(09-020) - Implementation of AR Lessons for Teaching Plant Tissue Culture in the Plant Biotechnology Learning Process in the Educational Model Tec21

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In the Tec21 educational model (competency-based learning) the essential component is the challenge, where students, teachers, and training partners converge. In educational blocks related to plant biotechnology undergraduate students exhibit marked difficulties to fully comprehend complex abstract concepts in plant physiology and tissue culture. Students must understand and apply theoretical knowledge such as selecting proper plant tissue sources and phytohormone combinations to trigger a determined process through in vitro tissue culture techniques. For this, the theoretical background must be understood to a basic level. Recent advances in education have highlighted the importance of incorporating technologies such as Augmented Reality. In the present study, students were provided with an app titled "The Explant" available for cell phones, which included AR resources along with animated flow charts, text boxes, and links for external resources (videos, scientific articles, quizzes), which increased and accelerated their understanding with positive effects in the long-term learning process. AR experience increases student motivation and helps them to develop transversal competencies (research, critical thinking, problem-solving, communication and collaborative work skills) which reflects in student outcomes, class involvement and discipline engagement which was observed in the present research.

Keywords: Plant; Tissue; Culture; Innovation; Education, Biotechnology

Implementación de Lecciones de RA para la enseñanza-aprendizaje de Biotecnología y Cultivo de Tejidos Vegetales en el Modelo Educativo Tec21

En el modelo educativo Tec21 (aprendizaje basado en competencias) el componente esencial es el reto, donde convergen estudiantes, docentes y socios de formación. En los bloques educativos de biotecnología vegetal, los estudiantes presentan dificultades para comprender plenamente conceptos abstractos complejos en fisiología vegetal y cultivo de tejidos. Se espera que comprendan y apliquen los conocimientos teóricos básicos como: selección de fuentes adecuadas de tejidos vegetales y combinaciones de fitohormonas para inducir procesos determinados mediante técnicas de cultivo de tejidos in vitro. Los avances recientes en la educación resaltan la importancia de incorporar tecnologías como la Realidad Aumentada. En el presente estudio, se proporcionó a los estudiantes una aplicación para celulares titulada "The Explant", que incluía recursos de RA junto con diagramas de flujo animados, cuadros de texto y enlaces a recursos externos (videos, artículos científicos, cuestionarios), lo que aumentó y aceleró su comprensión con efectos positivos en el proceso de aprendizaje a largo plazo. La experiencia de RA aumento su motivación y les ayudó desarrollar competencias transversales (investigación, pensamiento crítico, resolución de problemas, comunicación y habilidades de trabajo colaborativo) que se reflejan en sus resultados, la participación en clase y el compromiso disciplinario que se observó en la presente investigación.

Palabras clave: cultivo; tejidos; vegetales; biotecnología; innovación; educación

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1. Introduction

The process of teaching and learning complex concepts with a high level of abstraction is one of the great challenges in biological and biotechnological areas at different educational levels. Understanding how cells work, how they respond to selected experimental variables and how we can manipulate them, thus triggering biological responses with biotechnological application, constitutes the center of the teaching-learning process for many, if not all, areas of biotechnology. This is particularly important when the educational content is aimed at helping the student to understand the bases of *in vitro* plant tissue culture, basic principles of plant physiology, as well as the processes through which phytohormones intervene in the generation of different morphological responses in plant tissue culture (Balci et al., 2021).

In the Tec21 educational model of Tecnologico de Monterrey, the Biotechnology Engineering career is formed up of training units comprising both subjects and blocks. The latter consist of learning modules with both theoretical content and laboratory practices, as well as a challenge that students must develop in conjunction with partner training organizations (companies, research centers, environmental management units or botanical gardens, to mention a few). Within the framework of this new educational system, what was traditionally taught during a semester (15-18 weeks) must now be explained, understood, and used in the development of disciplinary and transversal competencies in a period of just 10 weeks, integrating both the traditional theoretical contents of the subjects with laboratory practices of selected topics. In this context, the BT2004B *In vitro* experimentation block is taught in the fifth semester, with only 10 weeks duration, and it is planned to integrate, in addition to the topics of *in vitro* plant tissue culture (theory), the topics of animal tissue culture, the development of laboratory techniques for plant and animal cultivation in conjunction with the design of experiments using statistical tools that have not been previously seen in the previous formation units. This is already a challenging and complex situation to impart theoretical knowledge and help the development of disciplinary competencies in a short period of time considering that the contents are complex and require a greater degree of analysis by the student. This knowledge is required by students to solve the challenges of the training unit, which implies that students can respond to the needs of the training partner institution in terms of proposing a methodology according to its special requirements. For example, the students have developed challenges where they have proposed a micropropagation system in endemic or ornamental plants along with the appropriate disinfection system that guarantees obtaining axenic explants.

In recent decades the integration of educational technologies to facilitate learning and generate interest in studying complex or abstract concepts has led to the development of strategies such as the use of virtual reality (VR), augmented reality (AR) or gamification, to mention a few. According to Lee et al (2017), AR is defined as the technology capable of generating 3D images by computer, converting living objects into virtual objects, allowing users to interact with them using the screen of a mobile device (cell phones or tablets). It is widely used in different fields of education as a teaching medium to increase students' interest in complex topics (Adami and Budihartani, 2016). It is therefore an immersive and sensory technology for the student that helps increase memory retention, and also facilitates long-distance learning independently (Sulistianingsih and Kustono, 2022). Being an immersive technology allows the student to feel attracted to experimenting and interacting with it (Sulistianingsih and Kustono, 2022).

Also, currently technological development has allowed the use of cell phones and electronic tablets in the teaching-learning process, which has had an impact on higher education with positive results. According to Crompton and Burke (2018), mobile learning describes the process that involves a mobile device, where only cell phones or electronic tablets are considered as such. Mobile learning undoubtedly provides users (teachers and students) with the flexibility to be used at any time, allows the exchange of information at any time, eliminating the barriers of physical learning in an institution, which is why it is considered to contribute to collaborative work (Arain et al., 2017). In this context, the use of mobile applications presents two main advantages: the usability or interactions that the user has with the app as well as the learning gains that they have when interacting with it (Meiselwitz and Sadera, 2008).

The use of AR and 3D modeling in teaching has been successful, facilitating the learning process of abstract concepts by increasing student activity and involving them in their learning (Low et al., 2022). This technology facilitates a permanent learning environment that generates concrete and measurable information with advantages such as: experiences not available in real time, increased attention, participation and motivation of students, entertaining learning, and saving time and space (Arici et al.,2019). Students have problems understanding the world on a cellular scale in biological topics that are difficult to understand because they are abstract and lack real-life references in which students can relate and anchor their understanding (Tibell et al., 2010; Reen et al., 2021). With the use of AR, students build their knowledge and change behavior towards learning (Low et al., 2022; Garcia-Bonete et al., 2016).

The learning of plant *in-vitro* tissue culture concepts is extremely complex, and sometimes it is very difficult to find visual and dynamic materials that help strengthen the biological knowledge that is important for the training of students. Due to the scarcity of dynamic and visual material, we consider that having free access to this type of platform is innovative and has a high-impact for the training of students in biotechnology, agronomy, or agri-food biosystems worldwide. Therefore, we have proposed an educational technology involved using AR with 3D modeling of *in vitro* plant tissue culture (PTC) processes that we selected to develop educational competencies aligned to the Tec21 educational model, facilitating the learning of abstract concepts for students of the Biotechnology engineer program. Thus, in the present research, an application titled “The Explant” was designed and built, which consists of descriptive modules of the main *in vitro* plant tissue culture processes: callogenesis, direct organogenesis, indirect organogenesis, direct and indirect somatic embryogenesis. Each section has a general process diagram, links to texts, videos, and scientific articles. Likewise, in each of the aforementioned processes, AR 3D models of the structures that are generated as a result of the morphogenesis induced by a certain type of in vitro plant tissue culture were integrated in the app. This application was placed on Google Playstore and Apple Store to be downloaded for free. In order to measure the impact of the use of the application on student learning, two evaluations were carried out, one before and one after its use, on the same group of students (sample).

The results obtained were analyzed using basic statistics through the T-paired test (mean, standard deviation, variance, mode, median, quartiles, and represented in histograms with normal, boxplot and t-student graphs (Hake, 2002)

2. Objectives

The objective of this study was to generate a platform to engage students into learning complex concepts in a fully immersive manner by integrating AR for different plant tissue culture processes supplemented with videos, scientific articles, text and dynamic workflows with interactive buttons and strategic placements of different sections that increase engagement and student involvement in study.

3. Methodology

a) “The explant” application design and general navigation outline

Accordingly, the application was designed so that navigating through it could be intuitive for all processes (**Figure 1 a to d).** A cover presentation was added as a title (**Figure 1 a to b**). The first general section comprises a general description of plant parts to allow students to read and understand the context of plant tissue culture, followed by a start button (**Figure 1c).** The next interphase depicts 4 main buttons divided as such: callogenesis, organogenesis, embryogenesis, and a final button with information of our team of professors **(Figure 1d).** The general pipeline used in all processes using the callogenesis process as example in **Figure 2 (a to e)** and contains the following information: as section containing a slide button and a “next” and a “previous” button so that the user can observe the morphogenetic process unfold according to each of the different plant tissue culture types, also buttons to access to the timeline and flowchart of the process (**Figure 2a).** In this same interface a “click to watch in AR” was added so that the user can deploy the AR of each corresponding process (**Figure 2 a).** At the end of this interface, a “theory” button that leads to a new interface where 3 main sections were added: “documentation”, “diagram” and “external info” (**Figure 2b).** In the documentation section, basic information regarding each process was added (**Figure 2c).** For example, in the case of callogenesis sections such as: explant selection, sterilization, culture medium, hormones, were added. This same information organization scheme was used for each plant tissue culture process. A diagram section was added so that the users have a easier access to the full flowchart of the process, this diagram is the same that is deployed when opening the first morphogenesis button (**Figure 2d).** In each process we added the AR button which depicts the result of the plant tissue culture technique analysed in 3D models that allow interaction with the user (zoom in or out, spin in both directions or to observe it from above or from under). Finally in the external information section (external info), we added links to YouTube videos of scientific based channels that provide further details in the process previously described. Also, links to scientific articles or reviews were provided so that users have access to a deeper understanding of the process in a scientific supported learning environment (**Figure 2 f)**

The AR 3D diagrams along were developed by a local developer (GrayScale Interactive). To facilitate this process, we provided figures from scientific articles of each process, and when possible the developers assisted the Plant Innovation Laboratory at the Department of Bioengineering located in Tecnológico de Monterrey, Querétaro Campus to document the available process by taking various pictures to document the plantlets or callus in real life. We also held several interviews with the developers to guide them in the scientific background for all AR models generated for “The Explant” app.

Figure 1. General navigation outline for “The Explant” app. a) and b) Entrance cover interface. c) Plant part explanation interface d) different plant *in vitro* tissue culture processes featured in the app.

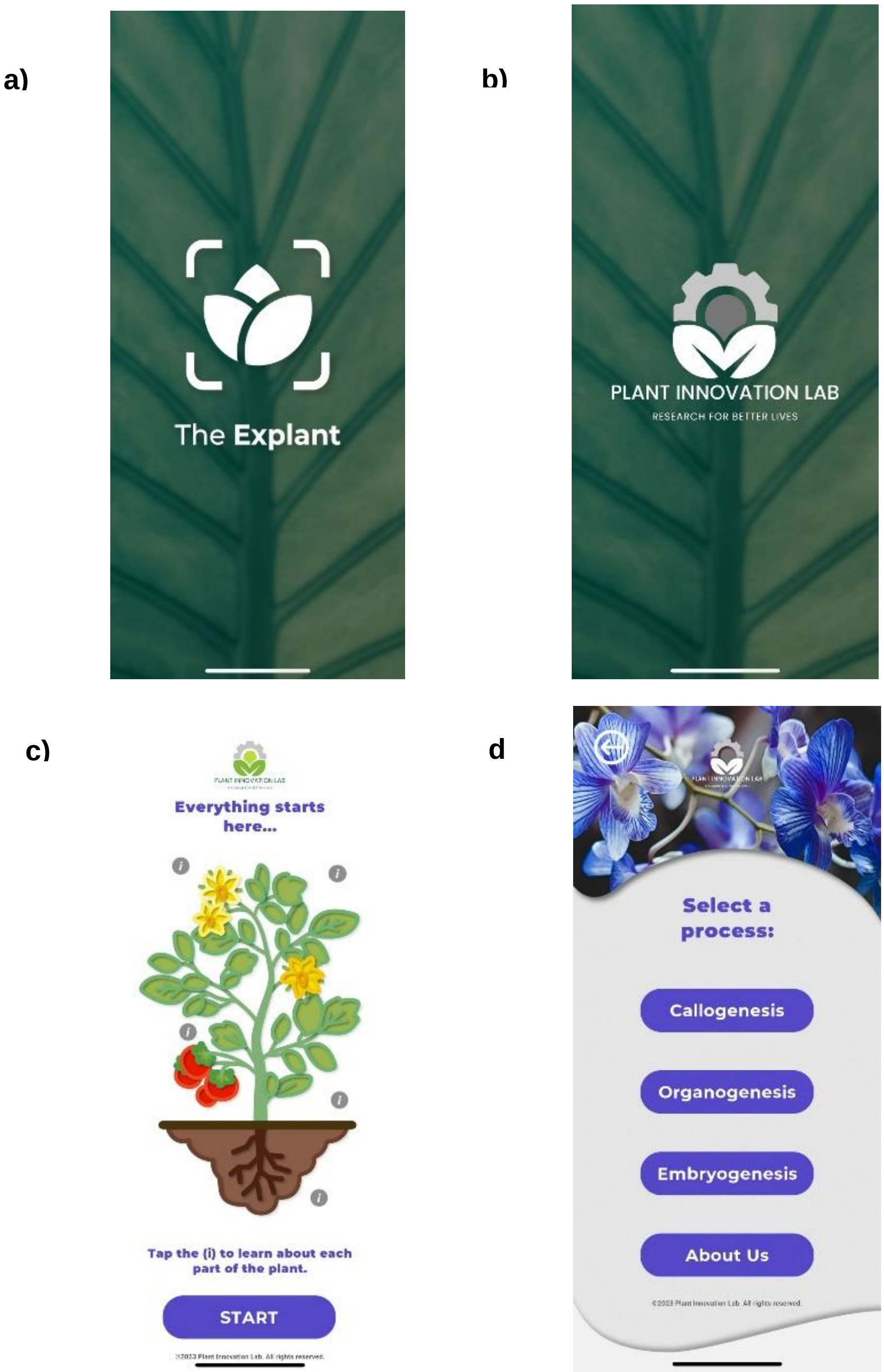


Figure 2. General navigation pipeline for a specific PTC process described in "The Explant" app. Points a) to f) describe the pipeline for the callogenesis process used as example.

As a result, developers delivered a set of AR figures as such that it simulates how particular resulting morphogenetic different outcomes appear in the laboratory, by resembling them in petri dishes.

b) Experimental setting for learning gain analysis

A sample of 21 students were asked to participate in the evaluation of the app. They all signed a consent agreement to document their interactions with the application through testimonies in video, photographs etc in line with the ethical guidelines of Tecnológico de Monterrey. Students were invited to participate in the study voluntarily for both exams, separated by 15 days between the after and before examination A pool of questions was developed from the application and other contents seen in class (BT2004B In vitro experimentation August-December 2023). To analyse the quantitative variable, the experiment was set in to apply the evaluation after and before interacting with the explant app. The exam consisted in 40 questions which were provided to the students in the electronic platform Socrative. All questions and answers were completely randomized, and students were not able to keep track of the correct answers in each evaluation, they only observed their final score. The results obtained were analysed with basic statistics (mean, standard deviation, variance, mode, median, quartiles, and represented in histograms with normal, box plot and t-student graphs with the Minitab program (Minitab® 21.4 2023)

4. Results and conclusions

As mentioned previously, students were evaluated prior and after the use of the application in a completely randomized exam. The main data was analyzed, and a paired t-test was done to test whether the mean difference between pairs of measurements is zero or not.

$$\text{Null Hypothesis: } H_0\text{: } \mu1 - \mu2 = 0$$

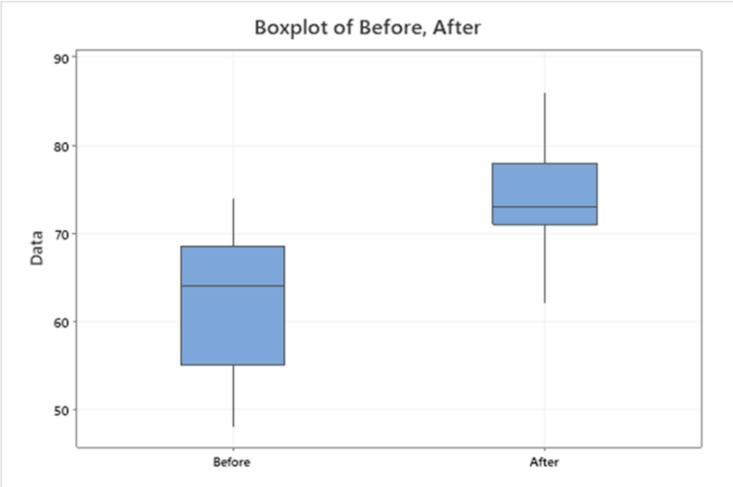
$$\text{Alternative Hypothesis: } H_1\text{: } \mu1 - \mu2 \neq 0$$

After performing the test, it can be concluded that with a p-value of 3.04E-07 and 95% confidence level (Figure 3a), the null hypothesis is rejected; hence, is not true that the two means are the same. After analyzing the confidence interval for the difference of the two means, it can be observed that the whole interval is negative (-15.1500, -8.5643), this implies that the mean grade after the use of the app is greater than the mean grade before using the App. Figure 3b describes the data distribution of both groups of the same students before and after presenting the exam and the results indicate that there is a visible learning gain after utilizing the application.

After this analysis, we can observe a positive effect on the learning gain value (quantitative variable) in all the students analyzed. Similar results have been reported for the use of mobile learning applications that integrate valuable information along with AR 3D models of abstract concepts such as biological processes (Venkatesan et al., 2021).

Figure 3. Box plot diagram and statistical results from the before and after evaluation of the use of "The explant" application in the same group of undergraduate students. a) Box plot analysis reveals an increase of the scores in the results of the exam after the use of the application b) Statistical evaluation of data.

a)



b)

Test Statistic	p-value
-7.5114	3.04E-07

In the present application we integrated the necessary elements required for the learning and understanding of complex concepts in the *in vitro* plant tissue culture techniques along with information and AR 3D models of the morphological outcomes derived from main Plant Tissue Culture techniques. These types of models are important since not always laboratories or schools contain the necessary infrastructure to physically show a given result to students such as a callus formation (organogenic or embryogenic), micropropagated shoots or roots. Therefore, the approach presented here is considered innovative and allows for the full immersion of the student´s in learning and interacting with the application. This was observed in the learning gain variable where the sample of students analyzed revealed a positive gain increasing the retention and understanding of such contents after utilizing the application. These results have also been reported in other applications of AR and mobile learning in fields ranging from elementary schools up to higher education (Umamah et al., 2020; Venkatesan et al., 2021). For biotechnology students it is crucial to learn complex or abstract concepts in plant tissue culture morphology so they can accurately describe the type of explant or response that triggers the process they are designing. For example, to understand under which conditions they will observe the formation of callus or when they will obtain shoots or roots. These processes require us to understand the action of phytohormones, plant tissue culture media, plant organs among others. Thus, after understanding these concepts, designing, and conducting experiments in the laboratory could be an easier process. In addition to gain theoretical knowledge, biotechnology students must also develop proper laboratory skills (Balci et al.,2020). In 2020, Balci et al, developed a gamification strategy to address the learning and comprehension of the variables that interfere with plant tissue culture in laboratory, after the application of this educational innovation they observed that students were more involved in their learning process with positive feedback from the students. Also, AR has been used in the teaching of biomedicine studies (Venkatesan et al.,2021) with positive results. Accordingly, several models were developed so that students have the possibility of been fully immersed and captured by them and completely involved in the teaching learning process.

To evaluate the qualitative variable of student perception on the use of this application we interviewed those that voluntarily wanted to and recorded some of their feedback. As a result, most of the students who participated in this part of the evaluation mentioned that they did feel a considerable difference between the two main moments of evaluation before and after they used the application as a tool to increase their scores. Also, they indicated that the use of AR is useful to visualize the structures generated by the plant tissue culture techniques explained in the application. In addition, the students described that the navigation through this app is intuitive and easy to follow. As improvement remarks some of the stated that they could benefit from including more AR diagrams and to make some headings more visually appealing by using different colors. Also, to reduce the extent of reading information and to also include alarms to remind them when to enter the app and start interacting for study.

Worldwide, traditional educational models are evolving towards the integration of novel educational technologies such as AR, VR, or Artificial intelligence (AI) among others, this process was accelerated during the SARS-CoV-2 pandemic era (Portugues-Castro et al., 2022). However, in third world countries there are still profound differences and inequalities that must be addressed to reach the sustainable development goals: 4th quality education, 15th life on land. Despite the difficult economic circumstances that these countries face, during the pandemic era studies described that they all had to adapt by integrating digital technologies to their educational strategies, which was described in a study conducted in Latin America (Ramirez-Montoya et al., 2020). Therefore we consider that mobile learning technologies that place the student at the center of their education, by facilitating when and where they can study, at their own pace, and allow the interchange of information and even more, provide AR models that allow to observe experimental outcomes that not always are available in their laboratories have a high impact on the learning gain and the overall learning experience of these digital natives generations (Portugues-Castro et al., 2022). Also, learning the basic principles for plant tissue culture can lead to developing strategies for plant conservation worldwide in line with the 15th sustainable development goal life on land. It is crucial to educate future biotechnologists to use natural resources in a sustainable way and return some of the knowledge to nature whenever possible.

In general, the innovation presented here in its first stage was designed to address the needs for educational changes in the teaching-learning process in biotechnology, specifically plant tissue culture topics. Our experiment (learning gain analysis and focus group) was conducted in this first assessment in biotechnology engineering students. Nevertheless, the materials designed and loaded onto our mobile application can also address the needs in other fields such as in agronomy engineering or agricultural biosystems engineering, where students also require learning and training in plant tissue culture methodologies. Furthermore, we are currently developing a second version of this innovation where we are addressing topics for animal cell culture which can expand not only to biotechnology but to fields like medicine or biomedicine. The design thinking process we followed to generate the present educational innovation in the form of a mobile application harnessing 3D models with AR along with dynamic flowcharts including precise and concise information relevant to each topic was carefully chosen so that when we designed the general pipelines the final user (students) can intuitively interact with it. This facilitates the learning process and places the student at the center of their education, increasing their engagement and empowering them with the flexibility to choose when and where to learn. In terms of project training the goal achieved with this innovation is that students have a first hand resource where they can consult if what they are designing (experimental setting), or testing (laboratory results from experimentation) is actually correct. If, however the students lack laboratory facilities and resources, the project training turns theoretical but it does not lack the experience of observing a close to natural structure in the 3D modelling AR when utilizing the mobile application developed here. On the other hand, project training can also be facilitated for the teachers so that they can design new teaching learning experiences in the classroom by explaining theoretical backgrounds and complementing the lecture with the use of our innovative mobile application. Thus, generating a set of technology-enhanced learning (TEL) experiences in each lesson, which has demonstrated that increases the student's engagement and involvement with the learning process (Han and Gen, 2023). This translates to a benefit for both end-users (teachers and students) where the experience can be more engaging, realistic and allow for the abstract concepts to be well understood. Finally, according to the results observed in our students and the interaction between them and the mobile application we consider that the present innovation can be utilized by other academic institutions and not only in the undergraduate level but also in graduate programs such as masters or doctorates in biotechnology and agronomy related areas. As well as for technical level education to operate this knowledge in practical areas such as micropropagation of commercial food crops.

5. References

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Communication aligned with the Sustainable Development Goals

4 QUALITY EDUCATION

15 LIFE ON LAND

OBJETIVOS DE DESARROLLO SOSTENIBLE