

Research Article

HistoNFC: An Innovative Tool for the Practical Teaching of Histology Using NFC Technology

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Despite the development of mobile device technology over recent years, its application in the field of teaching has not yet had a parallel development. For the past two decades teaching subjects such as histology has undergone a change in the digital use of its content and didactic methods based on Web applications, e-learning portals, etc., in which the use of high definition images enables the substitution of the light microscope for a “virtual microscope”. This paper describes a mobile device solution based on the use of Near Field Communication technology for supporting teaching in medical histology. The didactic contents are managed in a database which stores information and images corresponding to the histological slides that are handed out to students in the glass slides for their analysis under a microscope. By associating a single NFC chip to each glass slide and touching this chip with a smartphone, students are given access to all the multimedia information related to the histological slides, without needing a mobile device. The system developed, called HistoNFC, enables access to this information at any moment, as well as the follow-up to the didactic activity and student evaluation. Evaluation of the system has been carried out by histology students of medical degree at the University of Córdoba, assessing aspects of the assisted-learning process as well as technologies, and the results obtained have been very favorable for both, as can be seen in detail in this study.

1. Introduction

Histology is a basic morphological subject which is taught in the first courses of a medicine degree and which gives us information about the structure and composition of tissues and organs [1]. As in other subjects, such as anatomy or radiology, histology requires visual learning [2] that obliges students to be trained to analyze microscopic images.

Conventionally, the practical teaching of histology has been based on the microscopic observation of preparations in a classroom geared to that purpose with a teacher present and the help of an atlas. The new study curricula for the degree in medicine at the University of Córdoba [3] is based on the directives of the Bologna Programme for European higher education[4], which has resulted in a reduction of

student classroom hours and an increase in the time devoted to homework and self-learning. This makes it necessary to look for the tools that enhance this individual learning.

To this end, in recent decades an important change has taken place in the teaching of histology via the use of new technologies that complement and, in some cases, have replaced traditional teaching methods with technological ones [4–8], among which are those using interactive software [9–11], e-learning platforms [12–15], and, mainly, virtual microscopes [16–19], whose results have been studied by different authors [20–23].

The main aim of the application of these new teaching methods has been the digitalization of didactic content so that they are continuously accessible to students, the reduction of equipment (generally microscopes) needed for teaching an

ever-growing number of students, and, mainly, adaptation to the characteristics of the new generations of digital students [24, 25].

This new generation of digital students requires new teaching models and tools that incorporate the use of mobile device technologies giving them access to information any-time and anywhere [26].

Among these communication technologies can be found NFC (Near Field Communication) [27], a contactless technology that uses RFID (Radio Frequency Identification) for the exchange of information between devices, currently available in most smartphones on the market with an ever-increasing usage due to it being the technology in use for mobile phone payment [28].

The main characteristic of this technology compared to other wireless ones, such as bluetooth, is that it simplifies the interconnection process by connecting the smartphone to a reader, another smartphone, or Tag/Chip NFC [29]. Once this simple action is complete, the smartphone or reader receives the information in a standardized form [30] denominated NDEF (NFC Data Exchange Format).

For over a decade NFC technology has been used in universities mainly with three aims: (a) identification and control of attendance, (b) identification and access to information in libraries, and (c) educational games for learning.

Benyó et al. [31] have demonstrated the advantages of NFC in the following of student attendance at the University of Budapest, thereby reducing the incidence of absenteeism. Matas et al. [32] propose a series of NFC applications for universities to adapt better and faster to European directives in higher education put forward in Bologna. To do so they propose the use of NFC in the control of student attendance to classes, university information, access to learning areas and libraries, tutorial requests to teachers, payment of services, etc. [33, 34].

Lee et al. [35] have developed a ubiquitous learning platform based on NFC. By touching a Tag students gain access to exercises that can be changed dynamically by the teacher. The students' answers are evaluated in real time, generating a technological working environment that enhances learning.

Cheng et al. [36] associate NFC Tags to different physical objects, which when touched by students with an NFC device show them an evaluation test on the concepts related to the objects, checking that students' results improve when related to the physical and digital world [37].

The inclusion of games for learning using NFC has been studied by different authors [38, 39], identifying an increase in student motivation when they are integrated into the teaching process.

NFC has been widely incorporated into the field of healthcare, where there exists a wide range of medical instruments integrating NFC chips, wearables for patient and medical personnel identification, Tags associated with medicines which enable reading of instructions and dosage by patients, etc. [40–44]; however, we have no knowledge of proposals for the use of NFC in the teaching of medical students.

In the last years, contactless technologies such as NFC and RFID have demonstrated their advantages when compared to

quick response (QR) codes to be used as interface between the user and the real world.

Although mobile applications based on the reading of information encoded in a QR code are extended to several fields, like commerce, health, and education systems [45–49], as far as we are aware of the use of QR codes in the teaching of histology is unknown. Furthermore, most of the education applications using QR codes only consist in linking the URL stored in the QR label to Web contents. In these cases, the use of QR is just as a tool to avoid that the user would have to write the corresponding URL.

NFC technology facilitates a faster, simpler, more secure, and usable interface of communication, erasing many of the QR inconveniences when being used, such as the following:

- (i) The use of QR codes attached to a glass slide is not practical or impossible. The reduced size of the free space of the glass slide containing a histological sample impedes to attach a label containing a QR code with a size capable of being easily read by a mobile application installed in the mobile phone/smartphone. On the contrary, NFC micro-Tags of very short size can be found in the market.
- (ii) The reading of a QR code necessarily needs a Smartphone with an application installed. Our proposed solution does not need the installation of an application by the user. The mobile phones provided by NFC chip incorporate the necessary controller to read the chip.
- (iii) QR labels have not been rewritten, so it is not possible to modify the information stored in a QR label. The information stored in a NFC Tag can be rewritten as many times as necessary, permitting the tailoring of the applications.
- (iv) Security measurements are very hard to be considered in applications based on QR codes. The URL stored in the QR code is read and seen by the user. NFC Tags allow obfuscating the information stored in the chip.
- (v) There is poor maintenance of QR labels in labs environment in which the manipulation of the glass slides by many students and the risk of deterioration by the chemical products. On the contrary, The NFC chips used are prepared to be used in the conditions of the experiments carried out. The chip can be touched and even get wet without any deterioration.
- (vi) The usability of NFC technology is higher than QR. As a result, NFC technology has unseated QR in almost all the main applications (i.e., payment, identification, etc.). Thus, nowadays almost all mobile phones are equipped with NFC and students are used to manage this technology in their daily life.

As a result, in this study we presented a tool based on NFC (HistoNFC) technology applied to the teaching of medical histology to university students. With this tool students have direct access from their Smartphones to all the images and content of histological slides in the glass slides that they will use during their training.



FIGURE 1: Images of the NFC glass slides being used in the experiment. This figure has been taken from [50].

The solution proposed enables the personalization of didactic content, thanks to an information structure open to any type of multimedia content. An architecture based on Web services allows students to have access to this information anytime and anywhere, without needing to install applications on their mobile devices, so that they may study and revise the observations and content explained in the classroom.

The paper has been organized in the following manner: after the introduction and brief description of NFC technology and its use in didactic university activities, Section 2 describes the material and methods used in this research. Section 3 describes the proposed architecture to answer didactic needs in histology. Section 4 shows the proposed for the management of the teaching information. Section 5 presents the constructed tool, called HistoNFC, describing the different interfaces that enable the functionality for students and teachers. Lastly, Section 6 describes the results of the implantation of HistoNFC at the University of Córdoba, in which 122 second-year medical students participated, the results of which, shown in this study, support the viability and improvement that HistoNFC contributes to teaching activities and student training.

2. Materials and Method

At the Faculty of Medicine of Córdoba University practical classes in medical histology include 2-hour laboratory sessions in which groups of approximately 30 students examine histological preparations selected from organs and tissues of human origin under a microscope. Generally during these sessions each student is supplied with a microscope and a box with 3-4 preparations per session, as well as there being a microscope with an associated camera handled by the teacher, which allows the preparations to be viewed on 4 screens and via a projector.

Students are also given, prior to this via the Moodle [51] teaching platform, information about each preparation (origin of samples, staining method, and key elements to identify), and microphotographs of several enlargements of the slides they are going to observe.

Histological slides were used to carry out the experiment, corresponding to organs in the digestive tract, developed in

the laboratory, and which students observed during their practical classes. To do so, 4 histological slides were prepared in paraffin, corresponding to the oesophagus, stomach, small intestine, and large intestine. From each block, by means of microtome slides, 32 samples were extracted that were stained with hematoxylin-eosin and finally placed in a total of 128 glass slides.

Then a series of microphotos were taken at different enlargements using a Nikon ellipse 1000 microscope, equipped with a Sony camera connected to a desktop computer. The slides used were the same as those later used by students with their microscopes during their classroom practice.

An NFC microchip was associated with the glass slides carrying these histological samples, an NTag 215 chip being adhered to each of the 128 glass slides, as shown in Figure 1, which store the Tag identification and a URL that identifies access to the slide associated with the sample. Thanks to the unique identification of these chips, each one identifies each glass slide precisely, as well as the histological preparation in it. This integration of real and digital world, as has been demonstrated in other experiments, favors students' training and motivation in the learning process.

Besides this, the most relevant information about the main stains was compiled (including those used in the preparations for the experiment), as well as the basic concepts that students need to know about tissues and organs. This information includes texts, photos, and other relevant didactic information that may serve as support to them.

Prior to the development of the experiment, this information was uploaded to the HistoNFC database and tests were made for the correct functioning and accuracy of the system by those in charge of the subject material. Security and access options were also established, as will be described throughout the paper.

3. Architectural Proposal for the Solution

One of the main problems of the use of new technologies in teaching activities is being able to integrate three areas into a simple solution from a computer and user perspective:

- (i) The information domain, in which information should be handled and what form this should take

TABLE 1: Principal actors who intervene in the architecture of the solution.

| Actors | Activities | Related actors | Participating technology | Description |
|----------------|--|--|--------------------------|---|
| Teachers | Administration | Sample holders Samples, System | Web, NFC, Mobile | Create and update contents associated with the samples and sample holders |
| Students | Interact with sample holders and samples | Sample holders Samples | Web, NFC, Mobile | Principal actors who access the information about the samples associated or not to the sample holders |
| Samples | nothing | Sample holders Students Teachers | Web, NFC | Set of multimedia histological information wished to be offered to students for their learning |
| Sample holders | nothing | Students Samples Teachers | NFC, GPS | Glass slide containing a sample and a NFC chip with which the users interacts with their mobile device and NFC reader/writer. |

for quick and easy access by students in the teaching process.

- (ii) The functionality domain, that is, what kind of actions the student may carry out about this information and how these actions guarantee a constant and efficient access to it in a safe and satisfactory manner according to the requirements of the didactic activity.
- (iii) The teaching domain, that is, how to carry out the teaching activity, the rules, and regulations involved and maintained in each of the functional activities carried out by students so that it gives them access to the information they require.

The integration of these three areas demands that the design process for the technological solution is carried out globally, combining information, function, and requirements in the description and specification of all the actors involved.

Table 1 shows the actors who can be elicited in the practical teaching of histology. The teachers are the administrators in charge of generating the didactic content as well as the histological preparations that will be used. This activity must be able to be carried out from mobile devices as well as from any desktop computer and includes the preparation of glass slides, their identification, and integration in NFC technology.

The students' activity subscribes accessing information given by the teachers, which is managed by the system, didactic content which deals with knowledge the students must acquire. Students gain access to this information from their mobile devices as well as PCs via standard search engines and this process may include the glass slides and use of NFC technology and geolocation (GPS).

The samples are main actors in the solution proposed. A sample is a set of multimedia information related to didactic content and which is made up of a set of different objects of simpler information in an appropriate structure for students' correct learning.

Finally, the glass slides are physical objects that contain the histological preparation of a sample for its observation by students through a microscope. These glass slides will have an NFC chip associated with them that ensures security, control, and confidentiality of access to the information associated with the sample present in the glass slide.

Figure 2 shows how these four actors are interrelated and which technologies can be involved in this process, giving rise to the architectural solution proposed in this paper and consisting of the following:

- (i) A database storing the information related to each of the actors and their interrelated activities.
- (ii) A Web solution that allows actors to interact with the database without needing to install an application, thus enabling an interaction environment open to any mobile device, computer, or operative system.
- (iii) Some communication technologies that serve as a link between users, the Web solution, and the database. These technologies will be backed up by devices (NFC, GPS, GPRS, Wi-Fi, etc.) and are responsible for communicating the server with the different devices.

4. A Scalable Design of the Information Domain

The samples are the actors that are directly related to the didactic content that students must acquire, which is based on knowing a set of characteristics of the sample that students, with their experience, must distinguish from their observation of it through a microscope.

To enhance this knowledge an assisted learning curve is necessary, in which students are given extensive multimedia information of examples of samples for their study. Complete information of examples of samples is very difficult to find in the bibliography, so that this assisted learning curve is limited to the reduced classroom practice sessions.

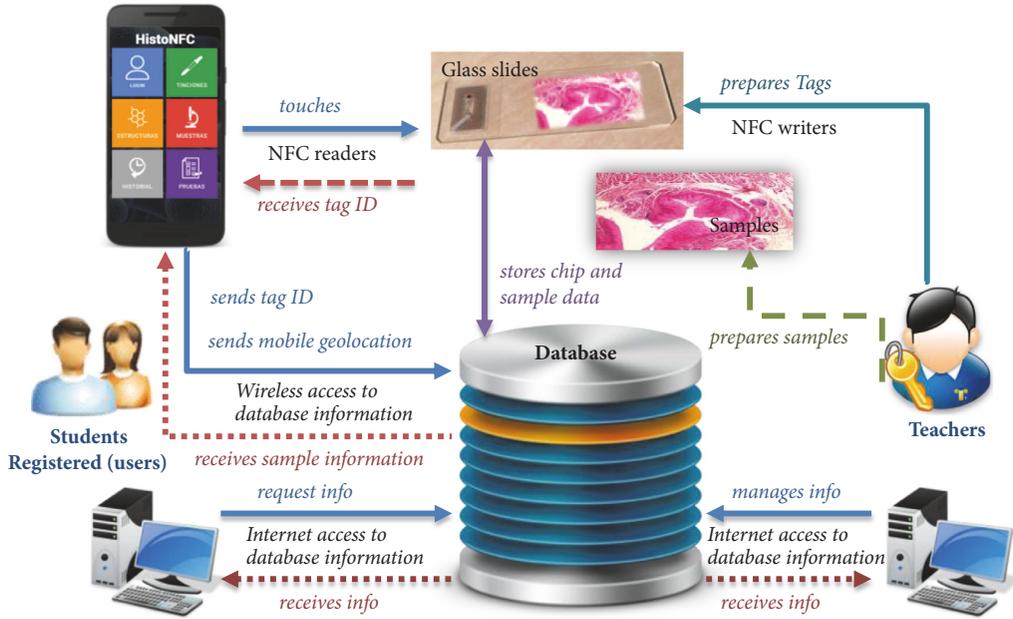


FIGURE 2: Actors, activities and implied technologies.

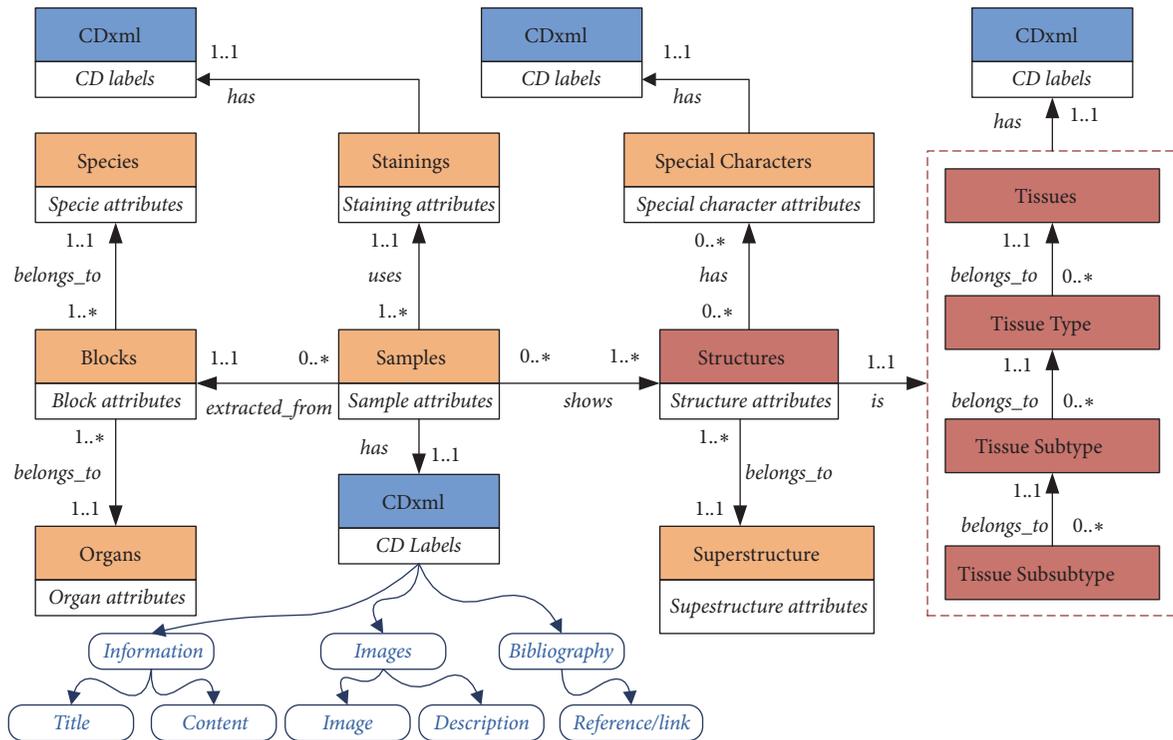


FIGURE 3: Main entities of the conceptual model for the information domain.

HistoNFC attempts to find a solution to this inconvenience, enabling the creation of an extensive database of examples of samples to which students can have access at any time or place. To do so it is necessary to propose an information structure that is open and scalable to any kind of sample and any kind of information that may be associated with it.

Figure 3 shows a conceptual diagram with the proposed solution. As can be observed, the following types of entities or elements of important information associated with a sample have been considered:

- (i) **Species**: representing the animal species corresponding to the sample.

- (ii) Organs: the organs that have been used in the preparation of the sample.
- (iii) Blocks: pieces of the organs that have been extracted and prepared by means of a method for their later use in the preparation of samples.
- (iv) Stains: techniques that are used in the coloring of a sample for its later observation under a microscope.
- (v) Superstructures: the main histological structures that can be observed in a sample.
- (vi) Structures: structural elements present in the superstructures.
- (vii) Special characters: specific peculiarities sometimes present in structures.

As can be appreciated, a sample can be represented by the aggregation of a set of elements of information that describe its very nature as well as its histological characteristics.

The conceptual model proposed and represented in Figure 3 will enable our solution to be open to any set of species, organs, and stains, as well as being extendable to any histological preparation and any type or size of information present in a sample.

However, in order to do so it is necessary to take into account that this information presents a hierarchical structure, as can be seen in Figure 3. Therefore the structures cannot exist unless they are associated with a superstructure, as can be seen in relation (1..1) between both elements of information.

Furthermore, the structures are complex information elements that must be described by means of a hierarchical structure in which more and more specialized “chunks” of information are being represented. Here the structures have been represented by means of a tissue hierarchy, tissue types, subtypes, and sub-subtypes. It is much like a tree hierarchy, father-son, in which an element at level n only exists if it is related to another element at level $n-1$ in the hierarchy.

Finally, the special characters do not exist by themselves. They must be associated with a structure, independently of their level in the hierarchy and, as can be seen in Figure 3, the structures can be associated with none or many of these special characters.

Once the elements of information and their relations have been determined, it is necessary to describe the properties and attributes that characterize them. In the solution proposed the elements of information may have multimedia information associated, such as the images so necessary in the teaching of histology.

If one wants the solution to be scalable and open to any type of content related to a sample it is not possible to associate static properties with these elements of information, but rather they must be dynamic and capable of storing any number and size of content.

The solution proposed is based on defining these properties as XML structures (eXtend Markup Language) [52], which are described in the *CDxml* element (Content Definition) represented in Figure 3 and contain the set of labels or attributes (independently of their cardinality) that may be associated with each element of information.

As can be observed, *CD.xml* is associated with the *Stains*, *Structures*, *Special characters*, and *Samples* elements of information, in such a way that it enables the adjustment of any didactic content to any type of sample. This didactic material is made up of blocks of information consisting of sections of descriptive text, images, and their corresponding explanatory text, as well as bibliographic references or links of interest for students, as is shown in Figure 3.

4.1. Building of the HistoNFC Database. The conceptual solution proposed must be implemented into a database for the management and handling of the information. To do so, this conceptual solution has been transferred to a relational logical model that has been implemented by using the database management system of public domain: MySQL version 6.2.

Figure 4 shows some tables of the relational schema; in order to simplify the figure, tables storing information on the management of the tests given to students in the classroom has not been included.

The elements of information described in the previous section can be represented in the relational schema in Figure 4. The stains used are managed in the table of the same name, which is related to a general table that keeps information about the staining types (acidophilus/basophile, amphiphilic, argentic, etc.). For each stain an image is stored that will be used as a miniature in the application interface and is related to a *CDxml* structure in which multimedia information about it can be described (description, procedure, preparation method, bibliography, images and their explanations, etc.).

The special characters that can be presented in the histological structures are managed by means of the *SpecialCharacters* table. As with the *Stains* table, each of these elements is accompanied by an image for the miniature and a *CDxml* structure in which any set of multimedia information about them can be described.

The different histological structures are managed by a set of tables, *Structures*, which keep information about the hierarchy in which they can be defined via the attributes *idtisue*, *idtype*, *idsubtype*, and *idsubsubtype*. As in the previous tables, each structure has an associated *CDxml* attribute that corresponds to an XML description of any didactic material that is required to be associated with an element in this table.

The *StructureStaining* and *StructureCharacter* tables manage the many relations between the histological structures and the stains and special characters. Thus, in the *StructureStaining* table each structure with the different stains is specified (and vice versa) and in the *StructureCharacter* table the different special characters that can be represented in a histological structure are managed (and vice versa).

Since the samples are extracted from blocks obtained from different organs, the *Blocks* and *Organs* tables are those dealing with the management of this information, in which the textual information of the process is also stored, the species corresponding to the block, the type of cut, preparation method, etc.

The samples, being the main element of the information domain, are managed by a set of tables. The *Samples* table keeps general information about the sample and its attributes

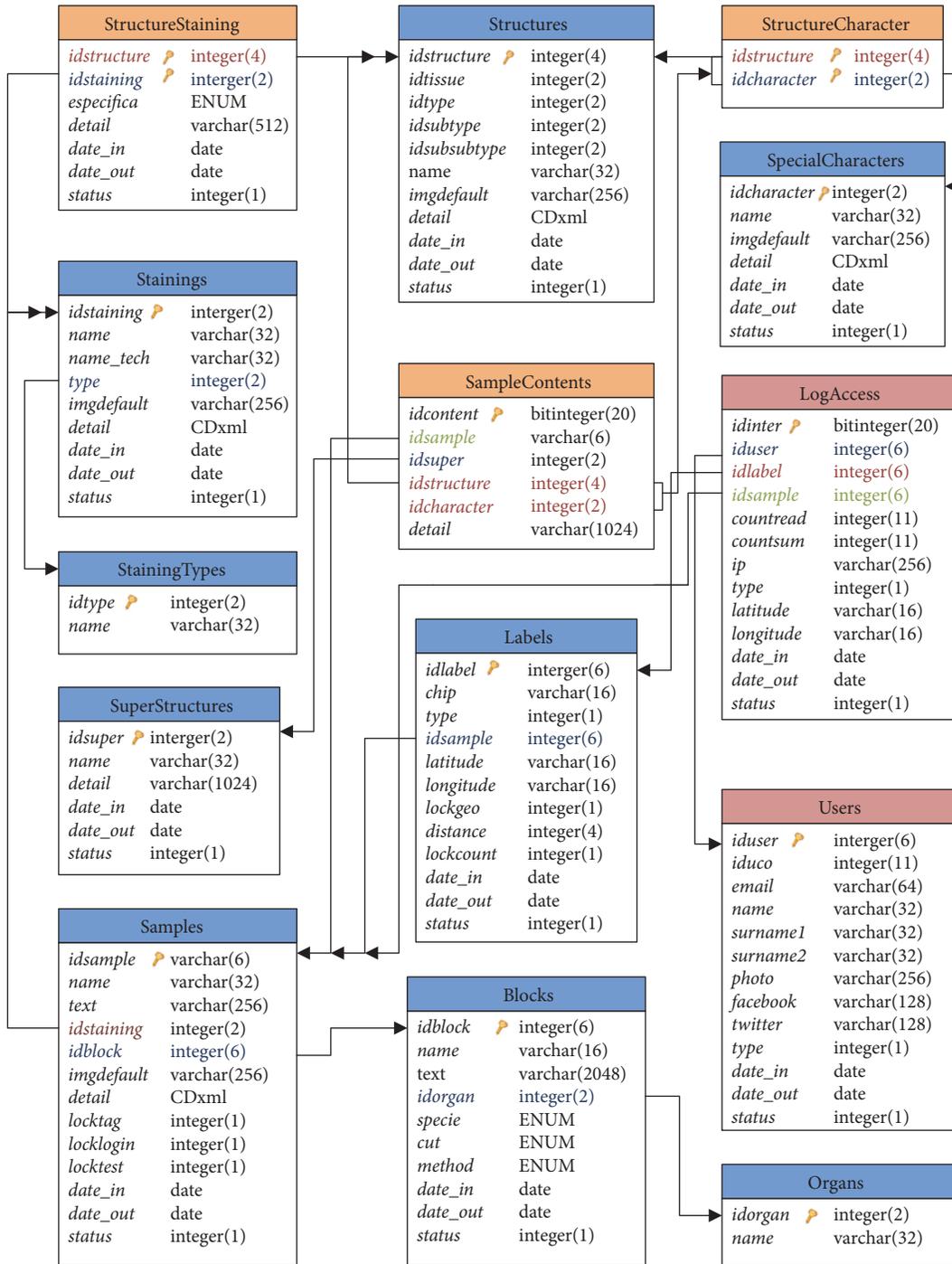


FIGURE 4: Relational database schema including the main attributes.

that enable the management of the mode of access to the information and its security.

Each sample has a unique identifier assigned to it, a name, a short description (up to 256 characters), an image for the miniature, and a *CDxml* structure in which any relevant multimedia information to that sample can be described.

As can be seen in Figure 4, this *Samples* table includes the control and security attributes that will be extensively described in the following section of this manuscript. These

attributes, *locktag*, *locklogin*, and *locktest*, according to their value, will determine the functional flow in which users can gain access to the information about the samples.

The histological structures observed in each sample are managed by the *SampleContents* table. Each element (tuple/row) in this table corresponds to a histological structure that will be related to a superstructure (managed by the table of the same name) and optionally with a special character, by which it maintains a relation to the *StructureCharacter* table, so

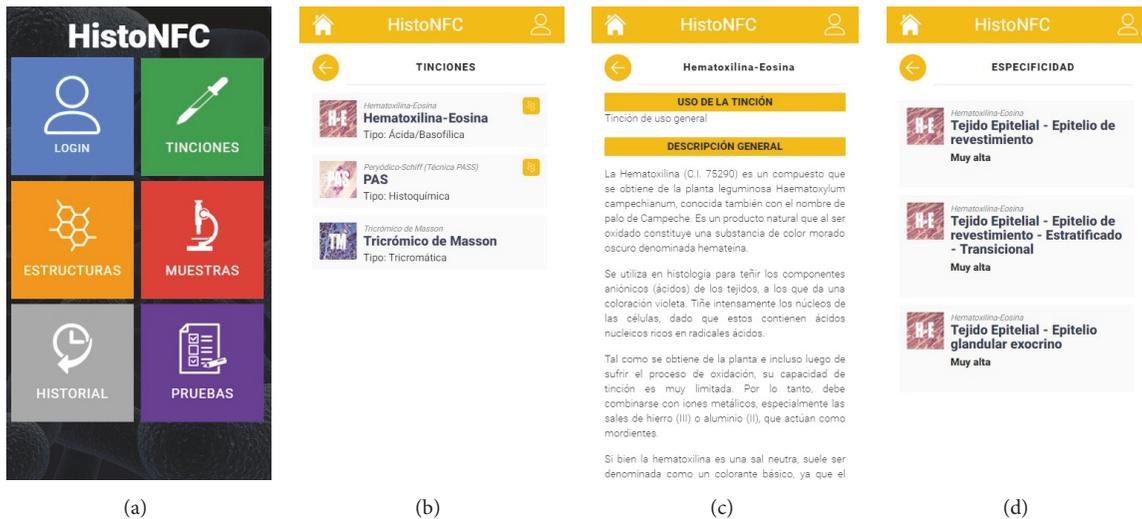


FIGURE 5: Screenshots of main menu and staining information.

that it guarantees that the special character associated with a structure of a sample can only be a special character permitted for that structure.

The *Labels* table keeps information about the NFC Tags that have been activated and associated with a sample. These tags are implanted in the simple holders and serve to identify the sample present in the holder as well as manage user access to the information associated with the sample. It can be observed in Figure 4 that each tuple in the *Labels* table contains a set of attributes that are also destined to control user access according to their geolocation and authentication of the tag. In addition, the information about users and their access to the database is managed by the *Users* and *LogAccess* tables that capture each access to samples made by users.

5. A Friendly and Open Mobile and Web Application

HistoNFC solution is based on a client/server Web solution, in which the end user does not need to install a local mobile application. This feature allows the proposed solution to be independent of the wide range of devices and operative systems, enabling it to be carried out by any mobile device or desktop equipped with a standard web browser. Thus, HistoNFC has been developed as Web application, using different tools and technologies such as pHP, HTML5, CSS3, JQuery, JavaScript [53], Ajax [54], Bootstrap [55], Framework7 [56], and Symfony2 [57] that can be executed with any standard Web browser and serves as a communication interface between users and server via the Web services.

The HistoNFC interface is conceived to be simple, attractive, and user-friendly for any kind of user with quick access to all information. As can be seen in Figure 5(a), the interface is organized with 6 icons that enable access to the main elements of information. Access to some of the HistoNFC functionalities can be restricted, requiring user identification.

When login icon is selected from the main menu, access is gained to a login application (Figure 6(a)). As can be seen users can identify themselves through Facebook or Twitter or register with the system.

When accessing staining, a list of available stains is presented (Figure 5(b)). Every existing stain in the database is shown as an item on the list which, when selected, shows all the information on staining (Figure 5(c)) including the set of associated images.

Moreover, each staining item is accompanied by the icon assigned to its structure. If this icon is selected, a list is shown for that particular stain and its usual histological use (Figure 5(d)), if users then press on an element in the list they are directed to the structure information.

The icon corresponding to the histological structures directs the user to a complete list of all the current structures on the database (Figure 6(a)). When an element is selected from the list the associated multimedia information is shown for that element (Figure 6(b)). This list is based on the structure elements for each structure (tissue, tissue-type, and tissue-subtype) and each item may have two associated icons: (a) the staining icon which would lead to the list of specific types of stain and (b) the icon that relates to the special characteristics that can be associated with that particular histological structure.

When this icon is selected a list of special characteristics comes up which may be relevant to that structure (Figure 6(c)) and if an element is selected from the special characteristics, access is gained to all the relevant multimedia information (Figure 6(d)).

To gain access to the sample information one selects the corresponding icon from the main menu and a list is presented of all the available samples and whose access does not require interaction with a Tag (see Figure 7(a)).

For each item the information is displayed along with a detailed textual explanation of the observation of the test (Figure 7(b)). By selecting the corresponding icon on staining, users gain access to a screen with the information



FIGURE 6: Screenshots showing histological structure functionality.

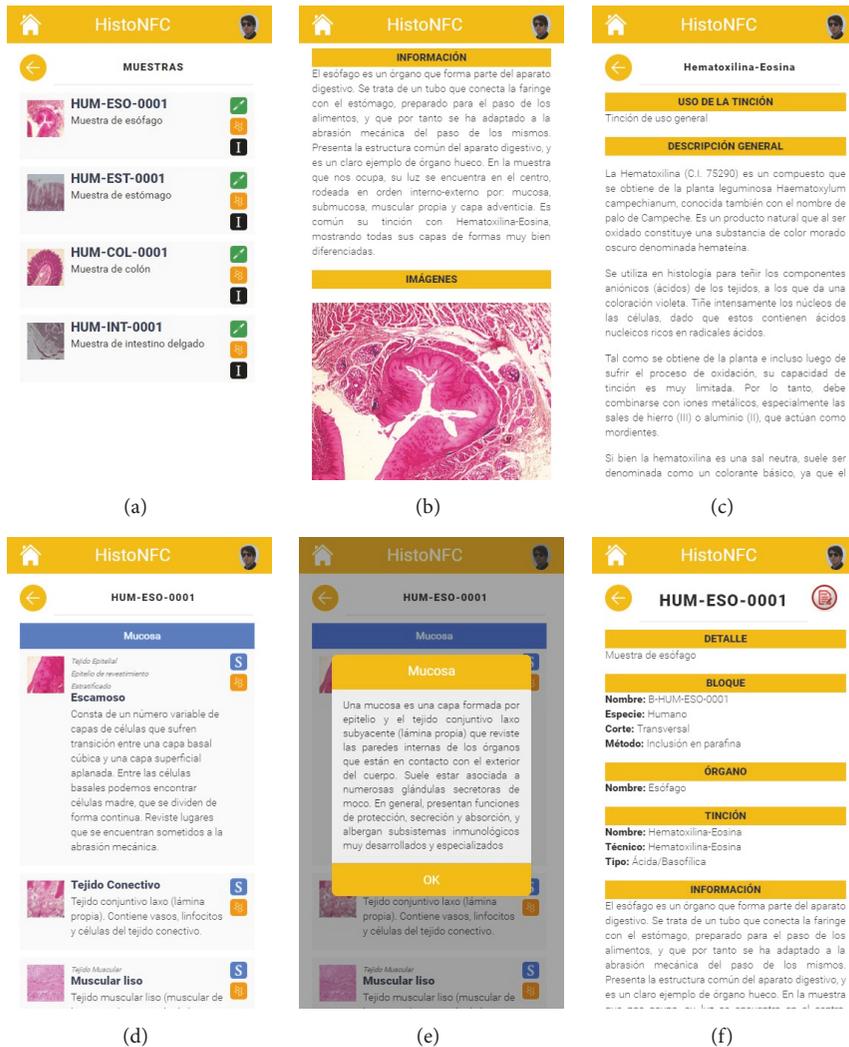


FIGURE 7: Screenshots of sample functionality.

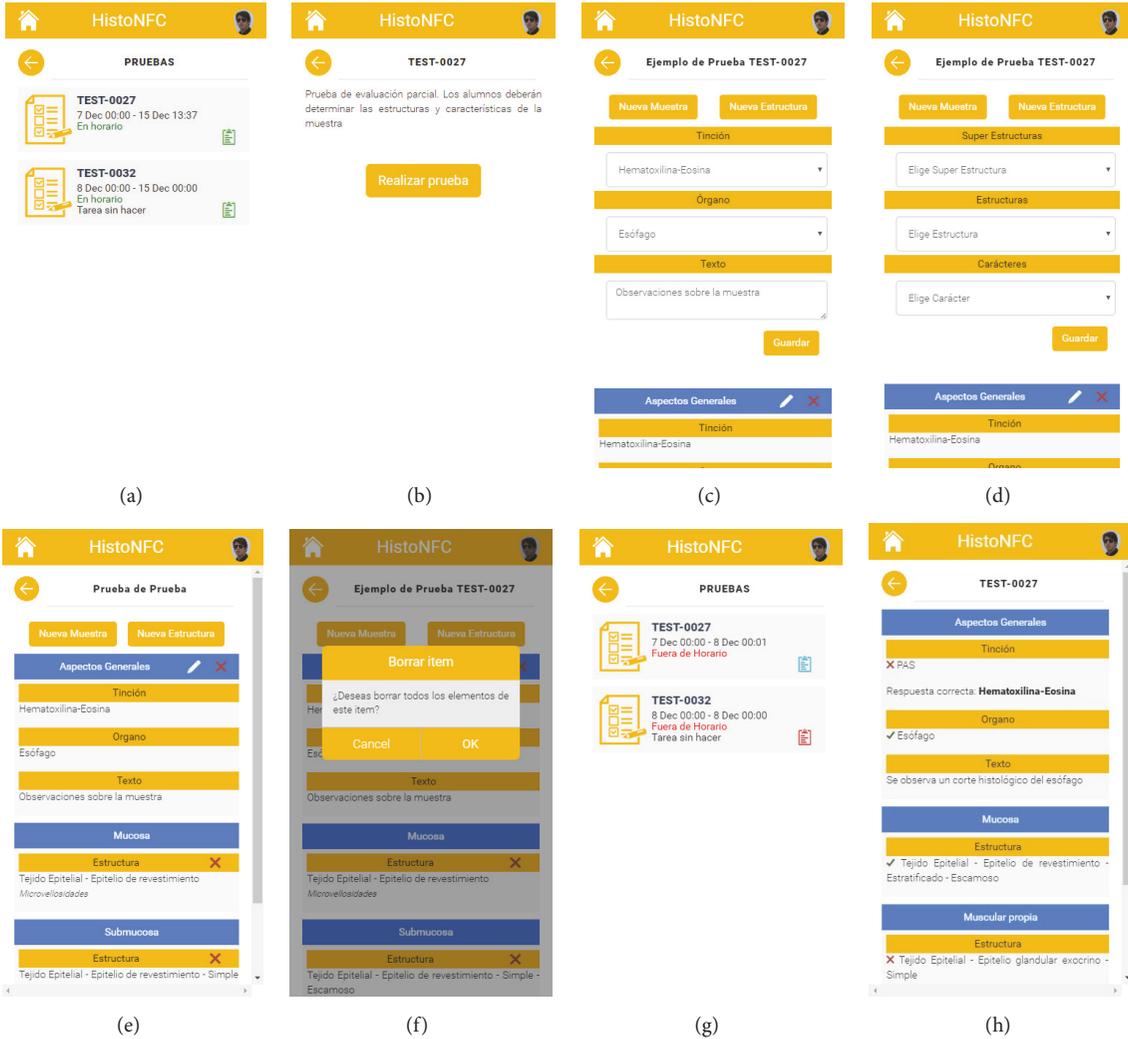


FIGURE 8: Screenshots of test functionalities.

stored in the database relevant to the staining used and the preparation of the sample (Figure 7(c)).

When selecting the structure icon that accompanies each item on the sample list, access is gained to the current structure list of that sample (Figure 7(d)). This will also be accompanied by two icons: (a) an icon that enables access to the superstructure (Figure 7(e)) and an icon that enables access to the stored structure information in the database relevant to that structure, as described earlier and can be seen in (Figure 6).

Finally, each element in the sample list is accompanied by an icon “I” which permits access to all the information on the sample. That is seen when users select the information on the sample and everything is then shown when they gain access to the current histological structures on the sample (Figure 7(f)). It is in effect a complete report on the sample, along with the option of creating a PDF so as the user can then download it and study it in detail.

HistoNFC manages the historical information of the users’ access to the samples. The (identified) users can access

their historical record at any moment, obtaining a list in date order, and paged, of the samples accessed.

When users gain access to the tests a screen is shown with a list of them (Figure 8(a)). Each item on the list gives information about the validity and state of the test (not started, finished, or in progress). If the item is selected a screen is shown with the objective or comment relevant to the test and, in this case, relevant images are shown concerning the test and serve as an aid to students (Figure 8(b)).

To do the test students complete the required information which is then divided into two sections:

- (i) General information: selecting this, the student is asked for information on the organ, staining, and their comment on their observation of the test. The student can supply the answer choosing an item from the existing organ and staining list in the database (Figure 8(c)).
- (ii) To give answers on the structures observed in the test, the student can add new observations by tapping

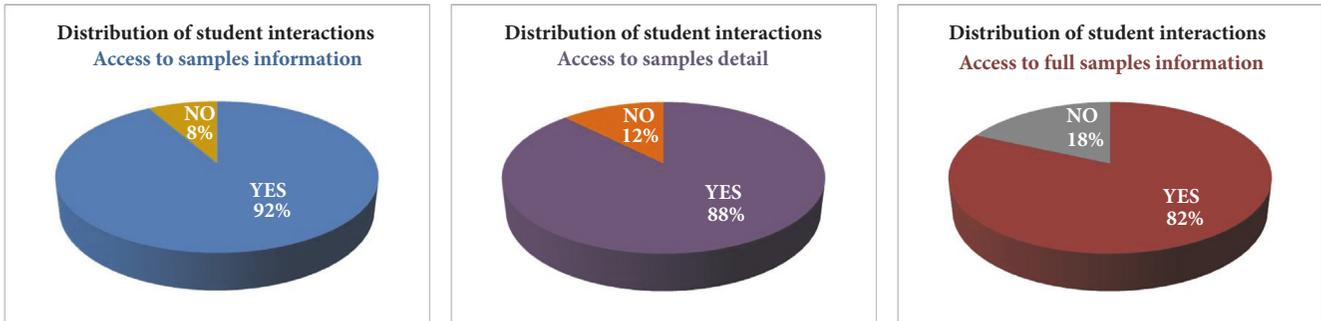


FIGURE 9: Distribution of students' behavior.

“New structure”. A drop-down list on superstructures, structures, and special characteristics is shown on the screen from which the student can choose (Figure 8(d)).

- (iii) The answers are shown in an ordered list of superstructures (Figure 8(e)). Each item on this list can be erased, thus allowing the student to view and correct their answers throughout the development of the test (Figure 8(f))

Once the test is finished, from the administration panel the teacher can automatically correct it. Once corrected, students will see that the test has finished and can access its evaluation. To do so, on the test screen the icon for access to the test information is colored in blue (Figure 8(g)). If a test has finished without the student activating this icon it is colored red (Figure 8(g)).

During the correction process, the system carries out a matching between the students' answers and the existing information in the database about the samples. The results of this process are stored in the database indicating whether each of the students' answers was correct or incorrect.

The outcome of this process allows the student to examine their exercise by looking at (Figure 8(h)) the evaluation for each of their answers and, if incorrect, the corresponding correct answer is shown.

This process is automatic and allows the teacher and student to get a first general evaluation of the test. Subsequently, the teacher can obtain complete information on the tests carried and evaluate any textual comment made by the student.

6. Testing HistoNFC

Having done the tests and refining the HistoNFC, validation is followed by incorporating the system to the practical teaching of medical histology in the second year of the medical degree at Córdoba University.

6.1. Testing Methodology. In the participated practical tests, distributed in 5 sections of two hours, 122 second-year medical degree students participated. The security measures on the test were carried out by means of students' geolocation. This was done activating the characteristic *lockgeo* from the

Labels table and a 20-meter radius was established between the Tags and the students' location, whereby the application detected whenever students accessed any of the prepared tests.

Thus, geolocation (GPS) has to be enabled in the students' smartphone in order to access the sample information in a test, when this security measure is set. When students touch the NFC Tag associated with the sample, the geolocation of the smartphone is gathered and sent to the server, which receives both user identification and tag information. Later, the server tests the smartphone geolocation with the value of geolocation associated with the sample and the restriction established by the parameter *lockgeo* in order to allow the students to access the sample information.

As a result, only students located in the practical laboratory had access to the information on the samples during the tests.

The database was not blocked during the development of the explanations, so that students could access any related information on staining, histological structures, and other existing samples in the database.

With the aim of finding out about students' experience concerning the inclusion of HistoNFC in the teaching curriculum, an anonymous survey was conducted which they had to complete before the following practical sessions. As shown in Table 2, the survey consisted of 22 items divided into two sections destined, respectively, for the evaluation on teaching aspects and assisted-learning (10 items), and HistoNFC as a technological support and use of HistoNFC (12 items). The students had to answer these questions from a scale of one to five: 1 (very negative) and 5 (very positive) or by simply answering Yes/No.

6.2. Testing Results. During the development of the five practical sessions 121 students were registered in the system and there were a total of 1027 accesses to the application HistoNFC. One of the students did not register in the system despite afterwards doing the anonymous opinion survey.

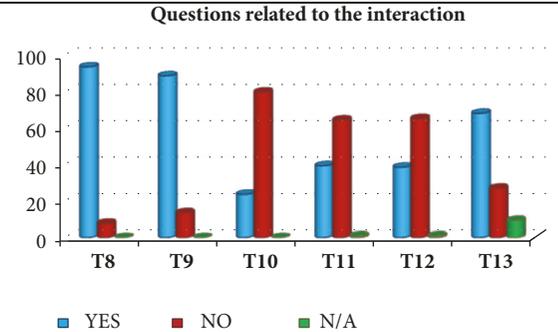
As can be seen in Figure 9, 92% of students accessed the general information about the samples, although 8% of them (10 students) did not interact with the application out of choice, due to not having a mobile device or reasons unknown.

TABLE 2: Survey carried out of opinion and satisfaction.

| Teaching aspects | | HistoNFC and NFC tools | |
|------------------|--|------------------------|--|
| L1 | Do you think it could help in the theoretical learning of the subject? | T1 | Was it easy to use? |
| L2 | Do you think it could help in the practical learning of the subject? | T2 | Did you like the interface? |
| L3 | Was it useful in carrying out the practical activity | T3 | Was it easy to surf through the options? |
| L4 | Would it be useful to serve as an aid throughout the practical activities? | T4 | Was it easy using the user register? |
| L5 | Would you like it to be incorporated as an aid to theoretical study? | T5 | Was it easy to access information? |
| L6 | Would you like it to be incorporated as an aid to practical study? | T6 | Was it useful to surf through the existing links for information? |
| L7 | Would you collaborate in completing the contents tool? | T7 | Is the format and the way the information is presented adequate? |
| L8 | Do you consider the information given to be appropriate? | T8 | Do you think it is an advantage not to install an application for its use? |
| L9 | Do you think its information is correctly structured for learning purposes? | T9 | Are you familiar with NFC technology? |
| L10 | Would you like to see this type of assisted-learning incorporated into other subjects? | T10 | Does your mobile have NFC resources? |
| | | T11 | Did you use NFC in the experiment? |
| | | T12 | Do you think NFC is more intuitive than QR? |

TABLE 3: Results of the surveys: items T8-T12.

| Item | %YES | %NO | %N/A |
|------|-------|-------|------|
| T8 | 88.52 | 13.66 | 0.00 |
| T9 | 23.77 | 79.64 | 0.00 |
| T10 | 39.34 | 64.41 | 0.95 |
| T11 | 38.52 | 65.18 | 0.96 |
| T12 | 68.03 | 27.09 | 9.51 |



General information about learning contents managed by HistoNFC can be free accessed by all the students enrolled in the course. In addition, information about samples used in practical teaching can also be freely accessed by the students if the teachers disable the accessing restrictions.

Out of 121 registered students, 88% accessed the general relative information on the structures and characteristics of the samples, which indicates that 4% of the students who accessed the general information did not access the detail on structures on one of the three samples of the practical session.

Finally, 82% of the students accessed the complete information on the samples, thus enabling them to extract the teaching material and also download it in PDF format,

although 10% of those who used HistoNFC did not interact with this application option.

Once the practical tests were finished, the sample information was accessible through HistoNFC so that students could access it from any location, proving that 98% of students had accessed the general information and completed detailed information about the three samples on successive days. These were predominantly accessed by mobile devices (91%) and from other locations other than the teaching centre (78%).

As can be seen in Table 3, the results of the survey show that out of the 122 surveyed, only 23.77% knew about NFC technology and only 39.34% had mobiles with NFC

TABLE 4: Results of the surveys: items T1-T7.

| Item | Average | STDEV |
|------|---------|-------|
| T1 | 4.52 | 0.85 |
| T2 | 4.48 | 0.76 |
| T3 | 4.48 | 0.83 |
| T4 | 4.22 | 1.16 |
| T5 | 4.59 | 0.78 |
| T6 | 4.48 | 0.85 |
| T7 | 4.66 | 0.67 |

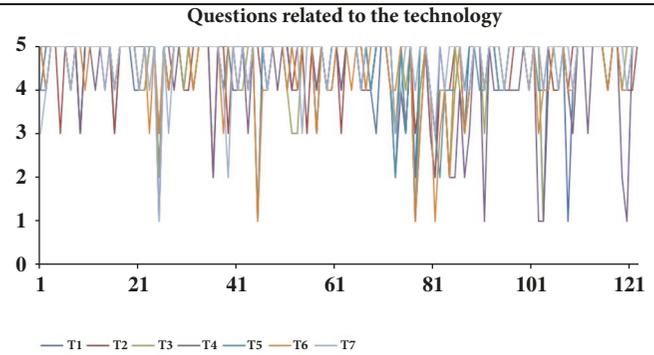
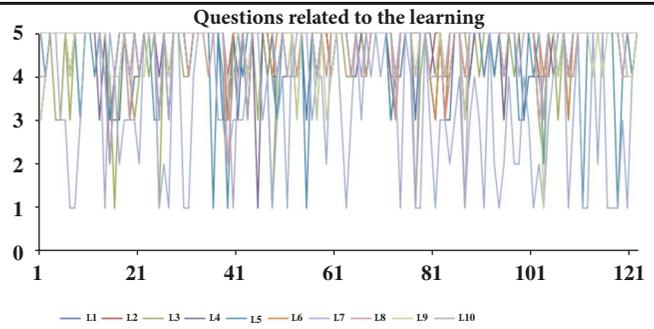


TABLE 5: Results of the surveys: items L1-L10.

| Item | Average | STDEV |
|------|---------|-------|
| L1 | 4.48 | 0.74 |
| L2 | 4.82 | 0.42 |
| L3 | 4.34 | 0.95 |
| L4 | 4.61 | 0.71 |
| L5 | 4.42 | 0.99 |
| L6 | 4.77 | 0.57 |
| L7 | 3.24 | 1.50 |
| L8 | 4.67 | 0.58 |
| L9 | 4.66 | 0.64 |
| L10 | 4.63 | 0.80 |



incorporated (locally, iPhone use is common which unfortunately is restricted in this technology to mobile payment). Consequently, they were allowed to access the sample information directly from the HistoNFC website. Moreover, six smartphones provided with NFC were put at disposal to those students to be used in the experience, although most of them (mainly iPhone users) preferred to access directly to the website information.

However, 38.52% of students used NFC to gain access the samples (98% had NFC on their mobile) and 68.03% considered NFC to be more intuitive than using QR, which included a high percentage of students that did not have NFC facilities on their mobile device.

The main advantage the students found was using NFC and HistoNFC without the necessity of having to download and install an application on their mobile device, according to 88.52% of the students surveyed, which indicates a very high percentage, taking into account that not all students used the application.

The results of the survey on HistoNFC and its characteristics were very satisfying as shown in Table 4. Students found it easy to use the application ($T1_{average}=4.52$), attractive ($T2_{average}=4.48$), very usable ($T3_{average}=4.48$, $T5_{average}=4.59$, $T6_{average}=4.48$), and adapted to using the contents ($T7_{average}=4.66$). The lowest score ($T4_{average}=4.22$) was attributed to the process of registering, although it was allowed to be done through the system or by social

networks such as Facebook and Twitter, owing to the fact that some users did not proceed and confirm in the register, answering instead by e mail to the system to ensure security, which is confirmed by a greater standard deviation ($STDEV=1.16$).

As can be seen in the accompanying Table 4, some students answered with a low score (values 1 and 2) to some of the questions. It is important to take note that these replies cannot be considered very representative, given that 8%-18% of students did not interact with the system as shown in Figure 9.

Students' satisfaction concerning the use of the HistoNFC tool as part of a learning process is clearly demonstrated by the results of the survey, as can be seen in Table 5. With an average value of $L1_{average}=4.48$ and $L2_{average}=4.82$, students considered that the tool can be favorable in the theoretical and practical learning process of the subject, and valued it as a favorable asset to be definitively included with all its contents for the theoretical learning process ($L5_{average}=4.42$) and the practical learning process ($L6_{average}=4.77$).

Students consider that HistoNFC has been very useful in the practical learning activities ($L3_{average}=4.34$) and see it as beneficial to include its use in the practical learning curriculum ($L4_{average}=4.61$). Students extend this positive evaluation as an assisted learning tool for teaching to other subjects and consider that it should be included in other teaching syllabuses ($L10_{average}=4.63$).

With respect to the teaching content that the HistoNFC tool provided students with as an aid to theoretical/practical studies, the results of the survey were very satisfactory. Students considered the information given by the tool was appropriate ($L8_{average}=4.67$) and well-structured for its accessibility and understanding ($L9_{average}=4.66$).

However, when students were asked whether they would like to collaborate with the department in activities destined to complete the systems (example: upload content to the database, contribute sample photos etc.), 21% of the students (26 students) responded negatively ($L7_{value}=1$) and 30% (37 students) responded positively ($L7_{value}=5$), therefore giving the lowest average contents ($L7_{average}=3.24$) and the highest standard digression ($L7_{STDEV}=1.50$).

This result indicates how difficult it is to motivate students to participate in activities that although not being part of the teaching syllabus could benefit and help in the training of other students.

Finally, as seen in the figures accompanying Table 5, some questions had a negative response (value=1). As mentioned earlier, this was primarily due to question L7 and other answers could be included within the error of 8% of students not having interacted with the tool.

7. Conclusions

This paper presents a mobile device solution based on the use of Near Field Communication technology as a support in the teaching of histology to university students. HistoNFC combines other teaching proposals based on portals of contents and virtual microscopes in mobile devices, adapted to the new generation of students and enabling access to information at any time or place, assessment and evaluation of students' activities, personalization of contents and their access management by teachers.

The use of NFC technology has allowed associating information to the glass slides containing histological samples, favoring an easy and quick access to the students to that information and allowing teachers to develop secure evaluations to those students.

Moreover, the use of NFC technology has allowed avoiding all the inconveniences that QR could have generated in this kind of applications as we have mentioned before in this manuscript: poor maintenance, large size to be attached to glass slides, the need of installing mobile applications, etc.

In addition, the simplicity of the use of NFC technology, which does not require the installation of a mobile application and its availability in most Smartphones that students possess, makes a previous teaching curve unnecessary as students have at their disposal an appropriate teaching support in their histology practice training.

Because of this, the results obtained from the experiments have been very favorable, valued as a simple, user-friendly and versatile tool that enables students to acquire images and content inside and outside the practical classes and which enhance the students' own work. HistoNFC has also shown itself to be a powerful tool for teachers since it can be used for questionnaires, assessment of students' use of the application and limit its access in certain situations.

Our next objective will be to complete the contents that HistoNFC currently manages in the teaching of other subjects of Histology, in particular, and of the Medical Degree that is taught at the University of Córdoba.

Data Availability

No data were used to support this study. Access to HistoNFC mobile application can be performed using the following link: <http://www.tocotoca.com/histonfc>.

Conflicts of Interest

The authors declare no conflicts of interest.

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