Engineering for UDL-based education: translating book images into interactive 3D educational materials for Health Sciences subjects
Ingeniería para la educación basada en el Diseño de Aprendizaje Universal: Interpretación de imágenes de libros, a materiales educativos e interactivos, impresos en 3D para temas de ciencias de la salud

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Summary. In science education at the university level, visual resources, such as images and videos, often receive greater emphasis compared to other sensory experiences like hands-on interaction with learning objects. This work was born as an initiative to support the education of higher education students majoring in Health Sciences, by making microscopic concepts of complex topics inclusive and engaging for everyone in the classroom, while being accessible to students with physical barriers to access. As one example of our long-term project, we describe the design and fabrication of novel three-dimensional educational materials to facilitate inclusive teaching/learning of one topic of Embryology. The process described here begins with one of the most challenging steps: the interpretation and translation of the information to be represented from textbooks into interactive 3D objects and the considerations for selection of the technology required to provide multisensorial experiences; likewise, we present the design of electronic elements incorporated and the final products. We also discuss the value of the multidisciplinary teamwork by the higher education students who are at the heart of the EduMakers, a student-researcher community of practice based on an academic makerspace. Finally, through several validation steps, we can sustain that the materials created by EduMakers offer an opportunity for all students to experience and understand firsthand, through several senses, complex scholar topics in science.

Keywords: Health Sciences, Higher Education, Inclusive Education, Universal Design for Learning.

Resumen. En la educación científica a nivel universitario, los recursos visuales, como imágenes y videos, a menudo reciben mayor énfasis en comparación con otras experiencias como la interacción práctica con objetos de aprendizaje. Este proyecto nació como una iniciativa para apoyar la educación de estudiantes de educación superior en carreras del área de ciencias de la salud, al hacer que los conceptos microscópicos de temas complejos sean inclusivos y atractivos para todos en el aula, al mismo tiempo que sean accesibles para los estudiantes con barreras físicas de acceso. Como ejemplo de nuestro proyecto a largo plazo, describimos el diseño y fabricación de materiales educativos tridimensionales innovadores para facilitar la enseñanza/aprendizaje inclusivo de un tema de embriología. El proceso aquí descrito comienza con uno de los pasos más desafiantes que es la interpretación y traducción de la información a representar, pasando de los libros de texto a objetos 3D interactivos y las consideraciones para la selección de la tecnología requerida para brindar experiencias multisensoriales. Asimismo, presentamos el diseño de los elementos electrónicos incorporados y los productos finales. Se discute también el valor del trabajo multidisciplinario en equipo por parte de estudiantes de educación superior que son quienes están en el corazón de EduMakers, una comunidad de práctica conformada por estudiantes e investigadores basada en un espacio maker académico. Finalmente, a través de varios pasos de validación, podemos sustentar que los materiales creados por EduMakers ofrecen una oportunidad para que todos los estudiantes experimenten y comprendan de primera mano, a través de varios sentidos, temas complejos de ciencia.

Palabras Clave: Ciencias de la Salud, Educación Superior, Educación Inclusiva, Diseño Universal para el Aprendizaje.

1 Introduction

Currently, science education at college level is still not accessible to all students, particularly those with disabilities [1]. In part, this is because science concepts are still primarily taught using traditional tools and resources heavily relying on the use of sight, such as photographs, schematic representations, and videos [2]. Even with the incorporation of innovative digital technology, such as immersive virtual learning environments, visual cues are given a high weight over other sensory experiences including physical interaction with learning objects. These educational practices exclude students whose primary (or preferred) source of information for learning is not sight.

In regular classrooms, it has been recognized that the application of the principles of Universal Design for Learning (UDL) is beneficial to all students; the UDL principles are: to provide learners with multiple forms of representation, multiple forms of engagement and multiple forms of participation and expression [3][4]. Although there is a growing trend to use UDL in K-12 education due to international conventions and agreements to reach an education for all [5], its application in higher education is less frequent and accessible learning resources, such as three-dimensional materials, are not much available for highly specialized topics at higher education levels. Not having access to obtain information as their peers affects the permanence of students with disabilities in the sciences; this is especially true in students with reduced sight [6].

We have previously reported the experience of involving a multidisciplinary group of college students through a social service initiative called EduMakers to produce tactile 3D educational resources that use technology to provide multi-sensorial and interactive educational experiences [7][8][9]. In the work present-ed here, the incorporation of other students from scholarship service and volunteers from student associations added diversity to EduMakers and helped the creation of novel educational materials to facilitate learning of complex topics at college level. For specific basic courses in the Health Sciences, such as Embryol-ogy and others related to the human body, 3D objects holding the scientific accuracy to be considered learning resources are limited to macroscopic forms and processes, such as 3D anatomical models of fetal growth. Thus, this work was born as an initiative to support college students majoring in Health Sciences, by making microscopic concepts of Embryology accessible to students with visual disabilities while being engaging for everyone in the classroom.

For this type of projects, a makerspace is ideal to exchange ideas and build prototypes. Also, a central part of makerspaces is sharing; indeed, the maker movement took from constructionism the philosophy of "learning by construct-ing knowledge through the act of making something shareable" [10].

2 Methodology

2.1 Delimitation of topics

For the larger project, prototypes and resources were developed for different topics; however, for the purposes of this article, we will focus on the teaching materials generated to show stages of the process called neurulation. In this stage that takes place within the embryonic development, the neural tube, which is the precursor structure of the central nervous system, is formed [11][12]. This process takes place approximately from day 19 to day 28 after fertilization [11][12]; however, for practicality and better understanding, we chose to represent the shape and features of five key structures from day 18 to day 23, to facilitate identification of the changes happening within that stage. Once the stage of embryo development was defined and delimited, the next step was to identify the exact information to be conveyed in three-dimensions.

2.2 Design process and prototype fabrication

A mixed design method was used for the design and generation of functional prototypes of technology-based 3D educational resources, so non-designers were able to develop ideas and find ways to materialize them. As in any product design process, several iterations of ideation, prototyping, testing, validation, and modification took place until functional prototypes were obtained.

The design process involved first, the making of low-resolution prototypes made of cardboard and rough drawings. Once these were tested by the designing team, high resolution prototypes were created, this time using PLA and resin. The prototyping process was iterated several times within the EduMakers team and with health sciences students and teachers; each iteration looking to be better than the last one in terms of materials, textures, and the translation of 2D images into 3D recognizable shapes. Validations involved team members and external volunteers who were experts in education, health sciences, biological sciences, medical sciences, and inclusive technologies.

The technology of choice for the generation of final prototypes of 3D objects to represent selected topics was 3D-printing although, other materials and technologies such as laser cutting using acrylic were also considered and discarded due to the complexity of structures represented for the embryonic stage.

2.3 Technology for interactive experiences

To provide engaging educational experiences, the 3D objects were complemented with a display of audible information using low-cost technology which was also developed by the engineering team using available materials such as an electronic board, a microcontroller (Arduino), sensors, audio output and voltage regulators. To select the optimal sensor, three options were tested; the first one was a "limit switch" that presented a possibility of being damaged due to the positioning of the piece and the hand force used to do it. Next, it was considered the use of optical sensors, such as photoresistors, but the illumination of the environment could affect the operating range.

Finally, we tested the use of Hall effect sensors, which is a type of sensor that detects the presence and magnitude of a magnetic field using the Hall effect that required placing magnets on the different objects. This technology basically takes advantage of the magnetic fields generated by a magnet to activate a relay and send a signal. When used as electronic switches, they are less prone to mechanical failure since there is no wear on physical parts. We tested different kinds of magnets such as ferrite and neodymium, and at the end we chose the last one since the magnetic field it produces is stronger, that allows the sensor to detect the presence of the pieces even if they were in wrong positions or not perfectly aligned. Therefore, it is not needed as much precision for placing objects as the other technologies described above, making easier to lift and return the objects by people with visual impairments.

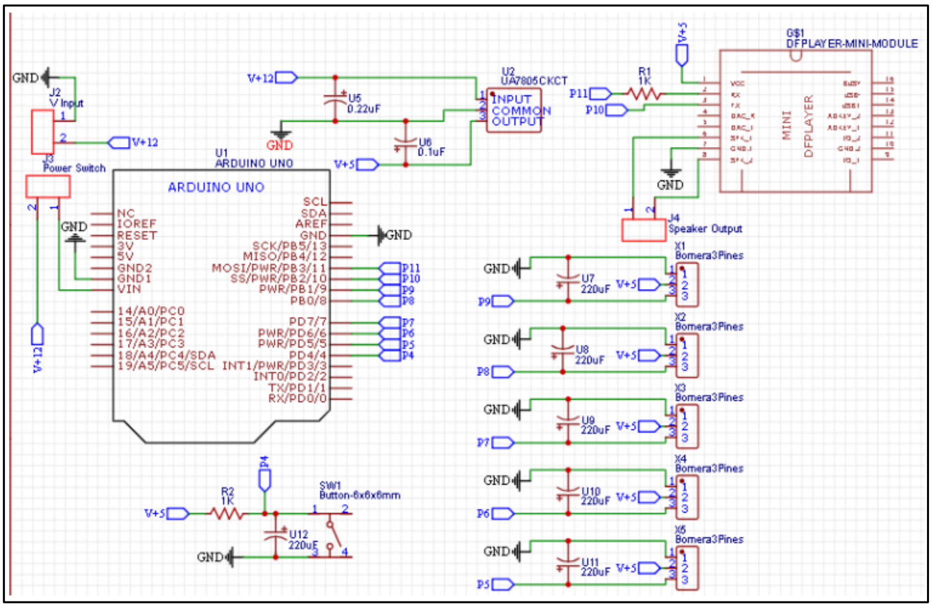

Figure 2. Schematic of the electronic board and controllers used to display audible information (de-signed by Luis F. Garza Vera).

To perform the task, an integrated board was designed to function under an Arduino controller (Figure 1), and sensors are read sequentially in a loop. When the objects are lifted, the controller reads a TRUE value, and it plays a pre-recorded audio with scientific information corresponding to the object lifted.

The Arduino was programmed using an open-source code from an Arduino-focused forum [13] which was modified to meet the specific needs of the system.

3 Results

3.1 Translation of images from 2D to 3D

To identify the exact information to be conveyed in three dimensions, at least two textbooks in the field were analyzed [11][12]. It is relevant to say that the selection of the images from the textbook to be represented in the 3D educational materials was not an easy task, given that the multidisciplinary team was mainly composed of engineering students at the beginning of the project. The primary textbook used as source of information contained micrographs and colored illustrations of the neurulation stages, but the challenge of translating this information to 3D was complex for the engineering team due to the nature of the subject mat-ter. At this stage, students from the health sciences, including biomedical engineers, joined the team, and helped identify and interpret important features of embryo development during neurulation. Because a single textbook does not hold all the information necessary to produce accurate representations, such as size and extent of changes other than shape, additional research was required to obtain the anatomical features that were as close as possible to the real object.

To define the exact scales of the 3D models, it was necessary to take into con-sideration the actual anatomical sizes for each day of the neurulation process described in the books consulted. The only measurement presented by Langman. Embriología Médica [11] for this process was taken as the first reference, where embryo's declared dimensions were 1.25 mm in length and 0. 68 mm wide on day 18. We next took into consideration the average lengths described by Embriología humana y biología del desarrollo [12] for the stages of embryonic development to establish the dimensions for each of the following stages presented in the models. As a result, final sizes range were within the real approximate values found in the literature. Most importantly, these inferences allowed to generate a congruent and organic 3D representation in comparison with the 2D graphic representation presented by Langman [11].

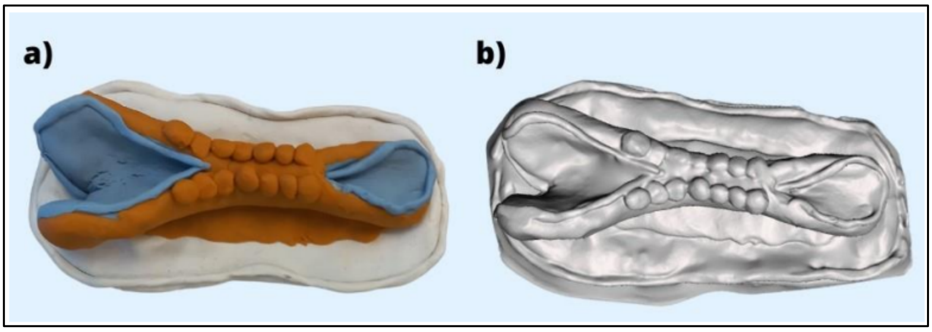

Figure 2. Example of (a) the handmade plasticine representation of the neurulation process during day 22, and (b) its respective 3D model generated with the scanner.

Due to the microscopic size and implicated ethics for obtaining images of hu-man embryo development, there is a lack of medical images containing sufficient details to facilitate digitalization using an image analysis software. Consequently, a first attempt to create 3D representations from information of the textbooks included the use of plasticine to produce handmade models, in order to add a third dimension to the 2D images from books (Figure 2a). These plasticine models needed to be digitized to obtain 3D files for the fabrication of reproducible 3D-printed educational materials.

This process was facilitated by a 3D scanner, which is used to digitally recreate high-quality 3D images by capturing a large number of photos. A comparative digital image pf the two models is shown in Figure 2.

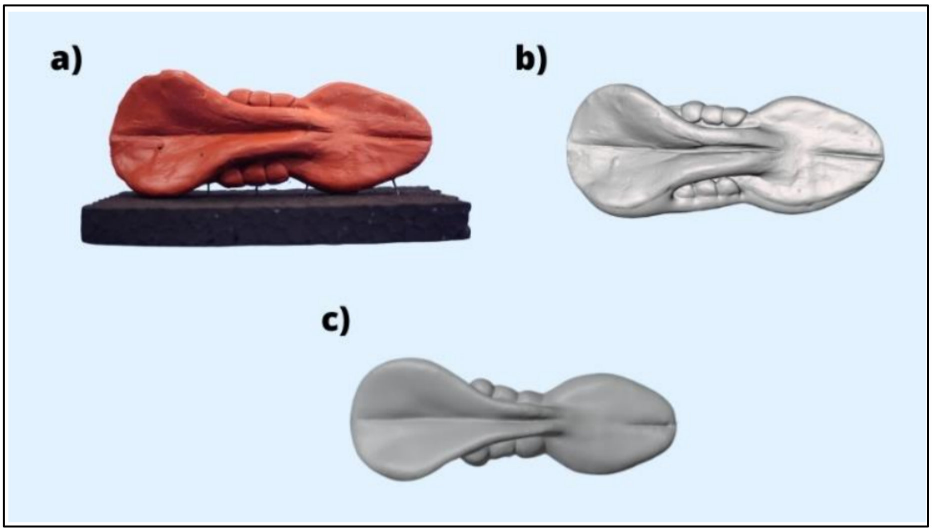

Figure 3. Example of (a) handmade moldable clay representation of the neurulation process during day 20, (b) respective 3D model generated with the scanner and (c) digitally improved image.

Because the resulting digital images were not optimal, support from students majoring in digital arts was sought to create a new version of the hand-made representations, now in moldable clay and with higher quality. These new hand-made models were scanned to obtain digital designs, that were further perfected before being 3D printed (Figure 3).

It should be noted that one of the main reasons for scanning the models, instead of making a digital design from scratch, is that originally the team was mostly made up of engineering students, who had more expertise in software such as Solidworks, which is not as useful for creation of organic forms and shapes.

3.2 Validation and functional prototypes

Throughout the design and fabrication process, several validation steps took place, and decisions were made always looking for the reproducibility of the products and aiming to facilitate the best understanding of the concepts.

After the first 3D printed quick prototypes were produced, scientific accuracy was revised, and more research was required. Several decisions led to changes in the models in response to the feedback given by experts. Once the necessary adjustments were made in the digital designs, the pieces were 3D printed in higher definition using extrusion methods.

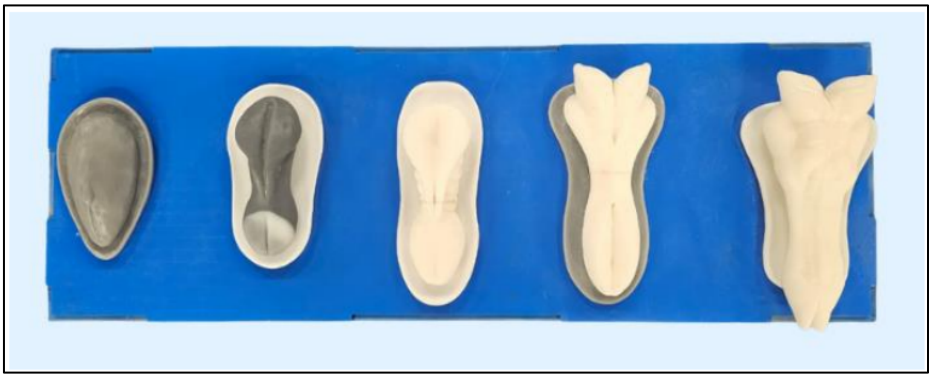

Figure 4. Assembly of the 3D educational resource to explain the neurulation stage during embryo development.

Following new adjustments and changes in the models, the process of 3D printing of advanced prototypes was also refined by using resin, so it was possible to obtain a first set of high-resolution educational resources of the neurulation process in a scale 1:100, as shown in figure 4. Further on, a new version was printed on a smaller scale, 1:50, which also have high resolution and added portability.

3.3 Use of magnet sensor technology for interactive educational experiences

A desirable feature of inclusive educational materials is to assure that people who use the material can do it in an autonomous way, so they can take all the time they need to explore the objects and learn about the scientific topics at their own pace. So, in parallel to the 3D design of the objects, affordable technology based on the use of Hall effect sensors was incorporated to provide audible in-formation of each stage of the process represented by the objects. This way, audios explaining each of the stages of the process play every time someone lifts the corresponding piece.

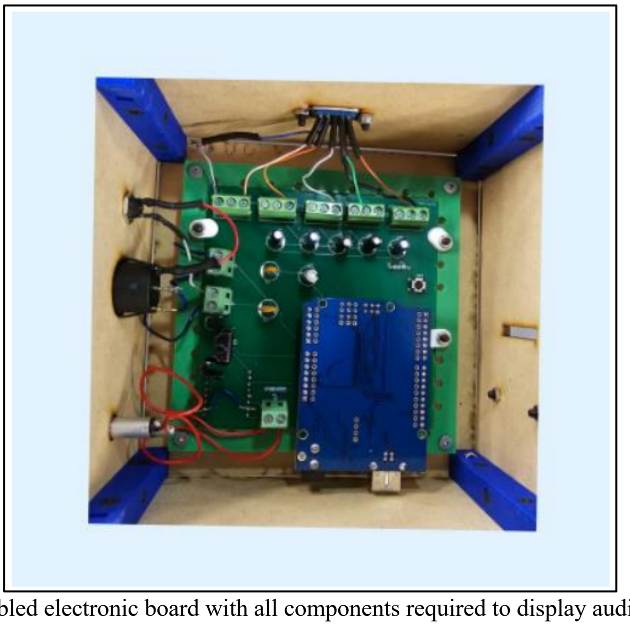

Figure 5. Assembled electronic board with all components required to display audible information.

3.4 Audio descriptions

While the physical objects were fabricated, the project team had to select the information that would be displayed when the objects were lifted. The premise for this information is that it will contain essential scientific information regarding the subject matter. The first draft of the information was revised by medical sciences students who previously took the embryology course, and later record-ed. Preliminary audios were placed in the SD card and read by the Arduino system inside the electronics, so audio information is displayed when the 3D pieces are lifted from their box.

3.5 Future directions and improvements

In EduMakers, improvement of products is always a must. After the most recent validations and piloting of the use of the educational resources produced, it was clear that the first validated prototype (Fig.4), although functional, is quite big and it is difficult to transport to the classroom; therefore, in the next iteration cycle of prototyping, the size will be reduced to make it lightweight and easier to move. We also noticed that the use of a microcontroller that uses external elements to play audio is more complex than using low-cost microprocessors which already contemplate the use of audio and video cards in their manufacture; hence, using these alternative microprocessors could facilitate the construction and reduce the size of the overall system. Further improvements also include using digital technology such as multiplexers to work with a greater number of digital signals using the minimum amount of electronic and computational re-sources possible. In addition, as the functional prototypes are still validated by various users, audios have to be further improved.

As we said before, one of the characteristics of solutions created in makerspaces, and one of the goals of this project, is to make objects that can be easily reproduced, that is why we are so keen on thinking beyond the final user, considering the maintenance and assembly aspects of the materials we design and pro-duce. After more tests with users, we will revise these aspects to identify if more changes are needed to assure long durability of the educational products.

The didactic materials created in this project have been registered with a Creative Commons license that allows the replication of the materials as long as credit is given to Edumakers Tec.

Once the improved educational resources are tested with more potential users, they will be shared with the community of health sciences educators in other colleges and universities, with the intention of creating an open access repository.

4 Conclusions

The work presented here is an example of the use of technology to create innovative inclusive educational materials for higher education students majoring in fields such as health sciences. In this case, we targeted one topic of embryo development which is of microscopic nature, with the aim of generating learning objects that would help providing multisensory information thought touch, visual cues, and sound.

In this process, one of the biggest challenges encountered was the interpretation of two-dimensional flat images into three dimensions, given that the text-books used for the subject provide mainly with schemes that, even if they were drawn from micrographs, they lack features such as three dimensionality; thus, the translation back to three dimensions had the risk of incorporating errors or missing important details of the structures.

In addition, we must recognize that the first attempt to translate drawings into 3D digital objects was performed by engineering students, whose field of interest, general expertise and knowledge of software for designing is somewhat distant from the health sciences. Although in EduMakers, we count with the participation of students majoring in biomedical bioengineering, which is an engineering major related to health sciences, their curriculum does not include an Embryology course. Then, working in multidisciplinary teams, formed by engineers, designers and medical school college students was a key aspect towards producing a successful outcome. In doing so, all the people involved in the project learned the importance of collaborating with other disciplines where each person can bring their expertise to the table, but also learn from others and at the same time, teach others through their own experiences and knowledge. This is in agreement with Halverson and Sheridan (2014), who define makerspaces as “communities of practice and designed learning environments”, and, they remark the fact that, by nature, makerspaces, such as the one used for this project, are places of democratization where the solutions ideated and built look to be replicable and shareable.

During user validation with other students who have no visual disabilities, we discovered that they found the materials extremely useful when revising the subject. They can complement the information they receive through their sight (using books with drawings, watching videos and animations, etc.), with the recordings the materials have. Also, they can touch the materials while listening to the recordings play, something that they cannot do while looking at books or watching a video. "Touch, often called the 'first sense', is fundamental to how we experience and know ourselves, others and the world" [14].

In summary, the materials created by EduMakers offer an opportunity for all students to experience and understand firsthand through several senses, scholar topics.

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