As previously, a series of Dunn's pairwise post hoc tests were carried out. Tables 5 and 6 present and summarize these results.

Given the findings in Tables 5 and 6, we can conclude that:

- When comparing the results of Group1 and Group2 (to both printed material was used, their difference was the teaching method), students in the latter group considered the procedure more motivating and the effect size was large. No other differences were noted.
- When contrasting the results of groups 1 and 2 with the results of groups 3, 4, and 5, we found that the latter groups surpassed the former in all cases. Therefore, we can infer that students considered laptops/webpages as well as tablets (either with the commercial app or with the non-commercial ones) more motivating, more effective in terms of

Table 4 Factor means and standard deviations

Factor	Group1 $n = 54$		Group2 $n = 49$		Group3 $n = 52$		Group4 $n = 55$		Group5 $n = 53$	
	M	SD	M	SD	M	SD	M	SD	M	SD
Enjoyment	2.83	1.24	2.96	1.05	3.78	0.98	4.36	0.54	3.80	0.77
Learning effectiveness	3.16	0.89	3.62	0.77	4.12	0.63	4.33	0.55	4.22	0.57
Ease of use	Not applicable				4.48	0.57	3.98	0.67	3.19	1.10
Motivation	2.57	1.03	3.35	0.96	3.98	0.68	4.47	0.48	4.01	0.66

Table 5 Factor post hoc comparisons

Factor	Pair	Mean ranks pair A–B		p	g	Pair	Mean ranks pair A–B		p	g	Pair	Mean ranks pair A–B		p	g
Enjoyment	1–2	86.76	89.49	1.000	–	2–3	89.49	146.50	.002	0.81	3–4	146.50	189.65	.033	0.75
	1–3	86.76	146.50	.001	0.85	2–4	89.49	189.65	<.001	1.71	3–5	146.50	143.34	1.000	–
	1–4	86.76	189.65	< .001	1.61	2–5	89.49	143.34	.003	0.92	4–5	189.65	143.34	.015	0.85
	1–5	86.76	143.34	.001	0.94										
Learning effectiveness	1–2	70.53	101.97	.359	–	2–3	101.97	150.72	.013	0.71	3–4	150.72	174.20	1.000	–
	1–3	70.53	150.72	< .001	1.24	2–4	101.97	174.20	< .001	1.07	3–5	150.72	160.24	1.000	–
	1–4	70.53	174.20	< .001	1.59	2–5	101.97	160.24	.001	0.89	4–5	174.20	160.24	1.000	–
	1–5	70.53	160.24	< .001	1.42										
Ease of use	Not applicable					Not applicable					3–4	110.69	81.09	.009	0.80
											3–5	110.69	50.26	< .001	1.47
											4–5	81.09	50.26	.005	0.87
Motivation	1–2	58.78	103.33	.030	0.78	2–3	103.33	149.16	.024	0.76	3–4	149.16	194.90	.019	0.84
	1–3	58.78	149.16	< .001	1.61	2–4	103.33	194.90	< .001	1.50	3–5	149.16	151.00	1.000	–
	1–4	58.78	194.90	< .001	2.37	2–5	103.33	151.00	.015	0.81	4–5	194.90	151.00	.027	0.80
	1–5	58.78	151.00	< .001	1.66										

Table 6 Summary of the factors' post hoc comparisons

Factor	Pair									
	1–2	1–3	1–4	1–5	2–3	2–4	2–5	3–4	3–5	4–5
Enjoyment	–	3	4	5	3	4	5	4	–	4
Learning effectiveness	–	3	4	5	3	4	5	–	–	–
Ease of use	Not applicable							3	3	4
Motivation	2	3	4	5	3	4	5	4	–	4

learning, and more enjoyable compared with the printed material. The effect sizes varied from large to extremely large.

- When comparing the results of groups 3, 4, and 5, we can note that students regarded the corresponding tools as equally effective in terms of learning. Interestingly enough, compared with tablets (either with the commercial or with the non-commercial apps), the laptops/webpages were considered as easier to use (the effect sizes were large to very large). Also, students considered the use of tablets together with a commercial app as a more motivating and more enjoyable experience. On the other hand, the use of laptops/webpages and the use of tablets with the non-commercial apps were considered as equally motivating and enjoyable.
- In sum, and for answering RQ3, the use of ICT tools (tablets and laptops alike) compared with printed material, yielded better results in all the factors we examined. The use of tablets with the commercial app motivated students more and provided a more enjoyable experience, while the laptops/webpages were considered easier to use. On the other hand, students considered all three ICT tools as equally effective in terms of their learning effectiveness.

7 Discussion

Our study embarked on the task of examining the impact of tablets and their apps on primary school student knowledge and misconceptions about plants. The data analysis revealed a series of findings worthy of further discussion.

Table 1 provides an initial set of interesting observations. By examining the first two rows (pre-test knowledge and pre-test misconceptions), it is more than evident that students, in all groups, were able to answer correctly about a quarter of the questions in both pre-tests. Thus, we can infer that student knowledge about plants was rather limited, while their misconceptions were significant, confirming previous research (e.g., Barman et al. 2006; Bates 2019; Fokides and Atsikpasi 2017; Özay and Öztaş 2003). The results were substantially better in all subsequent tests and in all groups. Depending on the group and the evaluation sheet, we noted an improvement ranging from 71% (Group1) to 230% (Group5). The same applies to misconceptions; the improvement ranged from 96% (Group1) to 200% (Group4).

There are two, somehow conflicting, ways to interpret these results. One might argue that even with lecturing and by using printed material (which was the method/tool that produced the poorest results), the advancement of student performance was impressive and it became striking in case of laptops and tablets. Yet, others might argue that it is not enough to debate on which teaching method or tool is superior compared with others; what is important is to examine how much "learning" was actually achieved. Indeed, by examining the results in the two delayed post-tests, we can note that students in Group1 wrongfully answered more than half of the questions. Though the results were better in groups 3, 4, and 5, still, the number of wrong answers was high (around two-fifths). This means that even with the most effective method/tool, students did not excel and several of their misconceptions were left intact. In this respect, our results confirm that plants are not an "easy" subject (e.g., Bates 2019) and that misconceptions are persistent (e.g., Barman et al. 2006; Marmaroti and Galanopoulou 2006).

We can also draw conclusions from Table 3. First, it provides hard evidence that tablets are expected to yield better learning outcomes compared with conventional tools (i.e., printed material) as others suggested (e.g., Bano et al. 2018; Crompton and Burke 2015; Crompton et al. 2016a, b; Tingir et al. 2017). Also, since in our study AR apps were utilized, the results we obtained are in line with previous research suggesting that this type of mobile apps helped students to acquire more knowledge (e.g., Garzón et al. 2019; Huang et al. 2016) and retain it (Zhang et al. 2014), especially when the learning subjects were difficult (Tarng et al. 2018) and/or related to natural sciences (Özdemir et al. 2018). The results of Group3 (the one in which laptops/webpages were used) were not as good as the results of groups 4 and 5, given that, in several occasions, students in the latter groups outperformed students in the former one. Although the literature comparing computers and tablets is narrow (Nedungadi and Raman 2012), it seems that tablets have certain advantages over computers, probably related to their small size, flexibility, and portability (Nguyen et al. 2015). Touchscreens may also be a contributing factor. Some suggested that the usual LCD displays are less user-friendly/ergonomic than touchscreens (Dündar and Akçayir 2017). Others suggested that touchscreens besides fostering visual and tactile modalities, also promote engagement with the learning activities (McClanahan et al. 2012).

In addition, we can draw an interesting conclusion by comparing the results of groups 4 and 5 (commercial and non-commercial tablet apps). In previous studies around 60% of the apps were tailor-made/non-commercial while the rest were commercial ones (Bano et al. 2018), but we are not aware of studies comparing both at the same time. As it is evident in Table 3, in all but one case, the results were similar. Yet, the commercial app we used in our study was, by far, more sophisticated compared with the "amateurish" apps the participating teachers were able to develop. This leads us to support that, as far as the learning outcomes are concerned, what it really matters is the learning content to be adequately presented. The questionnaire results are in support of our argument. Despite the fact that students considered the commercial app as being more motivating and enjoyable, probably because being professionally developed it had several attractive additional features, they also considered all three ICT tools equally effective in terms of learning (see Tables 5 and 6).

By probing more on the questionnaire results, we can observe that, in all cases, students considered the laptops and tablets more enjoyable and motivating than the printed material. Taken together with the results in the evaluation sheets, we can concur with the conclusions of previous studies supporting the view that tablets and AR apps have a positive impact on student learning, since they are motivating (Furió et al. 2013; Garzón et al. 2019) and offer an enjoyable experience (Chiang et al. 2014; Sloan 2012). On the other hand, compared with laptops, only the commercial app was considered more enjoying and motivating, probably because, as we mentioned in the preceding paragraph, it was more impressive than the tailor-made one. What we find rather puzzling is that students considered laptops as easier to use than tablets. Even though the relevant literature suggested that students find tablets easy to use (e.g., Chen 2013; Fokides and Atsikpasi 2017), it seems that students in our study were more familiar with the use of computers. Indeed, there are ICT courses included in the primary school curriculum that are conducted using computers. Then again, this familiarization with computers may also explain why tablets yielded better learning outcomes compared with laptops. Although young students are “digital natives,” they still perceive the use of technology in the classroom as something out of the ordinary. The novelty effect was probably stronger in case of tablets, because students are, up to a point, used in using computers during school, while tablets are still an unfamiliar sight. As others suggested, the novelty of mobile learning tools enhances achievement, satisfaction, and motivation (Jeno et al. 2019; Tamim et al. 2015). Although the results cannot be attributed solely to the novelty effect, nevertheless, there are some concerns, as accustomization wanes this effect of technology, which, in turn, decreases user/student motivation (Keller and Suzuki 2004).

As we mentioned in the “Procedure” section, we trained students in the use of laptops and tablets and for that matter, we used educational webpages and apps. We did so not only because we wanted to proactively deal with difficulties when using them (Fernández-López et al. 2013), but also because previous research suggested that students need to be trained on how to use these devices in an educational context (Tamim et al. 2014). There is a great distance between knowing how to operate a device and knowing how to purposively use the same device in order to learn. By allowing students to familiarize themselves with both cases, we can assume that there was a positive impact on their learning achievements.

As others have noted, mobile devices’ features are not enough for explaining student learning gains. Instructional strategies are needed able to seamlessly integrate these devices into everyday teaching, to enhance their effects, and to exploit their advantages (Sung et al. 2016). On the basis of the results, we can give support to these views. Table 3 clearly illustrates that the results in Group1 were inferior to that of all the other groups. What is important is that, in most cases, Group2 also surpassed Group1. Though both groups used printed material, the teaching method was different, namely, lecturing in Group1 and Bybee’s 5Es in Group2 (as well as in all the other groups). In this respect, our results provide evidence that, at least in science-related subjects, a constructivist teaching framework is more effective than lecturing (Osborne and Dillon 2008). Given that the learning outcomes were better with the use of tablets, we can support that their impact was maximized due to the constructivist teaching method we followed, as the literature suggested (e.g., Iserbyt et al. 2014; Tamim et al. 2015).

The main characteristics of the teaching method we employed were student active participation in the learning process, self-directed learning, and collaboration among peers. The above were paired with a one-to-one student to tablet ratio. In the “Procedure” section, we presented arguments in favor of both a one-to-one and one-to-many settings. Although we do not know what the outcomes might have been if we had chosen the latter setting, we can speculate that because students had their own tablets, independent, self-paced, and self-directed learning were enabled as others suggested (e.g., Ferrer-Torregrosa et al. 2015; Kearney et al. 2012; Sung et al. 2016). At the same time, students collaborated. In fact, collaboration took many forms; from discussions among group members, to students collectively recording their views, exchanging notes, or even their tablets. In this respect, the level of interaction and communication among peers was high and this also holds true for the interactions with the learning content. All the above were considered contributing factors to the positive learning outcomes when using tablets (e.g., Bujak et al. 2013; Heinrich 2012).

7.1 Implications for Practice

It is rather important to provide stakeholders (i.e., education policy-makers and administrators) examples of how mobile learning can be put into practice and how it can be used effectively. In this respect, the study's implications for educational practice mostly rest upon the way we designed and implemented it. Throughout this paper, we argued in favor of the introduction of mobile devices in education. Seven out of ten primary school students (at least in the USA), also endorsed this idea (Poll 2014). Alas, few teachers chose to use these devices during their teaching (Levin and Wadmany 2008); tablets' widespread application in schools is yet to be realized (Berge and Muilenburg 2013). Several barriers have been identified such as ineffective policies for the adoption of mobile learning, limited financial resources, and lack of infrastructure. Yet, to our view, two are the most significant problems (1) limited availability of suitable applications (Ward et al. 2013) and (2) lack of skilled educators (Crompton et al. 2016a, b), as most have not received any form of training (either pre- or in-service) on how to implement mobile pedagogies (Goktas et al. 2009). In fact, the latter case was confirmed during the preliminary stages of our research, as we became aware that none of the participating teachers had ever tried to incorporate tablets during their teaching. Moreover, none was familiar with any form of teaching framework which utilizes these devices.

To deal with both problems simultaneously, we took a rather bold decision, namely, to actively and extensively involve the participating teachers in all stages of the project's development. Our decision was guided by the views of Sung et al. (2016), who suggested that researchers have to act as mentors/collaborators, diffusing their expertise on educational technology to educators, so as the latter to become self-sufficient in implementing it. Equally important for us was the participating teachers to develop a digital culture that would allow them to act as "change agents" (Li et al. 2010). Thus, the whole idea was to refrain from offering them out-of-the-box, easy to apply solutions. Even though we provided technical assistance, in essence, they were the ones who designed the learning material and transformed it into webpages and AR apps. They were also the ones who designed the worksheets as well as the evaluation sheets. When, at a later stage, we demonstrated how everything can be stitched together and become a well-structured teaching framework, it was easier for them to understand (and apply it), as they had already developed an understanding, an insider view, on how mobile pedagogy works. The above approach had another positive effect. The educators' role is of paramount importance. Good teachers are able to produce satisfactory learning outcomes even if the tools they have at their disposal are not good and vice versa. By actively involving the participating teachers in the research process and, most importantly, by training them on how to teach with mobile devices, we ensured the uniform, as well as the satisfactory implementation of the project's teaching framework, thus, safeguarding the validity of the results. We have to admit that it was not an easy task to coordinate sixteen teachers who had no relevant expertise whatsoever; nevertheless, the results speak for themselves. Even though the commercial app was more motivating and enjoyable the learning outcomes were almost identical to those of the tailor-made/non-commercial apps.

Time management in a technology-based learning environment is also important. Having that in mind, we allocated two teaching hours for each session, so as students to have enough time to use their tablets, study the relevant material, to conduct the experiments, and to collaborate. Moreover, technical problems were also a consideration.

Consequently, we strongly advise education policymakers to make changes to the primary school timetable, dedicating more teaching hours to courses in which tablets are going to be used.

7.2 Limitations and Future Work

Though we tried to design and carry out the study as meticulously as possible, there are still certain limitations that bear mentioning. As we detailed in section "Sample selection and project duration", our sample size was more than adequate for the type of statistical analysis we followed. However, a larger sample would have allowed us to draw even more reliable conclusions. The number of sessions might also be considered inadequate; one can argue that the complexity/difficulty of the learning subject called for the allocation of more sessions/teaching hours. Although we acknowledge the validity of this argument, the fact that we conducted the study not in a controlled environment but in real-life conditions, limited our flexibility. Actually, the saturated and quite pressing school timetables, determined, up to a certain point, the project's duration. In effect, we more than doubled the teaching hours that the sixth-grade program of study for natural sciences allows; adding more teaching interventions would have rendered the project settings unrealistic. We could have also used qualitative data collection tools (e.g., interviews), so as to gain further insights into the pros and cons of mobile learning.

As for future research paths, an interesting one is to implement a similar project, but having as a target group younger students. Indeed, since problems and misconceptions about plants take root at younger ages, early interventions might prove to be even more useful/effective. Plants are just one of the many science-related subjects in which primary school students have problems. In this respect, it would be useful to examine the effects of tablets in such "problematic" subjects as well. It would also be useful to conduct longitudinal studies for examining the impact of mobile technology on student knowledge after the novelty effect has faded. Finally, we find an interesting idea to compare the effects of tablets with other emerging ICT tools (e.g., immersive virtual reality).

8 Conclusion

Taking into account the aforementioned results as well as the study's limitations, we feel that we formulated a quite comprehensive idea about if and to what extent tablets and their apps can be effective tools for teaching primary school students concepts related to plants. The result analysis produced enough evidence that allows us to claim that, through the use of tablets, students gained both declarative and procedural knowledge. What is more, we observed a noticeable positive impact on their misconceptions. Finally, we suggested an instructional framework for integrating these devices into teaching, which also contributed to the encouraging learning outcomes. Taking together the findings and the fact that the learning subject we selected was a "difficult" one, we can conclude that tablets are indeed a tool of considerable educational potential.

Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

References

Akçayır, M., & Akçayır, G. (2017). Advantages and challenges associated with augmented reality for education: A systematic review of the literature. *Educational Research Review, 20,* 1–11. https://doi.org/10.1016/j.edurev.2016.11.002.

Allagui, B. (2019). Writing a descriptive paragraph using an Augmented Reality application: An evaluation of students' performance and attitudes. *Technology, Knowledge, and Learning*. https://doi.org/10.1007/s10758-019-09429-2.

Amir, R., & Tamir, P. (1994). In-depth analysis of misconceptions as a basis for developing research-based remedial instruction: The case of photosynthesis. *The American Biology Teacher, 56*(2), 94–100. https://doi.org/10.2307/4449760.

Anderson, J. L., Ellis, J. P., & Jones, A. M. (2014). Understanding early elementary children's conceptual knowledge of plant structure and function through drawings. *CBE-Life Sciences Education, 13*(3), 375–386. https://doi.org/10.1187/cbe.13-12-0230.

Anderson, C. W., Sheldon, T. H., & Dubay, J. (1990). The effects of instruction on college nonmajors' conceptions of respiration and photosynthesis. *Journal of Research in Science Teaching, 27*(8), 761–776. https://doi.org/10.1002/tea.3660270806.

Antink-Meyer, A., & Meyer, D. Z. (2016). Science teachers' misconceptions in science and engineering distinctions: Reflections on modern research examples. *Journal of Science Teacher Education, 27*(6), 625–647. https://doi.org/10.1007/s10972-016-9478-z.

Bano, M., Zowghi, D., Kearney, M., Schuck, S., & Aubusson, P. (2018). Mobile learning for science and mathematics school education: A systematic review of empirical evidence. *Computers & Education*. https://doi.org/10.1016/j.compedu.2018.02.006.

Barman, C. R., Stein, M., McNair, S., & Barman, N. S. (2006). Students' ideas about plants & plant growth. *The American Biology Teacher, 68*(2), 73–79. https://doi.org/10.2307/4451935.

Bates, B. (2019). *Learning theories simplified: And how to apply them to teaching*. Thousand Oaks: SAGE Publications Limited.

Bebell, D., & O'Dwyer, L. (2010). Educational outcomes and research from 1: 1 computing settings. *The Journal of Technology, Learning and Assessment, 9*(1), 5–15.

Bell, B. F. (1981). What is a plant? Some children's ideas. *New Zealand Science Teacher, 31*(3), 10–14.

Berge, Z. L., & Muilenburg, L. (2013). Seamless learning: An international perspective on next-generation technology-enhanced learning. In Z. L. Berge & L. Y. Muilenburg (Eds.), *Handbook of mobile learning* (pp. 133–146). Abingdon: Routledge. https://doi.org/10.4324/9780203118764.

Bland, J. M., & Altman, D. G. (1995). Multiple significance tests: The Bonferroni method. *British Medical Journal, 310*(6973), 170–171. https://doi.org/10.1136/bmj.310.6973.170.

Brossard, D., Lewenstein, B., & Bonney, R. (2005). Scientific knowledge and attitude change: The impact of a citizen science project. *International Journal of Science Education, 27*(9), 1099–1121. https://doi.org/10.1080/09500690500069483.

Bujak, K. R., Radu, I., Catrambone, R., Macintyre, B., Zheng, R., & Golubski, G. (2013). A psychological perspective on augmented reality in the mathematics classroom. *Computers & Education, 68,* 536–544. https://doi.org/10.1016/j.compedu.2013.02.017.

Bybee, R. W., Taylor, J. A., Gardner, A., Van Scotter, P., Powell, J. C., Westbrook, A., et al. (2006). The BSCS 5E instructional model: Origins and effectiveness. *Colorado Springs Co: BSCS, 5,* 88–98.

Cañal, P. (1999). Photosynthesis and'inverse respiration'in plants: An inevitable misconception? *International Journal of Science Education, 21*(4), 363–371. https://doi.org/10.1080/095006999290598.

Carr, J. M. (2012). Does math achievement h'APP'en when iPads and game-based learning are incorporated into fifth-grade mathematics instruction? *Journal of Information Technology Education: Research, 11*(1), 269–286. https://doi.org/10.28945/1725.

Chen, C. P., & Wang, C. H. (2015). Employing augmented-reality-embedded instruction to disperse the imparities of individual differences in earth science learning. *Journal of Science Education and Technology, 24*(6), 835–847. https://doi.org/10.1007/s10956-015-9567-3.

Chen, X. B. (2013). Tablets for informal language learning: Student usage and attitudes. *Language Learning & Technology, 17*(1), 20–36.

Chiang, T. H. C., Yang, S. J., & Hwang, G. J. (2014). An augmented reality-based mobile learning system to improve students' learning achievements and motivations in natural science inquiry activities. *Educational Technology & Society, 17*(4), 352–365.

Cohen, J. (2013). *Statistical power analysis for the behavioral sciences*. Abingdon: Routledge. https://doi.org/10.4324/9780203771587.

Creswell, J. W., & Poth, C. N. (2017). *Qualitative inquiry and research design: Choosing among five approaches*. Thousand Oaks: Sage Publications.

Crompton, H. (2013). Mobile learning: New approach, new theory. In Z. L. Berge & L. Y. Muilenburg (Eds.), *Handbook of mobile learning* (pp. 47–58). Abingdon: Routledge.
Crompton, H., & Burke, D. (2015). Research trends in the use of mobile learning in Mathematics. *International Journal of Mobile and Blended Learning, 7*(4), 1–15. https://doi.org/10.4018/IJMBL.2015100101.
Crompton, H., Burke, D., Gregory, K. H., & Gräbe, C. (2016a). The use of mobile learning in science: A systematic review. *Journal of Science Education and Technology, 25*(2), 149–160. https://doi.org/10.1007/s10956-015-9597-x.
Crompton, H., Olszewski, B., & Bielefeldt, T. (2016b). The mobile learning training needs of educators in technology-enabled environments. *Professional Development in Education, 42*(3), 482–501. https://doi.org/10.1080/19415257.2014.1001033.
Culén, A., & Gasparini, A. (2012). Tweens with the iPad classroom-Cool but not really helpful? In *Proceedings of the 2012 international conference on e-learning and e-technologies in education* (*ICEEE*) (pp. 1–6). IEEE. https://doi.org/10.1109/ICeLeTE.2012.6333771.
Cumming, T. M., Strnadová, I., & Singh, S. (2014). iPads as instructional tools to enhance learning opportunities for students with developmental disabilities: An action research project. *Action Research, 12*(2), 151–176. https://doi.org/10.1177/1476750314525480.
Dass, P. M. (2001). Implementation of instructional innovations in K-8 science classes: Perspectives of inservice teachers. *International Journal of Science Education, 23*(9), 969–984. https://doi.org/10.1080/09500690010025021.
DeVellis, R. F. (2016). *Scale development: Theory and applications* (Vol. 26). Thousand Oaks: Sage Publications.
Diemer, T. T., Fernandez, E., & Streepey, J. W. (2012). Student perceptions of classroom engagement and learning using iPads. *Journal of Teaching and Learning with Technology, 1*(2), 13–25.
Doolittle, P. E., & MaRIanO, G. J. (2008). Working memory capacity and mobile multimedia learning environments: Individual differences in learning while mobile. *Journal of Educational Multimedia and Hypermedia, 17*(4), 511–530.
Dündar, H., & Akçayır, M. (2017). Tablet vs. paper: The effect on learners' reading performance. *International Electronic Journal of Elementary Education, 4*(3), 441–450.
Dunleavy, M., Dede, C., & Mitchell, R. (2009). Affordances and limitations of immersive participatory augmented reality simulations for teaching and learning. *Journal of Science Education and Technology, 18*(1), 7–22. https://doi.org/10.1007/s10956-008-9119-1.
Fančovičová, J., & Prokop, P. (2010). Development and initial psychometric assessment of the plant attitude questionnaire. *Journal of Science Education and Technology, 19*(5), 415–421. https://doi.org/10.1007/s10956-010-9207-x.
Faul, F., Erdfelder, E., Lang, A. G., & Buchner, A. (2007). G* Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39*(2), 175–191. https://doi.org/10.3758/BF03193146.
Fernández-López, Á., Rodríguez-Fórtiz, M. J., Rodríguez-Almendros, M. L., & Martínez-Segura, M. J. (2013). Mobile learning technology based on iOS devices to support students with special education needs. *Computers & Education, 61,* 77–90. https://doi.org/10.1016/j.compedu.2012.09.014.
Ferrer-Torregrosa, J., Torralba, J., Jimenez, M. A., García, S., & Barcia, J. M. (2015). ARBOOK: Development and assessment of a tool based on augmented reality for anatomy. *Journal of Science Education and Technology, 24*(1), 119–124. https://doi.org/10.1007/s10956-014-9526-4.
Field, A. (2013). *Discovering statistics using SPSS: (And sex and drugs and rock 'n' roll)* (4th ed.). London: SAGE.
Fisher, B., Lucas, T., & Galstyan, A. (2013). The role of iPads in constructing collaborative learning spaces. *Technology, Knowledge, and Learning, 18*(3), 165–178. https://doi.org/10.1007/s10758-013-9207-z.
Fokides, E., & Atsikpasi, P. (2017). Tablets in education. Results from the initiative ETiE, for teaching plants to primary school students. *Education and Information Technologies, 22*(5), 2545–2563. https://doi.org/10.1007/s10639-016-9560-3.
Fokides, E., Atsikpasi, P., Kaimara, P., & Deliyannis, I. (2019). Let players evaluate serious games. Design and validation of the Serious Games Evaluation Scale. *International Computer Games Association Journal, 31*(3), 1–22. https://doi.org/10.3233/ICG-190111.
Frohberg, D., Göth, C., & Schwabe, G. (2009). Mobile learning projects—A critical analysis of the state of the art. *Journal of Computer Assisted learning, 25*(4), 307–331. https://doi.org/10.1111/j.1365-2729.2009.00315.x.
Furió, D., GonzáLez-Gancedo, S., Juan, M. C., Seguí, I., & Costa, M. (2013). The effects of the size and weight of a mobile device on an educational game. *Computers & Education, 64,* 24–41. https://doi.org/10.1016/j.compedu.2012.12.015.

Garzón, J., Pavón, J., & Baldiris, S. (2019). Systematic review and meta-analysis of augmented reality in educational settings. *Virtual Reality*. https://doi.org/10.1007/s10055-019-00379-9.

Goktas, Y., Yildirim, S., & Yildirim, Z. (2009). Main barriers and possible enablers of ICTs integration into pre-service teacher education programs. *Journal of Educational Technology & Society, 12*(1), 193.

Grossman, P., & Thompson, C. (2004). District policy and beginning teachers: A lens on teacher learning. *Educational Evaluation and Policy Analysis, 26*(4), 281–301. https://doi.org/10.3102/01623737026004281.

Gurel, D. K., Eryilmaz, A., & McDermott, L. C. (2015). A review and comparison of diagnostic instruments to identify students' misconceptions in science. *Eurasia Journal of Mathematics, Science, & Technology Education, 11*(5), 989–1008. https://doi.org/10.12973/eurasia.2015.1369a.

Harlen, W., & Qualter, A. (2014). *The teaching of science in primary schools* (6th ed.). Routledge: Abingdon.

Hedges, L., & Olkin, I. (1985). *Statistical methods for meta-analysis*. New York: Academic Press.

Heinrich, P. (2012). *The iPad as a tool for education—A case study*. Longfield Academy, Kent: Naace.

Henderson, S., & Yeow, J. (2012). iPad in education: A case study of iPad adoption and use in a primary school. In *Proceedings of the 45th Hawaii international conference in system science* (HICSS), 2012 (pp. 78-87). IEEE. https://doi.org/10.1109/HICSS.2012.390.

Hershey, D. R. (2004). Avoid misconceptions when teaching about plants. Retrieved 24 March 2020 from http://www.actionbioscience.org/education/hershey.html.

Hsiao, H. S., Chang, C. S., Lin, C. Y., & Wang, Y. Z. (2016). Weather observers: a manipulative augmented reality system for weather simulations at home, in the classroom, and at a museum. *Interactive Learning Environments, 24*(1), 205–223. https://doi.org/10.1080/10494820.2013.834829.

Huang, T. C., Chen, C. C., & Chou, Y. W. (2016). Animating eco-education: To see, feel, and discover in an augmented reality-based experiential learning environment. *Computers & Education, 96,* 72–82. https://doi.org/10.1016/j.compedu.2016.02.008.

Iserbyt, P., Charlier, N., & Mols, L. (2014). Learning basic life support (BLS) with tablet PCs in reciprocal learning at school: Are videos superior to pictures? A randomized controlled trial. *Resuscitation, 85*(6), 809–813. https://doi.org/10.1016/j.resuscitation.2014.01.018.

Jeno, L. M., Vandvik, V., Eliassen, S., & Grytnes, J. A. (2019). Testing the novelty effect of an m-learning tool on internalization and achievement: A self-determination theory approach. *Computers & Education, 128,* 398–413. https://doi.org/10.1016/j.compedu.2018.10.008.

Kearney, M., Burden, K., & Rai, T. (2015). Investigating teachers' adoption of signature mobile pedagogies. *Computers & Education, 80,* 48–57. https://doi.org/10.1016/j.compedu.2014.08.009.

Kearney, M., Schuck, S., Burden, K., & Aubusson, P. (2012). Viewing mobile learning from a pedagogical perspective. *Research in Learning Technology*. https://doi.org/10.3402/rlt.v20i0.14406.

Keller, J. M., & Suzuki, K. (2004). Learner motivation and E-learning design: A multinationally validated process. *Journal of Educational Media, 29*(3), 229–239.

Kilty, T. J., & Burrows, A. C. (2019). Secondary science preservice teachers' perceptions of engineering: A learner analysis. *Education Sciences, 9*(1), 29. https://doi.org/10.3390/educsci9010029.

Kinash, S., Brand, J., & Mathew, T. (2012). Challenging mobile learning discourse through research: Student perceptions of blackboard mobile learn and iPads. *Australasian Journal of Educational Technology, 28*(4), 639–655. https://doi.org/10.14742/ajet.832.

Lally, D., Brooks, E., Tax, F. E., & Dolan, E. L. (2007). Sowing the seeds of dialogue: Public engagement through plant science. *The Plant Cell, 19*(8), 2311–2319. https://doi.org/10.1105/tpc.107.053587.

Lazarowitz, R., & Penso, S. (1992). High school students' difficulties in learning biology concepts. *Journal of Biological Education, 26*(3), 215–223. https://doi.org/10.1080/00219266.1992.9655276.

Levin, T., & Wadmany, R. (2008). Teachers' views on factors affecting effective integration of information technology in the classroom: Developmental scenery. *Journal of Technology and Teacher Education, 16*(2), 233–263.

Lewis, J., & Wood-Robinson, C. (2000). Genes, chromosomes, cell division and inheritance-do students see any relationship? *International Journal of Science Education, 22*(2), 177–195. https://doi.org/10.1080/095006900289949.

Li, S. C., Pow, J. W., Wong, E. M., & Fung, A. C. (2010). Empowering student learning through tablet PCs: A case study. *Education and Information Technologies, 15*(3), 171–180. https://doi.org/10.1007/s10639-009-9103-2.

Lin, C. P., Wong, L. H., & Shao, Y. J. (2012). Comparison of 1:1 and 1:m CSCL environment for collaborative concept mapping. *Journal of Computer Assisted learning, 28*(2), 99–113. https://doi.org/10.1111/j.1365-2729.2011.00421.x.

Lindemann-Matthies, P. (2002). The influence of an educational program on children's perception of biodiversity. *The Journal of Environmental Education, 33*(2), 22–31. https://doi.org/10.1080/00958960209600805.

Lindemann-Matthies, P. (2005). "Loveable" mammals and "lifeless" plants: How children's interest in common local organisms can be enhanced through observation of nature. *International Journal of Science Education, 27*(6), 655–677. https://doi.org/10.1080/09500690500038116.

Marmaroti, P., & Galanopoulou, D. (2006). Pupils' understanding of photosynthesis: A questionnaire for the simultaneous assessment of all aspects. *International Journal of Science Education, 28*(4), 383–403. https://doi.org/10.1080/09500690500277805.

McClanahan, B., Williams, K., Kennedy, E., & Tate, S. (2012). A breakthrough for Josh: How use of an iPad facilitated reading improvement. *TechTrends, 56*(3), 20–28. https://doi.org/10.1007/s11528-012-0572-6.

McNair, S., & Stein, M. (2001). Drawing on their understanding: Using illustrations to invoke deeper thinking about plants. In *Proceedings of the 2001 annual international conference of the association for the education of teachers in science* (pp. 1364–1375).

Metz, S. (2014). Science teaching and learning in the 21st century. *The Science Teacher, 81*(6), 6. https://doi.org/10.2505/4/tst14_081_06_6.

National Research Council. (1996). *National science education standards*. Washington, DC: National Research Council.

Nedungadi, P., & Raman, R. (2012). A new approach to personalization: Integrating e-learning and m-learning. *Educational Technology Research and Development, 60*(4), 659–678. https://doi.org/10.1007/s11423-012-9250-9.

Nguyen, L., Barton, S. M., & Nguyen, L. T. (2015). iPads in higher education-hype and hope. *British Journal of Educational Technology, 46*(1), 190–203. https://doi.org/10.1111/bjet.12137.

Nuhoğlu Kibar, P., Gündüz, A. Y., & Akkoyunlu, B. (2019). Implementing bring your own device (BYOD) model in flipped learning: Advantages and challenges. *Technology, Knowledge, and Learning*. https://doi.org/10.1007/s10758-019-09427-4.

Osborne, J., & Dillon, J. (2008). *Science education in Europe: Critical reflections* (Vol. 13). London: The Nuffield Foundation.

Özay, E., & Öztaş, H. (2003). Secondary students' interpretations of photosynthesis and plant nutrition. *Journal of Biological Education, 37*(2), 68–70. https://doi.org/10.1080/00219266.2003.9655853.

Özdemir, M. (2017). Educational augmented reality (AR) applications and development process. In *Mobile technologies and augmented reality in open education* (pp. 26-53). IGI Global. https://doi.org/10.4018/978-1-5225-2110-5.ch002.

Özdemir, M., Sahin, C., Arcagok, S., & Demir, M. K. (2018). The effect of augmented reality applications in the learning process: A meta-analysis study. *Eurasian Journal of Educational Research, 18*(74), 165–186. https://doi.org/10.14689/ejer.2018.74.9.

Poll, H. (2014). *Pearson student mobile device survey 2014*. Retrieved 24 March 2020 from http://www.pearsoned.com/wp-content/uploads/Pearson-K12-Student-Mobile-Device-Survey-050914-PUBLIC-Report.pdf.

Remillard, J. T. (2005). Examining key concepts in research on teachers' use of mathematics curricula. *Review of Educational Research, 75*(2), 211–246. https://doi.org/10.3102/00346543075002211.

Roth, K. J. (1984). Using classroom observations to improve science teaching and curriculum materials. In C. W. Anderson (Ed.), *Observing science classrooms: Perspectives from research and practice. Yearbook of the Association for the Education of Teachers in Science* (pp. 77–102). Columbus, OH: ERIC/SMEAC.

Ryman, D. (1974). Children's understanding of the classification of living organisms. *Journal of Biological Education, 8*(3), 140–144. https://doi.org/10.1080/00219266.1974.9653932.

Sahin, A., Cavlazoglu, B., & Zeytuncu, Y. E. (2015). Flipping a college calculus course: A case study. *Journal of Educational Technology & Society, 18*(3), 142–152.

Sanders, D. L. (2007). Making public the private life of plants: The contribution of informal learning environments. *International Journal of Science Education, 29*(10), 1209–1228. https://doi.org/10.1080/09500690600951549.

Schussler, E., & Winslow, J. (2007). Drawing on students' knowledge. *Science and Children, 44*(5), 40–44.

Sharples, M., Arnedillo-Sánchez, I., Milrad, M., & Vavoula, G. (2009). Mobile learning. In *Technology-enhanced learning* (pp. 233-249). Springer, Dordrecht. https://doi.org/10.1007/978-1-4020-9827-7_14.

Simpson, M., & Arnold, B. (1982). Availability of prerequisite concepts for learning biology at certificate level. *Journal of Biological Education, 16*(1), 65–72. https://doi.org/10.1080/00219266.1982.9654420.

Sloan, R. H. (2012). Using an eTextbook and iPad: Results of a pilot program. *Journal of Educational Technology Systems, 41*(1), 87–104. https://doi.org/10.2190/ET.41.1.g.

Smith, E. L., & Anderson, C. W. (1984). Plants as producers: A case study of elementary science teaching. *Journal of Research in Science Teaching, 21*(7), 685–698. https://doi.org/10.1002/tea.3660210703.

Strgar, J. (2007). Increasing the interest of students in plants. *Journal of Biological Education, 42*(1), 19–23. https://doi.org/10.1080/00219266.2007.9656102.

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. https://doi.org/10.1016/j.compedu.2015.11.008.

Tamim, R. M., Borokhovski, E., Bernard, R. M., Schmid, R. F., Abrami, P. C., & Sokolovskaya, A. (2014). *Technology use in teacher training programs: Lessons learned from a systematic review*. Paper presented at the AERA 2014 annual meeting in Philadelphia, PA.

Tamim, R. M., Pickup, D., Borokhovski, E., Bernard, R. M., & El Saadi, L. (2015). *Tablets for teaching and learning: A systematic review and meta-analysis*. Commonwealth of Learning. Retrieved 24 March 2020 from http://oasis.col.org/bitstream/handle/11599/1012/2015_Tamim-et-al_Tablets-for-Teaching-and-Learning.pdf?sequence=1&isAllowed=y

Tarng, W., Ou, K. L., Lu, Y. C., Shih, Y. S., & Liou, H. H. (2018). A sun path observation system based on augment reality and mobile learning. *Mobile Information Systems*. https://doi.org/10.1155/2018/5950732.

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. https://doi.org/10.1111/jcal.12184.

Trundle, K. C., Atwood, R. K., & Christopher, J. E. (2002). Preservice elementary teachers' conceptions of moon phases before and after instruction. *Journal of Research in Science Teaching, 39*(7), 633–658. https://doi.org/10.1002/tea.10039.

Wandersee, J. H., & Schussler, E. E. (2001). Toward a theory of plant blindness. *Plant Science Bulletin, 47*(1), 2–9.

Ward, N. D., Finley, R. J., Keil, R. G., & Clay, T. G. (2013). Benefits and limitations of iPads in the high school science classroom and a trophic cascade lesson plan. *Journal of Geoscience Education, 61*(4), 378–384.

Warschauer, M., Zheng, B., Niiya, M., Cotten, S., & Farkas, G. (2014). Balancing the one-to-one equation: Equity and access in three laptop programs. *Equity & Excellence in Education, 47*(1), 46–62. https://doi.org/10.1080/10665684.2014.866871.

Wilkinson, K., & Barter, P. (2016). Do mobile learning devices enhance learning in higher education anatomy classrooms? *Journal of Pedagogic Development, 6*(1), 14–23.

Wojciechowski, R., & Cellary, W. (2013). Evaluation of learners' attitude toward learning in ARIES augmented reality environments. *Computers & Education, 68,* 570–585. https://doi.org/10.1016/j.compedu.2013.02.014.

Wu, H. K., Lee, S. W. Y., Chang, H. Y., & Liang, J. C. (2013). Current status, opportunities and challenges of augmented reality in education. *Computers & Education, 62,* 41–49. https://doi.org/10.1016/j.compedu.2012.10.024.

Zhang, J., Sung, Y. T., Hou, H. T., & Chang, K. E. (2014). The development and evaluation of an augmented reality-based armillary sphere for astronomical observation instruction. *Computers & Education, 73,* 178–188. https://doi.org/10.1016/j.compedu.2014.01.003.

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.