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Development of usable applications featuring QR codes for enhancing interaction and acceptance: A case study

Rubén Hernando and José A. Macías (*)
Escuela Politécnica Superior. Universidad Autónoma de Madrid
Madrid, Spain

(*) Corresponding Author (j.macias@uam.es). ORCID iD: 0000-0001-5071-0076.

Abstract
QR codes provide potential opportunities to improve interaction in different areas of application. Even so, this technology has been utilized in punctual and specific standalone applications, being barely applied to broader contexts, such as the educational one, where different scenarios can be considered to take advantage of the same QR-code approach. In this paper, key issues for the development of applications that utilize QR codes to improve sharing and availability of resources are presented, specifically focusing on improving interaction and acceptance. In this way, a holistic approach has been developed where the system is aimed at improving the interaction between educators and students. On the one hand, educators use a web interface to manage educational resources and announcements and automatically generate QR codes. On the other hand, students scan those QR codes using a mobile device, obtaining updated information related to their lectures. This scenario has been evaluated by educators and students, obtaining good results in terms of acceptance, cognitive burden, and overall usability. The approach provides development clues and the evaluation method that can be applied to different contexts, thus representing a generalizable solution.

Keywords
Human-computer interaction; QR code; usability; technology acceptance; software development; multimedia.

1. Introduction

DENSO designed the QR (Quick Response) code in 1994. The idea behind this was to easily and quickly classify replacement pieces for different products. The standard ISO/IEC 18004 [31] defines the codification of the QR code, including the use of the Reed-Solomon algorithm for error detection and correction. The QR coding structure consists of different position markers. One is used to quickly recognize the code when scanned, whereas another is an alignment pattern for faster reading. There are also timing patterns to recognize the size easily. In addition, there are reserved areas in order to indicate the coding version, the format, and the error correction. Data contained in a QR code can be diverse, being alphanumeric data the most common type, storing up to 4.296 characters.

The utilization of QR codes has experimented substantial increase. They were initially used for marketing purposes [14], supplying static information about advertising. Also, city location or environment information are other well-known applications [41]. However, there is a current trend towards mobile technology and QR codes in the educational context, as it provides enriched behavior and new interaction modalities. In general, QR codes offer new challenges for mobile learning [12, 33] due to their readiness [19]. Recent studies have verified the efficacy of QR codes as a learning tool [20], as they effectively promote knowledge gains [21]. Also, the integration of QR codes has been considered relevant to facilitate active and distributed learning in the classroom, especially in higher education [22], being a helpful tool for building a bridge from concrete to digital content [23]. Partial approaches and experiments have demonstrated the power of QR codes in re-using information resources to achieve learning goals [28], promoting active-learning activities [40, 42, 59], and supporting collaborative knowledge construction and scaffoldings [28, 61]. Also, in recent times, the outbreak of COVID-19 has provided evidence of benefits in the utilization of QR codes in order to promptly access educational information without the necessity of using physical paper-based documents [32, 56], as well as to facilitate other commonplace academic tasks in off-site environments and the distance [27].

However, there is a lack of approaches featuring QR codes and augmented items for the educational context as an overall and holistic solution [1, 40]. As previously commented, partial and experimental approaches can be found to demonstrate the benefits of QR codes in education. However, they are biased and primarily used in isolation [24] and not in a broader learning environment dealing with resources, announcements, and courses management, and tested with different stakeholders (i.e., students and educators) in terms of acceptance and interaction, remaining as an attractive area of research offering promising challenges [66].

The research here presented is based on two main hypotheses, which also reflect the main contributions of the paper:

1) It is possible to develop an approach that meets the mentioned information exchange using QR codes in a broader educational context, providing generalizable clues to other applications.
2) It is possible to carry out such an approach while obtaining an acceptable cognitive burden and overall satisfaction, providing satisfactory usability levels to enhance interaction and technology acceptance.

In order to corroborate the first hypothesis, this paper contributes a system comprising two different parts: a web authoring interface used by educators to upload multimedia resources and information to be distributed to students as QR codes, and a mobile application used by students to scan the codes and thus retrieve updated information and resources. Main contributions can be summarized as follows:

- The system has been created through an engineering process considering QR codes for education and including specific user-centered design techniques that have been used to ensure usability and improve interaction. In this way, usability objectives have been defined and later evaluated considering user experience metrics.
- Architectural and deployment decisions have been considered to improve readiness and efficiency when managing QR codes and improve storage of video and image, including open-source technology to adapt the application to other platforms in the future.
- The system allows to instance different educational contexts of use that imply creating multimedia resources and information to deliver. In this way, educators, using the authoring tool, can upload an image or video, automatically obtaining the associated QR code. Then, they distribute the code to students in printed and digital formats (e.g., electronic files and messages, textbooks, lecture notes, etc.).

Thus students, by using the mobile application, scan de QR code to access such resources. Resources may be modified later on by educators, preserving the same QR code.

- The system also allows managing courses to deal with announcements and alerts that could be of interest to enrolled students. Indeed, the approach may be helpful in the actual pandemic caused by COVID-19 to deal with educational resources and announcements in off-site environments and the distance [27].
- Development steps are detailed to identify clues to be applied in other contexts, thus producing a generalizable solution that can be extrapolated to other domains.

An evaluation based on an educational case study involving real users (educators and students) utilizing the system under a specific context of use has been carried out to corroborate the second hypothesis. Results are measured through metrics based on the four principal dimensions of usability used to corroborate each construct. A percentage of 75% has been considered as a final acceptance benchmark, which indicates a normalized number between 5 (agree) and 6 (very agree) that can be considered an acceptable value for most usability dimensions. Main contributions can be summarized as follows:

- The evaluation reported positive results to answer the research questions, featuring an acceptable average value related to the usability (91.1%) that enhances interaction, including a high average value (90.16%) for the perceived satisfaction.
- Acceptable average values for usefulness (85.48%) and ease of use (93.95%) have been obtained, corroborating the technology acceptance of the proposal.
- Acceptable values for effectiveness and efficiency, as well as high average values for ease of use (93.95%) and learning (94.75%), have been obtained, corroborating that the proposal features an acceptable cognitive burden.
- Evaluation is informed to be applied in other educational contexts, detailing the evaluation design and the standards and theories by which the evaluation is inspired.

This paper is structured as follows. The following section presents related work, including details about QR codes and applications that implement such technology; the differential contribution of the system presented is also included. Section 3 describes the system developed and a case study. Section 4 presents the evaluation with real users based on the case study, analyzing and discussing the main results. Finally, Section 5 reports on conclusions and future work.

2. Related work

Over the last years, there has been a remarkable increase in mobile device users, overcoming 80% of the population in major industrialized countries [57]. The number of capacities and applications included in such devices has notably increased [82], providing new challenges for learning purposes [13, 55, 73, 85]. Main hardware features incorporated in modern smartphones include cameras and sensors to obtain location. These features have led to developing human-centered applications to assist users in daily-solving activities. An example of this is the use of QR codes together with augmented reality [8] to manage multimedia resources [34].

Applications intended to read QR codes widely vary depending on the information codified. In most cases, these codes include a URL address, and the app redirects to the device's browser to navigate through the web page. This is the case for some current apps based on city locations or museums [41], which use QR codes to include a link to public information sources, allowing the user to scan the code and get additional or location information. In this sense, applications exist to generate QR codes from GPS locations, contact cards, URLs, or text messages. Some examples of such applications are QRDroid [63] and QRafter [25]. In the system proposed, the QR-code authoring is carried through a web application. In this sense, existing mobile applications scan the codes and export different kinds of information such as contacts (vCard), calendar events (iCalendar), or text. This is the case for QRStuff [64] and other QR-code generators and readers [24], which generate and scan QR codes for unique digital resources in isolation. There are other applications, specifically related to marketing and gaming, where the content of the QR code is presented as augmented items (or reality) [75] over the real world. The QR code acts as a data container in these systems, placing the element on the camera visualization. This element is usually either an image or a video. An example of this approach is Onvert [60], which provides an editing application to create content and a mobile application to retrieve them.

The utilization of QR codes provides an added value in the educational context, which can benefit from QR codes to deliver multimedia content using augmented items, thus providing readily available information. Students can benefit from reusing such information resources on mobile devices to achieve their learning goals [28]. Also, QR codes enable active-learning activities that can be exploited in several ways [40, 59]. For instance, the utilization of QR codes and document-based lectures allows students to control their own learning pace, providing a personalized process that can be controlled through learning tasks created by educators [42, 59]. In this sense, some academic studies have provided satisfactory results about using QR-code technology to support collaborative knowledge construction and scaffoldings through concrete applications and experiments [28, 61]. In general terms, the existing bibliography points out the necessity of introducing mobile technology to improve classroom interaction and active learning strategies in STEM [17]. In recent times, the outbreak of COVID-19 has increased the utilization of QR codes throughout the world [83]. Even in the educational context, the pandemic has caused to carry through off-site and online learning activities, where QR codes have become relevant to remotely provide information without the necessity to use physical paper-based information. Some specific applications have emerged to provide those facilities, such as the work presented in [27], where an approach enabling participants to subscribe to a live calendar of teaching events using QR codes is presented. Also, QR codes have been successfully used during the pandemic for students to obtain diverse multimedia content provided by educators [32, 56].

However, QR codes embodying augmented items have been barely exploited in the educational context as an overall solution [84]. In some related works, both QR codes and augmented items come together to feature learning-oriented interactive games [36]. This is the case for LearnAR [2] that overlaps 3D pictures about the subject of study over the camera using markers similar to QR codes. Also, HELLO [43] is an application that uses QR codes and augmented reality to help students improve their English. This application includes a specific m-learning system where students interact and speak in English with a virtual partner. A similar m-learning system is presented in [39], where students scan QR codes placed outdoors in nature, retrieving information about surrounding objects.

Also, [16] presents an approach where QR codes are used to learn information that students retrieve using tablets and other interactive applications based on QR codes and mobile devices [15]. In [40], authors present some initial works using QR codes in the academic context, such as the catalog search at the library of the University of Bath, the exploration of life nature for primary students (using QR codes to identify trees), academic resources sharing, and a periodic table using QR codes.

However, after analyzing different QR-code applications, some common problems and drawbacks were identified [37]. First, there is a lack of usability and many deficiencies in terms of user-centered design. QR-code applications usually consist of a web application, where the user uploads contents and generates a QR code, and a client tool, which is used to scan the code and retrieve contents. Nonetheless, the action of uploading content usually requires technical skills related to graphic design and computer systems, so users with a basic profile are not able to easily achieve tasks that involve editing and authoring QR codes. To solve this problem, it is necessary to reduce the cognitive burden by decreasing the complexity of the current user interfaces, thus providing a trade-off between expressivity and ease of use [48, 49, 58, 69].

All in all, there are not too many approaches concerning QR codes application for the educational context as an overall and holistic solution [1, 40], remaining as an attractive area of research offering promising challenges [66]. Although there are many approaches based on QR-code generators and readers in isolation, there is a lack of specific solutions providing specific academic facilities involving a closer educator-student relationship in m-learning [1] that can also be generalizable to other situations or similar application domains.

The proposal presented in this paper attempts to address all the previous drawbacks mentioned, providing a software solution that can be instanced in the educational context to implement different learning strategies and improve student-educator interaction. Table 1 summarizes the most related approaches, indicating the differential contribution of the system proposed in this paper.

Approach	**Differential contribution of the system proposed**
Cornejo et al. [15, 16]	It is not restricted to test with QR-code questions. On the contrary, it can be used in a broader academic domain to facilitate learning and management.
HELLO [43]	It is not restricted to the learning of English. On the contrary, it can be used in any (enrolled) course, and even in more than one at the same time.
Lai et al. [39]	Integrated functionality. No specific or additional scanning and visualization software is needed.
LearnAr [2]	No specific or additional hardware is needed (just a mobile device) to deploy the desired functionality.
Onvert [60]	Increased automatism and easy interaction. It does not require specialized knowledge about video or image design, being easy to use for unskilled users. More suitable for broader academic purposes.

QRafter [25]	More suitable for academic purposes, as QR-code management is integrated into a functional academic domain.
QRStuff [64]	A simplified set of options, getting a trade-off between expressiveness and ease of use. More suitable for broader academic purposes.

Table 1. Most related approaches and the differential contribution of the system proposed in this paper.

In addition, the existing and most related approaches are far from considering usability and technology acceptance issues, which are of principal interest in today's interactive software developments. Indeed, this paper considers enhancing interaction and technology acceptance through the solution proposed and, more specifically, through the case study presented, which is based on a specific context of use. In this sense, and analyzing existing models and theories on how interaction and acceptance are evaluated in the related bibliography, it can be observed that perceived satisfaction and acceptance usually determine the quality of the interaction [18]. Moreover, according to Human-Computer Interaction theories [18, 62, 68], interaction is determined by the system's characteristics, the users, the development process, and the context of use. All these issues contribute to the acceptance of the system and the interaction from the user's perspective [76]. A standard definition of interaction is reported in [62], where it is stated that interaction is carried out within the scope of a given situation, a task, and a specific context. In order to measure usability, it is necessary to understand the context of use of the system, being a good indicator for the interaction [53] as it defines the quality of interaction between the user and the system [76]. According to ISO 9241-11 [30], usability can be defined as the degree to which specified users can use a product or system to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use.

On the other hand, some other studies consider acceptance as a user attitude based on affective and cognitive evaluation of the system's parts that influence the interaction with the user [18]. Sometimes, acceptance and satisfaction are treated as equivalents [4], whereas in other studies, acceptance is considered a construct defined by usage and satisfaction [74]. In more prescriptive literature, acceptance is expected to be measured under a specific context of use, where the user's tasks have to be considered to analyze how the system fits the user's requirements [3]. Additionally, the Technology Acceptance Model (TAM) [5] is one of the most used models to measure acceptance, considered as the user's "intention to use" and assessed and predicted by measuring two specific dimensions or variables: usefulness and ease of use

3. The proposal

The system proposed here was conceived through an engineering process, considering practical applications to interchange information through QR codes and bearing in mind the drawbacks found in previous approaches, all to elicit main requirements. The proposal has been conceived using a general software architecture. Therefore, different instances can be developed to create scenarios where authors and consumers can share information using QR codes. In this way, Section 3.1 presents the general development clues, whereas Section 3.2 presents the specific instance with the selected case study.

3.1 Technical development

As a differential contribution to other approaches, the development process includes specific user-centered design techniques (i.e., competitive analysis, Thinking Aloud, remote user testing, and questionnaire-based usability evaluation) to ensure usability and improve interaction. In this way, usability objectives have been defined as non-functional requirements, being later evaluated and validated considering user experience metrics about product usage. In addition, an informal heuristic evaluation, based on expert criteria (authors of this paper), was also carried out. This expert evaluation was applied to early prototypes in order to check the main functionality and usability issues. On the other hand, some architectural and deployment decisions have been considered to improve availability and efficiency when addressing QR codes and video and image storage, including open-source technology to adapt the application to other platforms in the future.

3.1.1 Analysis

Since the main objective was to build an environment to share educational multimedia resources and information, and according to the competitive analysis of existing approaches previously carried out, the main functional requirements elicited were the following:

- Resource authoring: Educators should be able to upload information and resources and make them available to students. It is required to have a manageable web tool that automatically generates a QR code associated with each resource to carry out this task.
- Resource update and management: Information and resources are required to be updatable without modifying the associated QR code.
- Resource retrieval: Students should receive information and resources from educators by scanning the QR code generated. A mobile app must scan the QR code and automatically show the related information overlapped onscreen to carry out this task.

In all cases, acceptance as a construct of usefulness and ease of use [72] and efficiency should be considered. Moreover, non-functional requirements aimed at ensuring usability were also considered:

- Simplicity: Since the system will be used in different domain areas, the system must be as simple as possible.
- Ease of use: This implies increasing ease-of-use resulting in a lower cognitive load [46, 48].
- Learnability: All functionalities, both in the authoring and the mobile application, must be easy to remember and learn. This implies reducing the cognitive load by adapting the tasks to the user's mental model.
- Accessibility: Some elements and functionalities will be considered to make the system accessible to the final user. As for the web interface, a responsive design [54] must be considered to adapt to different devices and screen sizes. As for the mobile app, the video will be displayed in full-screen mode.

Requirements were evaluated and validated considering user experience metrics [72, 77] about product usage, according to ISO 9241-11 [30]. This specification allows concretizing usability targets on efficiency, effectiveness, and subjective satisfaction in a real evaluation with final users (see Section 4).

3.1.2 Design and implementation

According to the previously elicited requirements, the system's initial development features a three-layer design through an MVC (Model-View-Controller) pattern, comprising two different environments: the web authoring interface and the mobile application (see Figure 1).

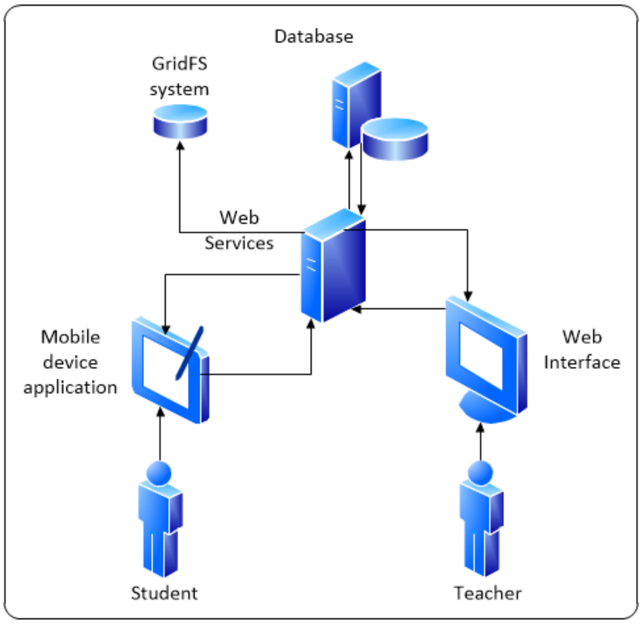

Figure 1. System overview comprising both the educator authoring tool and the student mobile application. The main components and services are shown.

As shown in Figure 1, the web interface is intended as an authoring tool enabling the educator (teacher) to upload educational resources and information associated with different courses. The number of options has been reduced to simplify the interaction and thus the cognitive burden. The web interface is implemented using Ruby on Rails and Twitter Bootstrap [79] to provide a responsive design. On the other hand, the client application is intended for the student to scan QR codes to retrieve the educational resources uploaded by the educator. The number of options in the mobile app has also been reduced to simplify the interaction and thus reduce the cognitive burden. The tool has been developed for mobile devices and is currently implemented (for the time being) for Apple iOS. This application is freely available on the Apple App Store. Client application utilizes the ZXing framework [87] to read QR codes. It is an open-source technology, and it includes the possibility to adapt the application to others platforms, like Android, in the future.

The implementation includes a Restful API [21] in both the web tool and the mobile application. This API is used to communicate both tools with the database and the resources service. QR-code generation is carried out using Ruby rQRCode library [67], storing the necessary information in the QR code (i.e., specific codes to identify resources and related courses) to help the mobile application recognize the corresponding identifiers and thus automatically send the pertinent information for each request.

As shown in Figure 1, the server-side utilizes database services for storing the uploaded files and their associated QR-code information. The proposed system utilizes two database services: MySQL and MongoDB. MySQL is a relational database management system that deals with information about users, courses, lists of resources, and corresponding meta-information. Also, a NoSQL database supported by MongoDB with GridFS [71] is used, where the files uploaded by educators are stored for improving availability and efficiency in both the storage and recovery of resources.

3.2 Case study

According to the developed solution previously presented, a concrete application has been created under an educational context of use that will be evaluated with real users later on. The case study shows the interchange of information between educators and students using QR codes. In this case, an educator, using the authoring tool, uploads an image (video is also supported), automatically obtaining the associated QR code. Then, the educator distributes the code to the students in printed and digital format (e.g., electronic files and messages, textbooks, lecture notes, etc.). Thus, by using the mobile application, students scan the QR code to access the resource and other information of interest. The resource may be modified later on by the educator, preserving the same QR code.

The main steps are described down below, accompanied by different figures to illustrate the case study:

1) Once logged into the web interface, the educator has two options: s/he can manage courses or resources (see Figure 2.a). The management of courses is shown in Figure 2.b, where the educator can create, see, remove and edit different courses. The educator can create a course to restrict access to related resources only to enrolled students. In addition, the educator can upload standalone resources not restricted to any specific course.

Figure 2. Server authoring tool for educators. Once logged in, the educator can manage courses or resources (a). Also, the courses management screen is shown (b).

2) To upload a resource, the educator has to access the resources management screen, which is depicted in Figure 3. This way, a resource can be uploaded and linked to a

specific course, such as "Cálculo Intensivo y manejo de datos a gran escala (COMP)" appearing as the second option in the list of resources shown in Figure 3). The web tool can store information, such as announcements, and resources such as videos or images. Once uploaded by the educator, the system automatically generates a QR code for each recourse (see the QR codes generated at the right in Figure 3) that can be downloaded. Such QR codes can be utilized by educators and distributed to students as images. In addition, educators can modify any resource associated with an existing QR code. In this way, students continue accessing updated information using the same QR code.

Figure 3. Server authoring tool for educators to create and upload educational resources. Here descriptions and images are associated with specific courses and QR codes that are automatically generated by the system.

3) Once the educator has uploaded the resource and a QR code has been automatically generated and delivered to students, they can use the mobile application to retrieve the information. Initially, the application allows students to scan QR codes or manage courses (see Figure 4.a). The students can enroll in new courses (previously created by educators) of a specific grade or post-grade (see Figure 4.b). Courses information is codified in the request, so students will only receive information about the courses they are enrolled in. The scanning option operates by using the mobile device's camera, similar to other apps for scanning QR codes.

(a) (b)

Figure 4. Mobile app for students. Once initiated, the student can either scan QR codes or manage courses (a). Also, the course enrollment screen is shown (b).

4) When the students read the lecture material, they can scan the QR code delivered by the educator in the notes. Once the mobile application has scanned a QR code, it sends a request to the server (including the code identifier) to get back the corresponding multimedia resource (see Figure 5), depending on whether it is restricted to a specific course where the student is enrolled or not. In the example shown in Figure 5, the student has enrolled in the course "Cálculo Intensivo y manejo de datos a gran escala (COMP)", so that s/he has access to such a resource previously created by the educator, which will be shown in the mobile terminal. If the resource retrieved is an image (or a video), the representation will be arranged using augmented reality techniques, as shown in Figure 5, automatically overlapping the image on top of the scanned QR code.

Figure 5. Augmented representation of an image in the student's mobile terminal. Once the QR code, included in a lecture note, has been scanned and recognized, the image is retrieved from the server and displayed on the terminal.

5) Additionally, once the selection of courses has been carried out, the student can get announcements about the courses enrolled by scanning a QR code generated by the educator and placed on a scholar bulletin board (see Figure 6) or similar. To carry out this task, the application sends the list of identifiers of the selected courses to the server. The

server will execute the search of all the announcements in the database associated with the courses in the list. In this way, it will return a list of the messages associated with these courses, and the device will show an alert for each message received from the server. Thus, the student will be aware of the events of the courses of interest.

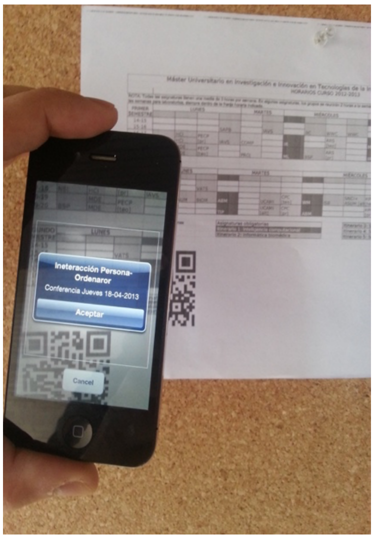

Figure 6. Announcement related to the courses in which the student is enrolled, obtained by scanning a QR code on a scholar bulletin board in the student's mobile terminal.

4. Evaluation

Based on the case study previously presented, an evaluation involving potential final users in a specific context of use was carried out. The evaluation was divided into two parts: one for the web tool involving educators and another for the mobile application involving students. The main goal of this evaluation was threefold: to corroborate initial hypotheses, validate the system requirements, and provide an answer to the proposed research questions.

4.1. Method

The assessment comprised a controlled evaluation, where enrolled users carried out a list of tasks using the tools to observe their behavior and obtain valuable information about the interaction in the proposed context of use. The evaluation was achieved in two different modalities: in-person and remotely by conducting remote testing [23]. Reliability at obtaining homogenous results was similar in both modalities [78]. In both cases, the Thinking Aloud protocol [6] was applied to observe users' reactions. During the interaction, different measures such as effectiveness, efficiency, and user satisfaction were obtained according to the ISO 9241-11 [30] to have an idea of the principal usability measurements [38, 65].

Users did not receive any tutorial, but only a paper with the instructions and tasks to perform. Although this strategy increases the possibility of having weaker results, it also provides more accurate measures concerning ease of use and learning.

Once accomplished the tasks, every user was asked to complete the USE questionnaire [44], which comprises one of the most comprehensive and non-proprietary questionnaires for measuring usability. USE questionnaire features a high psychometric validity, and it is based on 30 questions reporting measures for four different usability dimensions (usefulness, ease of use, ease of learning, and satisfaction). The same questionnaire was used in both evaluations. Responses follow a Likert scale ranging from 1 to 7, where 1 means "strongly disagree" and 7 means "strongly agree". Results were normalized using percentage values. Although there are other shorter usability questionnaires, such as SUS [77], USE allows measuring the usability construct based on four dimensions, describing the most representative values of perceived usability. Table 2 summarizes the items included in the USE questionnaire, divided into the four dimensions mentioned before.

Dimension	**#Question**	**Content**
Usefulness	Q1	*It helps me be more effective*
	Q2	*It helps me be more productive*
	Q3	*It is useful*
	Q4	*It gives me more control over the activities in my life*
	Q5	*It makes the things I want to accomplish easier to get done*
	Q6	*It saves me time when I use it*
	Q7	*It meets my needs*
	Q8	*It does everything I would expect it to do*
Ease of Use	Q9	*It is easy to use*
	Q10	*It is simple to use*
	Q11	*It is user friendly*
	Q12	*It requires the fewest steps possible to accomplish what I want to do with it*
	Q13	*It is flexible*
	Q14	*Using it is effortless*
	Q15	*I can use it without written instructions*
	Q16	*I don't notice any inconsistencies as I use it*
	Q17	*Both occasional and regular users would like it*
	Q18	*I can recover from mistakes quickly and easily*
	Q19	*I can use it successfully every time*
Ease of Learning	Q20	*I learned to use it quickly*
	Q21	*I easily remember how to use it*
	Q22	*It is easy to learn to use it*
	Q23	*I quickly became skillful with it*
Satisfaction	Q24	*I am satisfied with it*
	Q25	*I would recommend it to a friend*
	Q26	*It is fun to use*
	Q27	*It works the way I want it to work*
	Q28	*It is wonderful*

	Q29	*I feel I need to have it*
	Q30	*It is pleasant to use*

Table 2. Summary of the USE questionnaire [44]. Item contents are referred to the system to evaluate.

4.2. Research variables and questions

According to the method previously described, the following dependent variables were considered:

- Quantitative variables:
    - Effectiveness: number of tasks successfully accomplished by users.
    - Efficiency: time spent for users to complete each task.
- Normalized values (0-100%) obtained from the USE questionnaire: usefulness, ease of use, ease of learning, and satisfaction.
- Qualitative variables:
    - User behavior and observations obtained from the evaluation sessions.

Research questions and validation criteria can be defined in terms of the above variables:

- RQ_1: To what extent do the users accept the utilization of QR codes in the given context?
    - Validation criteria: percentages over 75% for usefulness and ease of use are expected.
- RQ_2: Does the solution proposed feature an acceptable learning curve?
    - Validation criteria: acceptable effectiveness and efficiency values and percentages over 75% for ease of use and learning are expected.
- RQ_3: Can the usability of the system be considered as acceptable?
    - Validation criteria: minimal problems found during user interaction and percentages over 75% for usefulness, satisfaction, ease of use, and learning are expected.

A percentage of 75% has been considered as a final acceptance benchmark for most usability values. This rate represents a positive benchmark level to indicate agreement concerning user satisfaction when responding to the different questions in a Likert scale; 1-7 for the case of USE questionnaire. A normalized average of 75% represents a number between 5 (agree) and 6 (very agree), which can be considered an acceptable value for most usability dimensions.

4.3. Web authoring tool evaluation and results

A total of 15 different educators were enrolled for this evaluation. All were males with ages ranging between 28 and 38 (M=33, SD=3). As for the background, participants were asked about their computer skills on a Likert scale ranging from 1 to 5, where 1 means "no knowledge" and 5 means "expert". For this evaluation, an average value of 3.8 (SD=1.1) was obtained.

Participants were asked to perform the following six tasks with the system:

1. Register in the system (TW_1).
2. Create a course (TW_2).
3. Upload an image into the course, previously created in TW_2, and save the QR code automatically generated by the system (TW_3).
4. Upload a video into the course, previously created in TW_2, and save the QR code automatically generated by the system (TW_4).
5. Replace an existing image previously uploaded in TW_3 (TW_5).
6. Create a textual announcement for the course previously created in TW_2 (TW_6).

Only TW_1 and TW_2 were requested to be achieved sequentially. Actually, except for TW_1 and TW_2, and meeting the order in replacing an image (TW_5) with other already created (TW_3), the rest of tasks were given to the participants in a random order to avoid the bias due to similar task sequencing.

	TW_1	**TW_2**	**TW_3**	**TW_4**	**TW_5**	**TW_6**
Mean	52.2	120.1	129.1	210.4	61.9	66.2
Min	30.0	43.0	54.0	51.0	23.0	29.0
Max	80.0	206.0	270.0	423.0	100.0	180.0
SD	12.3	50.7	80.1	120.4	19.5	40.9
Median	50.0	133.0	97.0	148.0	64.0	52.0
CI 95%	12.3	20.3	57.0	112.1	13.2	27.6

Table 3. Efficiency results (in seconds) for the web tool evaluation according to the tasks accomplished by educators. 95% confidence interval values (CI) are also indicated.

The effectiveness metric was estimated using the number of tasks successfully performed. In all cases, effectiveness reached 100%. However, two different cases have to be distinguished: tasks completed without the necessity to provide advice, and those where some doubt arose, and it was necessary to advise the user to complete the task. This fact happened in TW_1 and TW_2, where the user needed assistance in several cases (26.3% and 43.2%, respectively), likely for being the first tasks to achieve.

Table 3 depicts efficiency values in seconds. Acceptable efficiency values and confidence intervals (less than 1 minute) were obtained, except in TW_4, where the task exceeded 2 minutes. In some cases, there is a higher deviation as the time used to upload files varies depending on the time spent by users to find the file and upload it (TW_3 and TW_4).

Results obtained from the USE questionnaire were positive. The overall average value for the four dimensions was 90.0%, which is acceptably high and closer to the satisfaction value (88.13%). Usefulness was the dimension with the lowest value (83.20%). This rate may be because users were working only with the web interface and did not have a general vision of the system. On the other hand, ease of use (93.7%) and ease of learning (95.0%) obtained the highest values. These results shed light on the general usability of the authoring system for the educational context proposed, as the web tool was designed to be intuitive and straightforward for the final user.

4.4. Mobile application evaluation and results

A total of 15 different undergraduate and graduate students performed this evaluation: 10 males and 5 females with ages ranging between 24 and 38 (M=26, SD=3). Participants were asked about their knowledge of mobile applications since they were required to use the camera and mobile apps. Only 15.3% of users reported that they did not have any experience with such specific facilities.

The five tasks designed for this evaluation were the following:

1. Download the app "QR info EPS-UAM" from the Apple Store on your mobile phone (TM_1).
2. Enroll in 10 different courses and save the selection (TM_2).
3. Given a set of 5 pages of lecture notes containing 5 QR codes, display the corresponding images (TM_3).
4. Display a lecture (video) from a printed QR code (TM_4).
5. Get announcements about the courses enrolled from a QR code placed on a scholar bulletin board (TM_5).

As in the web tool evaluation, some of these tasks had to be sequentially performed -i.e., TM_1 must be achieved first, and TM_2, must be done before TM_5.

Effectiveness was estimated using the same method as in the web evaluation: degree of task success. Once again, effectiveness reached 100%. However, some tasks related to QR-code scanning (TM_3, TM_4, and TM_5) needed some advice in about 35% of cases. Most of the doubts arose because users did not initially know how to scan a QR code.

Table 4 depicts efficiency values in seconds. As shown, these results are significantly better than those obtained in the evaluation of the web tool. Confidence intervals are lower and more homogeneous, which is a positive aspect of mobile application usage. TM_1 was the task that took more time for users to be performed. This time is slightly significant as this task depends on the time consumed to download and install the app, and it has to be performed only once. The other two tasks with higher average times were TM_2 and TM_4. However, TM_4 has an implicit penalization due to the time spent on downloading the video.

	TM_1	**TM_2**	**TM_3**	**TM_4**	**TM_5**
Mean	73.8	47.4	40.8	53.7	46.9
Min	34.0	14.0	19.0	20.0	16.0
Max	124.0	184.0	62.0	150.0	163.0
SD	27.6	50.1	15.7	47.8	55.0
Median	77.0	26.0	42.0	41.0	30.5
CI (95%)	12.8	37.9	7.7	20.2	21.8

Table 4. Efficiency results (in seconds) for the mobile application evaluation according to the tasks accomplished by students. 95% confidence interval values (CI) are also indicated.

Results for the four different dimensions obtained from the USE questionnaire also provided positive results. They resulted higher than those obtained in the evaluation of the web tool. The average value for the four dimensions was 92.2%. Compared with previous results, higher values were obtained for usefulness (87.76%), ease of use (94.2%), and satisfaction (92.2%), whereas ease of learning (94.5%) obtained a lower value. As shown, the dimension with the highest result was the ease of learning, which means that users easily understand the application functionality, thus denoting a good learning curve.

4.5. Discussion

Concerning effectiveness and efficiency, similar values were obtained in both evaluations. These represent a positive quantification of the way the tasks fit the user's mental model.

As for the usability dimensions studied, compared values can be observed in Figure 7, where successful scores were obtained in both the mobile app and the web authoring tool for usefulness (87.76% vs. 83.20%, respectively), ease of use (94.2% vs. 93.7%, respectively), ease of learning (94.5% vs. 95.0%, respectively) and satisfaction (92.2% vs. 88.13%, respectively), revealing positive assessments for the perceived usability concerning the context of use proposed.

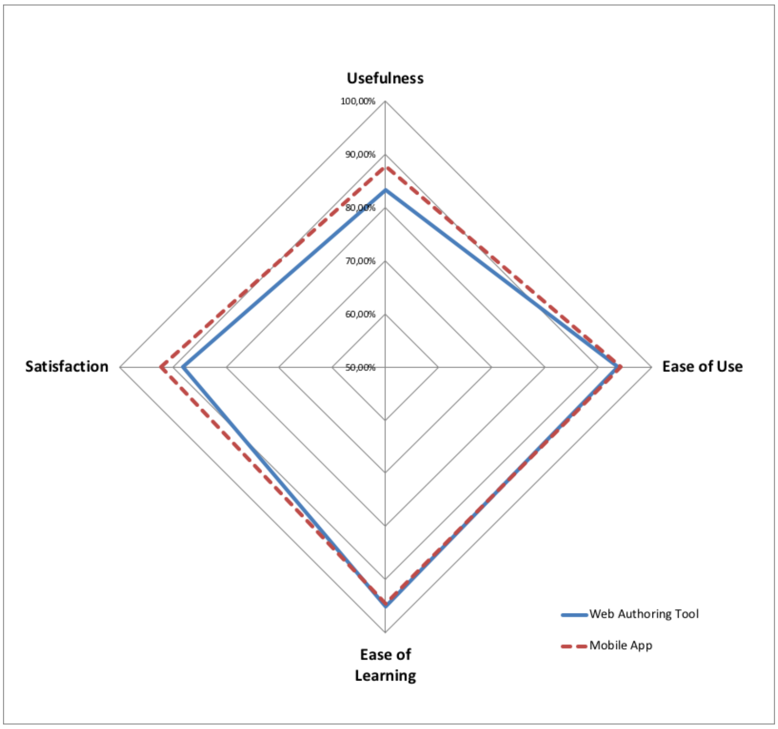

Figure 7. Average values obtained in both the web authoring tool and the mobile app evaluations for each dimension of the USE questionnaire.

Results obtained from both evaluations helped validate functional and non-functional requirements, corroborate the system's overall usability, and provide an answer to the proposed research questions. On the one hand, RQ_1 (proposal acceptance) can be answered in the affirmative, as users considered the QR-code solution, under the educational context proposed, as useful and satisfying. Average values obtained for usefulness and ease of use in both evaluations were 85.48% and 93.95%, respectively, while the minimum value expected to validate this claim was 75%. On the other hand, RQ_2 (cognitive burden) can also be answered in the affirmative, supported by acceptable values for effectiveness and efficiency, featuring also high values for ease of use (i.e., the average value obtained in both evaluations was 93.95%) and ease of learning (i.e., the average value obtained in both evaluations was 94.75%). The minimum value expected to validate this claim was 75%.

The average value obtained for the four questionnaire dimensions represents a reasonable estimation of the overall usability for the system and the proposed context of use. According to that, average values resulted in 90.0% for the web authoring tool and 92.2% for the mobile application. These values indicate that the mobile application features a better usability score. Furthermore, no significant problems were found during the user interaction and, as both usability values are over 75% (minimum expected to validate the claim), RQ_3 (overall usability) can also be answered in the affirmative.

In addition, observations obtained from the Thinking Aloud protocol revealed no significant problems related to the contexts of use proposed. The most important findings were that some students suggested including the lectures in which they are enrolled on the front page of the app to quickly access this information without the necessity of entering the lecture-selection screen. Also, other students suggested including some help or visual feedback in the scanning functionality to carry out this task easily. As for educators, some of them suggested providing tips when filling in the fields used to create a course. Also, some others suggested including some functionality to customize the application's colors. In general, students and educators positively reported on the ease of use of both tools, appreciating the prompt response and usefulness they perceived in the contexts of use proposed and other similar ones that they might envision.

This paper meets the aforementioned principal theories to evaluate interaction and acceptance. On the one hand, the system usability, which provides an indicator for the quality of interaction, has been assessed according to ISO 9241-11 [30], providing values for effectiveness, efficiency, and satisfaction in a specified context of use. In addition, four dimensions of usability have been assessed: usefulness, ease of use, ease of learning, and satisfaction, providing the two principal variables to measure acceptance: usefulness and ease of use. Additionally, this paper provides information about the principal characteristics of the system developed, the target users, and a use case to assess the interaction and acceptance under a specific context of use. Also, an evaluation has been carried out by defining specific research questions that have been validated through the corresponding evidence (quantitative values) in an evaluation with real (target) users, obtaining acceptable values for all usability dimensions and, by extension, for the interaction and the acceptance of the system proposed.

4.6. Threats to validity

No specific threats to validity are foreseen. The evaluation design has been conceived to test with independent groups, avoiding assignment bias, generalization problems, individual variability, or carryover effects.

On the other hand, and according to the evaluation objective, the proposed sample size allows detecting a high percentage of problems that might represent the utilization of the system with real users. In this way, 15 users of each type (educators and students) allow identifying problems that impact 18% or more users with a 95% probability of observing them in the evaluation. According to the binomial probability, the number of users to test can be calculated as $\text{Log}(1-0.95) / \text{Log}(1-0.18) \approx 15$ users. It is worth noting that the discovery rate can be considered as high (95%), and an impact percentage of 18% enables to find complex problems. A problem-impact percentage between 30%-60% implies problems affecting a lot of users (i.e., coarse-grain errors), whereas reducing this figure to a more restrictive percentage (10%-20%) helps find a higher number of problems, and more specifically, those being more difficult to find (i.e., less apparent problems). This trade-off would help find the most critical problems, so it is possible to affirm that a sample size of 15 users is adequate given the typology of problems expected to observe according to the evaluation carried out [20, 26, 29, 72 77].

5. Conclusions and future work

Recent technologies have provided mechanisms to control user access to information resources [19, 35], providing new challenges for empowering education [86]. In this paper, a system to improve sharing and availability of online educational resources has been presented. The system features the utilization of QR codes and other essential technologies such as responsive design and mobile development to provide a usable context of use to enhance m-learning and other learning pedagogies [47, 50, 81].

A specific application scenario has been developed, where the system enables educators to upload resources and information without using different complex authoring tools. Automatically, the system generates QR codes for the resources and information created that can be updated easily without modifying the associated QR code. On the other hand, students can display the resources anytime and anywhere just using the mobile application to scan the QR code, improving the quality and availability of their educational material and notes.

This case study can be generalized according to the development and evaluation clues detailed throughout the paper. Indeed, the system can be applied to other scenarios related to the following educational activities:

- Recording and playing lectures. Since the system allows to upload video resources, it is possible to record a lesson or a conference and then upload it using the authoring tool. In this way, the generated QR code can be located in an accessible location for students who did not attend the lecture, enabling them to visualize the lecture using the mobile app.
- Delivery information about specific courses. Educators can upload information and messages in text format associated with a specific course using the web tool. In this case, the system creates a generic QR code for each course, and the students who have previously configured the mobile application for courses in which they are interested can easily access the corresponding updated information and messages by scanning the generic QR code delivered.

The approach presented proposes a development process that ensures the final product's usability and efficiency [11, 45, 51]. Also, and compared with other approaches, the proposal has focused on broader usability [9] evaluation carried out with final users of each kind (students and educators) [10, 52]. However, there is a lack of approaches featuring QR codes and augmented items for the educational context as an overall and holistic solution [1, 40]. As previously commented, partial and experimental approaches can be found to demonstrate the benefits of QR codes in education. However, they are biased and primarily used in isolation [24] and not in a broader learning environment dealing with resources, announcements, and courses management, and tested with different stakeholders (i.e., students and educators) in terms of acceptance and interaction, remaining as an attractive area of research offering promising challenges [66].

Some of the difficulties faced during the evaluation are related to the Thinking Aloud and remote testing protocols and the fact of enrolling final users for the evaluation. In this sense, it was necessary to consider two different modalities for the scheduling of the evaluation. In cases where a meeting was not feasible, the evaluation was conducted similarly, using the remote testing protocol. For this protocol, a webcam was required, together with the necessity of remotely sharing the screen. In addition, data from the web server's logs were obtained to check the user's actions later on, ensuring the same results as with the on-site testing using the Thinking Aloud protocol. In all cases, it was necessary to request final users to express their emotions and feelings in the more expressive way possible. However, only the Thinking Aloud protocol was used in the mobile application testing since recording the actions is more complex when used remotely. Also, it was necessary to provide the user with additional printed material with the QR codes, so remote testing was not possible. Although it would be desirable to have more users for the evaluation, as previously justified, this number represents an acceptable trade-off to find many of the usability problems that may arise, allowing to improve the systems in the future.

All in all, and according to the results obtained from the evaluations, it is possible to conclude that the two initial hypotheses were satisfied –i.e., the development of a system that meets the QR codes technology for information exchange in educational contexts, also ensuring overall usability. Moreover, the system satisfies both functional and non-functional requirements. Results also provided answers to the research questions, demonstrating significant evidence for the proposal acceptance, the cognitive burden, and the overall usability that enhances interaction, highlighting a trade-off between expressiveness and ease of use [7, 49].

As for the approach's differential contribution and added value, it has been justified above that, in general, there is a lack of approaches featuring QR codes and augmented items for the educational context as an overall and holistic solution. Admittedly, partial and experimental approaches can be found to demonstrate the benefits of QR codes in education. However, they are biased and primarily used in isolation and not in a broader learning environment dealing with resources, announcements, and courses management, and tested with different stakeholders (i.e., students and educators) in terms of acceptance and interaction. The approach here presented provides insights on all these issues and, compared with other approaches, it is focused on broader usability evaluation carried out with final users of each kind (students and educators). In general, the existing and most related approaches are far from considering usability and technology acceptance issues, which are of principal interest in today's interactive software developments.

More specifically, the research here presented overcomes other existing approaches as follows:

- The approach is not restricted to testing with QR-code questions or the learning of English. On the contrary, it can be used in a broader academic domain to facilitate learning and management, and it can be used in any (enrolled) course, and even in more than one at the same time.

- The approach has integrated functionality. This way, no specific or additional hardware for scanning and visualization is needed. (just a mobile device) to deploy the desired functionality
- The approach provides increased automatism and easy interaction. It does not require specialized knowledge about video or image design, being easy to use for unskilled users. It is also more suitable for broader academic purposes, as QR-code management is integrated into a functional academic domain. Also, the approach provides a simplified set of options, getting a trade-off between expressiveness and ease of use.

Such valued characteristics allow to carry out future work easily since the functional technology and the evaluation method have already been developed. This way, other application scenarios can be considered with the minimum effort, just applying the development clues and the evaluation extracted from the presented case study. Those scenarios can be related to:

- Grades information. Students can read a specific QR code related to a course and receive the corresponding grades.
- Managing bibliography. Educators can propose related bibliography for a given course and different access modes using the presented technology.
- Educational events. These would allow dealing with special dates or conferences managed by educators and administrative staff.

Also, the results obtained from the evaluation will be considered to improve the approach. In addition, specific usability requirements [70] and quality metrics related to user experience [80] will be applied to enhance the user-centered development process [11] as well. Furthermore, other platforms, such as Android, will be considered to implement the system. Also, other educational formats will be integrated.

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The authors report no conflict of interest.

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