Authoring Tools: The Road to Democratizing Augmented Reality for Education

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Abstract: Augmented Reality (AR) has great potential to facilitate multisensorial and experiential learning. However, creating activities in AR for everyday classroom use is far from an easy task for non-experts users, such as teachers and learners. To examine if and how an *authoring approach* for AR can be beneficial for educational contexts, we first designed MIXAP through a participatory design with 19 pilot teachers. MIXAP enables non-expert users to create AR activities using interactive and visual authoring workflows. To evaluate our approach with a wider audience of teachers, we conducted a study with 39 teachers examining the usability, utility, acceptability, and transfer between pilot and non-pilot teachers. We found that this approach can help teachers create quality educational AR activities. For both groups, the effect sizes were significantly large for ease of use, emotional experience, and low cognitive load. Additionally, we found that there is no significant difference between the pilot and non-pilot teachers in terms of ease of use, learnability, emotional experience, and cognitive load, highlighting the transfer of our approach to a wider audience. Ultimately, we discuss our results and propose perspectives.

1 INTRODUCTION

Augmented reality (AR) is becoming an important medium for formal and non-formal learning and training (Dengel et al., 2022). Because AR creates a multimodal playground for representing and interacting with content in an immersive way (Roopa et al., 2021), users can interact and enact better the concepts through sound, sight, motion, and haptic (Xiao et al., 2020). Such immersive modalities can support multisensorial and experiential learning (Shams and Seitz, 2008), for many disciplines including, art, design, science, technology, engineering, mathematics, and medicine (Ibáñez and Delgado-Kloos, 2018; Arici et al., 2019). Research advocates that schools should integrate AR in their curricula to enable immersive learning that engages learners and facilitates comprehension of content and phenomena (Billinghurst and Duenser, 2012).

However, authoring AR activities that support pedagogical objectives, is still far from easy for teachers. Authoring AR content still requires advanced programming knowledge and skills in specialized toolkits, such as Unity[1], Vuforia[2], ARCore[3]. This makes authoring AR only accessible to a small group of people with advanced programming skills. Furthermore, because existing AR toolkits are designed for general purposes, they lack support for educational AR content. Currently, it is harder for educators to harness this emerging learning medium in everyday classroom.

Authoring tools (Lieberman et al., 2006) offer a new approach that can democratize AR for education by lowering the barriers to creating AR content. AR authoring tools can provide users with tools that enable them to create or modify AR artifacts without programming (Ez-Zaouia et al., 2022). This is promising because people who are not professional software developers might be able to create AR activities, using user-friendly and easy-to-use interactions. For instance, educators can take a photo of an object, a poster, or a book and add multimodal resources as vir-

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[1] https://unity.com/
[2] https://www.ptc.com/en/products/vuforia
[3] https://developers.google.com/ar

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tual augmentations, such as texts, audios, videos, images, or 3D models. While AR authoring approaches seem very promising for teachers, they have not been studied extensively, especially not by involving end-users in the design process. Systematic reviews have raised several challenges in educational AR, such as the complexity of the technology, difficulties in usability, and a lack of ways to customize AR contents (Akçayır and Akçayır, 2017; Yang et al., 2020; Ibáñez and Delgado-Kloos, 2018). Other reviews have found that existing AR authoring tools have limited support for educational content (Ez-Zaouia et al., 2022; Dengel et al., 2022), suggesting that more work is needed.

To examine if and how AR authoring approaches can benefit teachers, we first designed MIXAP, a prototype that enables teachers to create educational AR activities through simple authoring workflows (Figure 2). We designed MIXAP through an iterative and participatory design with 19 pilot teachers. To evaluate our approach with a wider audience of teachers, we designed and conducted a study with two groups of 39 teachers focusing on usability, utility, acceptability, and transfer. More specifically, we compared the group of pilot teachers to a second group of non-pilot teachers. The non-pilot teachers used the MIXAP for the first time. We found that MIXAP can support both groups of teachers in creating quality educational AR activities. We found that for both groups, the effect sizes of ease of use, emotional experience, and low cognitive load of [TOOL] were significantly large. In addition, we found that there is no significant difference between the pilot and non-pilot teachers in terms of ease of use, learnability, emotional experience, and cognitive load, highlighting the transfer of our approach to a wider audience.

2 BACKGROUND

Numerous systematic reviews have revealed trends, benefits, and challenges of educational AR applications (Radu, 2014; Akçayır and Akçayır, 2017; Arici et al., 2019; Dengel et al., 2022; Hincapie et al., 2021; Ibáñez and Delgado-Kloos, 2018; Garzón et al., 2020). For example, Radu (2014) analyzed 26 studies that compared AR learning to non-AR learning and found that AR had several benefits for learners, such as fostering motivation, collaboration, retention, and learning spatial structures. Focusing on the pedagogical approaches taken in AR, Garzón et al. (2020) reviewed the impact of AR factors, namely collaborative learning, project-based learning, situated learning, multimedia learning, intervention duration, the environment of use (e.g., classrooms, outdoors, field drops, museums). The authors found that collaborative AR showed the highest impact on learners. Ibáñez and Delgado-Kloos (2018) reviewed AR literature concerning science, technology, engineering, and mathematics fields (STEM) and characterized AR applications, instructional processes, research approaches, and problems reported.

Given the availability of the above-mentioned studies, in this paper, we instead focus on the creation of AR content by the teachers themselves using *authoring tools*. Such tools attempt to make creating, modifying or extending software artifacts less technical, easier, and accessible to people who are not professional developers. They also provide end-users the means to adapt the content to their needs and not be limited to what pre-made artifacts offer. This is particularly important for education in three main ways. First, teachers can automate the creation of AR artifacts. Second, they can customize and personalize artifacts to suit their teaching needs. And finally, they can appropriate and take ownership of tools and artifacts in their unique ways.

While the authoring approaches are extremely important for the wider adoption of AR in education, they have not been studied extensively. Very few studies reviewed design aspects underlying AR authoring tools. Nebeling and Speicher (2018), classified existing authoring tools relevant to the rapid prototyping of AR/VR experiences in terms of four main categories: screen types, interaction (use of the camera), 3D content, and 3D games. Mota et al. (2015) discussed authoring tools under the lens of two main themes: the authoring paradigms (standalone, plug-in) and deployment strategies (platform-specific, platform-independent). Dengel et al. (2022) reviewed 26 AR toolkits cited in scientific research. They characterized toolkits by their level of required programming skills (high, low, or medium), level of interactivity (static, i.e., without user interaction, or dynamic), affordability: (free or commercial), device compatibility (mobile, desktop, HMDs, or web) and collaboration capacity (yes or no). However, the aforementioned research focused mainly on authoring tools that require some level of programming and mostly the ones cited in scientific research including non-educational tools. Ez-Zaouia et al. (2022) recently analyzed 21 educational authoring tools that do not require programming, from both industry and academia. They formulated a design space of four design dimensions of AR authoring tools, namely, (1) authoring workflow (production style, content sources, collaboration, and platform), (2) AR modality (object tracking, object augmentation, interaction, and navigation), (3) AR use (device type, usage, content collection, connectivity, and language) and (4) Content and User Management (sharing, administration, and licensing). In addition, these reviews raised several design challenges of educational AR, such as usability, lack of customization, expensive technology, and lack of holistic models and design principles for AR (Ez-Zaouia et al., 2022; Dengel et al., 2022; Akçayır and Akçayır, 2017; Yang et al., 2020; Ibáñez and Delgado-Kloos, 2018; Nebeling and Speicher, 2018).

While these studies provided insights into the design and use of AR, there is still a lack of design-based research into AR authoring tools for education. To the best of our knowledge, studies that involve teachers in the design process of AR authoring tools are very limited in number. We build upon previous studies (Ez-Zaouia et al., 2022; Dengel et al., 2022, e.g.,) to better understand if and how authoring approaches can benefit the design and use of AR activities in educational settings. We engaged with teachers in an iterative and participatory design process. We designed an authoring tool to make education AR accessible to non-export users, taking into account design considerations of the authoring workflows, customization, multimodality, and interactivity.

3 TEACHER-CENTERED ITERATIVE DESIGN PROCESS

We conduct our work in the context of a design-based research project that involves end-users, namely teachers, learners, and educational managers (who train teachers). We followed an iterative teacher-centered design process and went through four main iterations (Ez-Zaouia, 2020). Figure 1 summarizes our four main iterations.

3.1 Understanding AR Use in Classrooms

To understand AR use, teachers' practices, and challenges related to integrating AR in everyday classrooms, we created a partnership with CANOPE, a public network that offers professional training for teachers in France. One of the main focuses of CANOPE is to help teachers integrate innovative technologies in their classrooms. This partnership allowed us to identify challenges that CANOPE's educational designers/managers experienced first-hand in their recent work with teachers on educational AR. Over several weeks, we conducted several meetings with the educational managers where they shared with us (i) their work with teachers, (ii) existing AR technologies used by teachers, and (iii) challenges that teachers face with existing AR technologies.

The recurrent challenges in existing AR technologies that were evoked were: usability difficulties, lack of ways to customize the experiences and the contents, inadequacy of existing technologies for teachers, and difficulty to design effective AR activities. These findings corroborate previous results from systematic reviews (Dengel et al., 2022; Akçayır and Akçayır, 2017; Yang et al., 2020; Ibáñez and Delgado-Kloos, 2018; Nebeling and Speicher, 2018), suggesting that these challenges are not addressed yet. We traced most of these challenges to the authoring approaches of existing AR technologies for education, see a review (Ez-Zaouia et al., 2022). On one hand, many of the existing AR authoring technologies offer either off-the-shelf content or editable templates for AR. However, off-the-shelf and editable templates provide pre-made activities (one-size-fits-all) that teachers cannot customize and personalize to suit their needs best. This is a major barrier for teachers because it prevents them from creating personalized content for more *situated* AR learning, which is shown to have the highest impact on learners (Garzón et al., 2020). On the other hand, some tools allow users to create AR experiences using their content. However, most of these tools do not enable the creation of pedagogical activities that can address classrooms' needs. Ez-Zaouia et al. (2020) found that existing AR authoring tools lack "built-in" support for helping teachers and learners use AR to its full pedagogical capacity (Ez-Zaouia et al., 2022).

In sum, our domain exploration revealed three main gaps in existing research and practice around educational AR: (1) lack of pedagogical approaches in existing authoring tools, (2) lack of authoring approaches that are suitable for teachers, and (3) lack of guidance and principles on how to design effective educational AR activities.

3.2 Understanding Teachers-needs for AR Activities

After our domain exploration, we felt important to formally engage with teachers to understand their needs for AR. Through CANOPE, we recruited 19 pilot teachers from various disciplines: [Gender: (women = 8, men = 11), Teaching Years: (min = 2, max = 40), School Level: (elementary = 5, middle = 11, high = 2, university = 1)]. Teachers have various technology-use expertise in classrooms, AR Use: 26.3% and Smartphone Use: 63.2%. We conducted two 3-hour co-design sessions where teachers

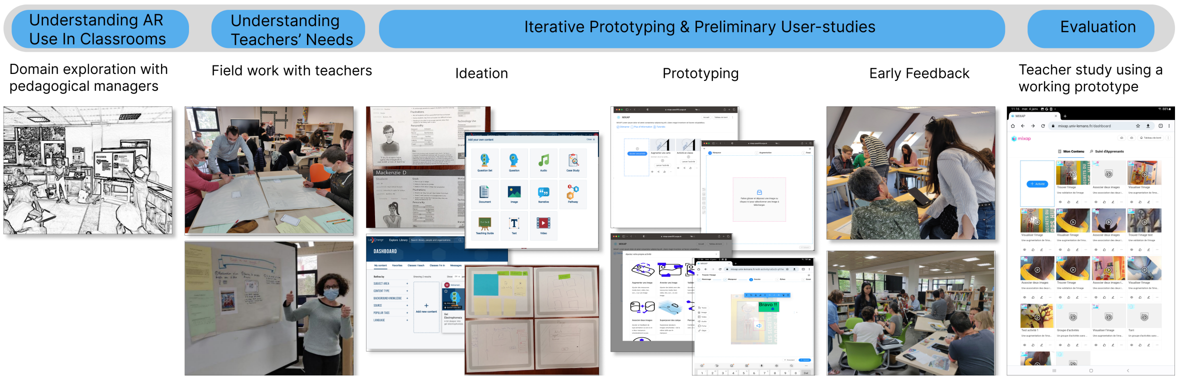

Figure 1: Teacher-centered design process we followed in this work, including (1) understanding AR use in classrooms, (2) understanding teachers-needs for AR, (3) iterative prototyping and preliminary user studies, and (4) formal study with teachers.

paper-prototyped AR activities they wanted to create for their classrooms.

AR Elicitation and Ideation. For each session, we started with a 30-minute elicitation phase, during which teachers explored 11 AR educational applications[4]. We then asked them to paper prototype one or more AR activities for their course. We opted for paper prototyping to remove technical constraints. We provided teachers with a toolkit, i.e., large paper worksheet, markers, tablet screens printed out on paper, and guidelines to help them describe (i) the context in which the AR activity is used (ii) the objects they wanted to augment, (iii) the augmentations they wanted to add, and (iv) the interactions they wanted their students to have access to via the tablet's screen. After the paper prototyping, we asked the participants to present their prototypes to the group. We videotaped the workshops. We collected the recordings and 24 worksheets. Three authors analyzed the recording and the worksheets to identify teachers' needs. The collected data is open online (Author, 2022).

Pedagogical AR Activities That Teachers Want. In our analysis, we identified five types of pedagogical AR activities and two ways of combining AR activities together to create sequences. The most common type of activity is **image augmentation**. In this activity, teachers would like to add multimodal resources (texts, images, videos, audios, 3D models, and interactive menus) to images, such as posters, books, and exercise sheets. For example, a primary school teacher wanted to augment the pages of a book with audio recordings of her narrating textual vocabulary (e.g., "The reindeer has four hooves and 2 antlers"). She also wanted to augment imaginary illustrations of animals in a book with real images so that kids associate real and imaginary illustrations. Another teacher wanted to augment the photos of his high-school students with 3D models they created in technology class. It is not surprising that most teachers have thought of this type of activity since it is the one available the most in the authoring tools but it is quite limited in the number or type of resources that we can create. The second type of activity is **image annotation** in which teachers wanted to associate information (e.g., legends) to specific points of an object. For example, a teacher wanted to add specific legends to different areas on a map.

The third type of activity is **image validation**, in which teachers wanted to create activities that learners can complete on their own by using AR to validate automatically if the chosen image is correct or not. For example, a middle school science teacher wanted to ask students to assemble the pieces of a map correctly. Another teacher wanted students to identify a specific part of a machine (e.g., motors) by scanning image markers attached to the machine. The fourth type of activity is **images association** in which teachers wanted to display multimodal resources when two image markers are visible on the scene at the same time. For example, a primary school teacher wanted children to practice recognizing the same letter, written in capital and small letters. Another teacher wanted to use this type of activity for learning concepts by associating different modalities, for example, learning fruit vocabulary using words (e.g., banana) and imagery. The fifth type of activity is a **images superposition** in which teachers wanted to display layers of information on the top of an image. For example, a university geology teacher wanted students to be able to activate or deactivate layers of information showing various types of rocks and tectonic plates on geographic maps. Finally, teachers wanted to create **activity clusters** and **activity paths** by combining ac-

[4]Foxar, SpacecraftAR, Voyage AR, DEVAR, ARLOOPA, AnatomyAR, ARC, Le Chaudron Magique, SPART, Mountain Peak AR, SkyView Free

tivities without or with predefined order. Clusters and paths are essential for teachers who design their activities in a form of a pedagogical sequence. Apart from image augmentation, the activities that the teachers wanted are rarely supported by the existing authoring tools.

3.3 Iterative Prototyping and Preliminary User-Studies

To address teachers' needs, we iteratively designed, over a period of five months, three main prototypes leading to a working prototype, We decided to use web technologies for AR, which we knew will facilitate rapid prototyping and also support teachers' various needs.

In the first month, we were able to design the first prototype with the image augmentation activity. This was important for us to rapidly gather user feedback using a concrete tool. We conducted a first preliminary user study with more than 20 teachers in a local seminar about serious games. We prepared a worksheet with 5 activities. In each activity, we asked the participants to augment an image with different media resources, namely, text, image, audio, video, and 3D object. We had several issues with the software during this user study. In part, the image, audio, video, and 3D object were not loaded correctly in the AR view. We ended up using only text augmentations with the participants. Other issues relate to teachers adding multiple augmentations to a marker. The prototype had issues handling positions of multiple augmentations. Teachers also wanted to take a photo of their objects (e.g., books, flyers) and add them as markers but the first prototype allowed only uploading existing images from the user's device. Even though this first prototype had many issues, most participants reacted positively to the visual authoring approach of the tool (see Section 4). They highlighted that the interface is simple and user-friendly. Also, the steps we designed in the editor provided guidance in helping the user incrementally create an AR activity.

In the following month, we designed a second prototype that addressed all the issues that we faced during the first preliminary user study. Similar to the first prototype, we focused on the image augmentation activity. We then conducted a second user study with the help of CANOPE, for which we invited 12 of our partner teachers to evaluate the new prototype. We asked teachers to bring their educational materials (e.g., books, flyers, images) so that they can use the prototype to create their AR activity. We also had some minor issues. One issue was that markers that are photos taken by the camera took too long to process for an AR view, partly because the teachers' tablets have limited memory and processing units. However, apart from minor issues, the prototype worked well. In this study, we validated the design choices of the visual authoring approach. All the participants reacted positively to using user-friendly interactions (click, drag, resize), and configuration menus with smart-default parameters to personalize the look and feel of the content (e.g., text and image styles). In addition, the participants highlighted some improvements, such as adding the possibility to record audio or a video rather than uploading a file from the user's device.

We decided to combine image annotation and augmentation since the position of the augmentations is precise enough to annotate a precise part of an image marker. In the following two months, we refined the tool and designed authoring workflows for the other types of activities. We refined the augmentation/annotation and designed authoring workflows for the association, validation, cluster, and path activities.

3.4 Formal Study with Teachers

To evaluate whether an authoring approach can support teachers in creating various AR activities, we designed a formal study with two groups of teachers. One group was composed of pilot teachers who partnered with the project through CANOPE. The second group was composed of teachers who were unfamiliar with the project. We provide details about the study in the method and report the results in the results section.

4 MIXAP: AN AUTHORING TOOL FOR EDUCATIONAL AR

We designed MIXAP to make creating educational AR activities easier and less technical for non-expert users, such as teachers and learners. Based on our domain exploration with teachers and literature review, we derived three design goals to support teachers' needs.

4.1 Design Goals

DG1: Incorporate Authoring Workflows to Facilitate Creating Pedagogical AR Activities. A major challenge in authoring tools for AR is the lack of support and guidelines to help users in creating AR content for classroom use (Ez-Zaouia et al., 2022; Dengel et al., 2022). To alleviate this challenge, we designed five authoring workflows in MIXAP to guide

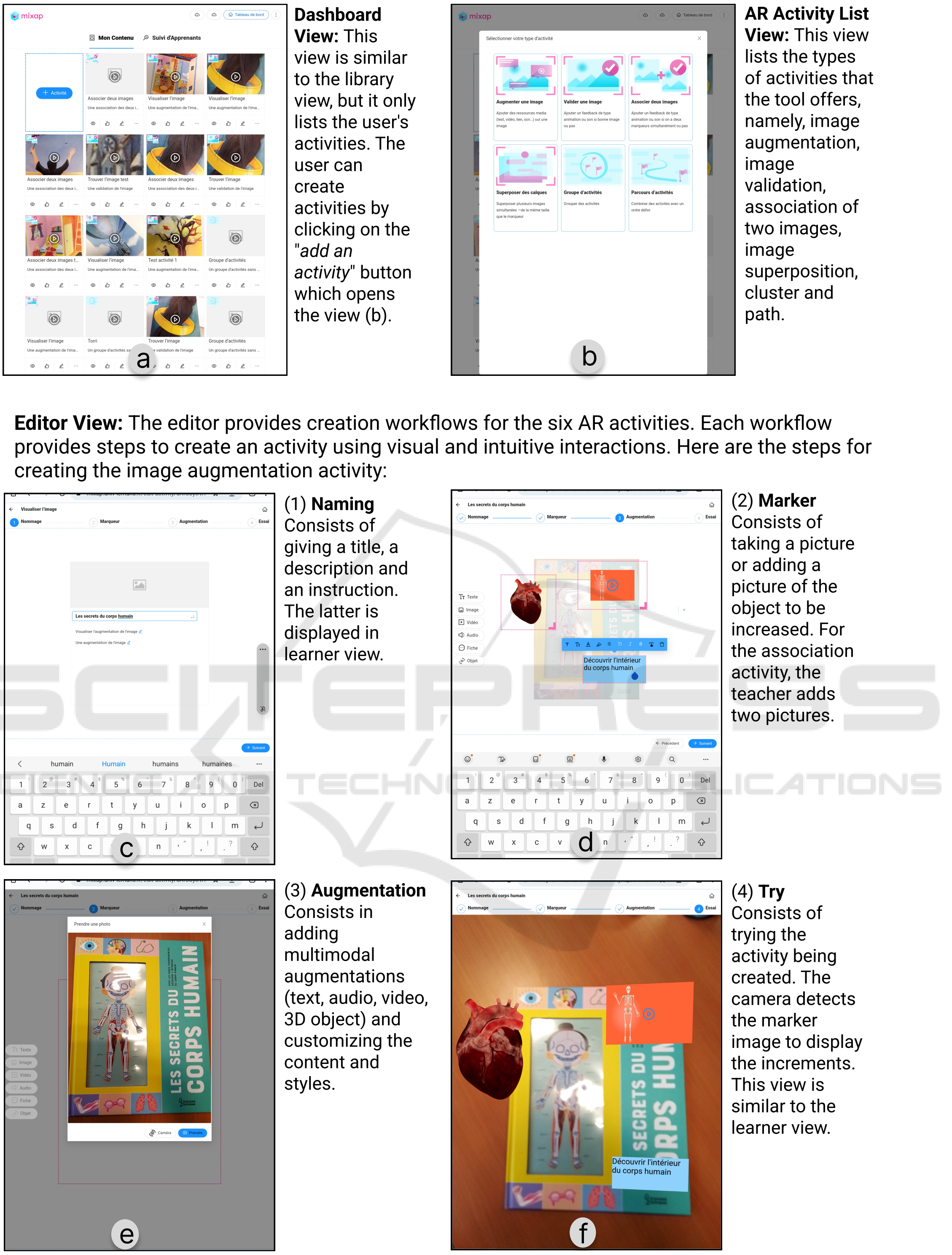

Figure 2: Main views of the user interface of MIXAP. (a) is the **dashboard** view which displays all the AR activities of the user. (b) is the list of **AR activities** that teachers can create. (c, d, e, f) are views of the **editor**. Each AR activity has a set of steps (workflow) to guide the user in creating the activity —steps are placed on top of the editor: (c) naming, (d) marker, (e) augmentation, and (f) try the activity. The marker is placed in the center of the editor. The palette of tools to add multimodal resources as augmentations to an activity (text, image, video, audio, modal, and 3D object) are on the left of the editor. Users add resources drag and drop them on the canvas. MIXAP allows users to customize all aspects of augmentations in terms of content and appearance (rotate 3D assets, change sizes and styles of assets).

end-users in creating the AR activities that we identified during the participatory design with teachers (i.e., augmentation, validation, association, superposition, cluster, and path). Each workflow has a specific set of incremental authoring steps.

DG2: Provide a Visual Authoring Approach to Reduce the Cognitive Burden of Creating Educational AR Content. A major challenge hindering the wider adoption of AR in education is, in part, related to the technical complexity of authoring AR activities. A visual authoring approach is more suitable for teachers because it leverages user familiarity with widely-used tools in education, such as Google docs and PowerPoint. Such an approach enables users to author content using user-friendly interactions, such as drag-and-drop and configuration menus.

DG3: Support Users in Personalizing the Look and Feel of an AR Activity Content. Another major limitation in existing AR applications for education is that teachers can not customize the content. Because personalization is crucial for learning (Mayer, 2005), MIXAP enables users to personalize all aspects of an AR activity. In terms of content, users can create or import different media resources. For example, users can import files from their devices, such as images, 3D models, audio, and videos. They can take photos and record audios and videos. They can also fine-tune the styles, such as size, color, shape, and fonts of the resources of an AR activity.

4.2 User Interface

The user interface of MIXAP (Figure 2) consists of four main views: a library, dashboard, editor, and player.

Library View. Lists all the AR activities that all users created and shared publicly. Users can create an AR activity by clicking on the button "add activity" and then selecting the type of activity they want to create (**DG1**, Figure 2-b).

Dashboard View. This view is similar to the library view, however, it only lists the AR activities of the user (Figure 2-a). Similarly, the user can also create their AR activities by clicking on the button "add activity".

Editor View. The editor provides specific authoring workflows for each of the five AR activities (**DG1**). Each authoring workflow provides a few steps to create an AR activity using visual and user-friendly interactions (**DG2**). For example, one step is naming an activity by providing a title and a description (Figure 2-c). Another step is adding a marker image of the activity, which consists of either uploading an image or taking a photo of an object (Figure 2-d). In the case of an association activity, we prompt the user to add two marker images. Another step is adding multimodal augmentations on the top of a marker (Figure 2-e). The augmentations are the media resources that the user can add to an AR activity, namely, text, audio, video, modal, and 3d objects. Another step enables trying the activity in AR view (Figure 2-f). When the user launches an activity in AR view, we recognize the marker object through the user's device camera, and we project the digital (virtual) augmentations on the tangible (real) marker object. In addition, users can customize the size, color, shape, and fonts of the resources of an AR activity. Finally, users create clusters of paths from existing activities by selecting two or more activities and grouping them with or without order.

Player. Launches an activity in AR View (similar to Figure 2-f but in full screen). The player opens the user's device camera and loads the marker as well as all the augmentations of the activity. The player, then, (i) scans the scene to detect the maker of the activity and (ii) projects the augmentations on the scene.

4.3 User Interaction and Customization Modalities

All the resources in MIXAP have built-in smart-default parameters (**DG1**). In addition, MIXAP provides user-friendly modalities so that users can customize the look and feel of an AR activity (**DG2**, **DG3**). The users can upload resources from their local devices or create and edit resources using built-in media-resources tools (images, audios, videos, and 3D models). In terms of interaction, the users can rotate resources in 3D three-dimensional space. They, scale up or down the size of the resources. And they can drag resources to arrange them in unique ways on the canvas. Further, MIXAP offers options to change text size, font, color, and background.

4.4 Implementation

We implemented the user interface of MIXAP using Typescript[5] and Reactjs[6]. We use MindARjs[7] for image tracking. We use RxDB[8] to store the resources of the AR activities in the user's device. We use Supabase[9] to enable sharing AR activities between different devices.

[5]https://www.typescriptlang.org/
[6]https://reactjs.org/
[7]https://github.com/hiukim/mind-ar-js
[8]https://rxdb.info/
[9]https://supabase.com/

5 TEACHER STUDY

We conducted a user study with 39 teachers to examine whether they can easily use MIXAP to create high-quality educational activities in augmented reality. We used mixed methods analysis and followed an overall factorial design with the following factors and levels:

- **Group** of participants: Pilot Teachers (P) & non-pilot teachers (NP).
- **Category** of evaluation: Usability, Learnability, Utility, Emotion, Cognitive Load, and
- **Demographics**: Participants' Age and Discipline (STEM, Non-STEM, Computer Science Other)

5.1 Hypothesis

We examine seven main hypotheses:

- *Usability:*
  - **H1:** The usability of MIXAP will be higher than the median value (Likert = 3).
  - **H2:** The ease of use of MIXAP will be higher than the median value (Likert = 3).
- *Utility:*
  - **H3:** The utility of MIXAP in creating AR activities for teachers will be higher than the median value (Likert = 3).
- *Acceptability:*
  - **H4:** The emotional experience of MIXAP will be higher than the median (Likert = 3).
  - **H5:** The cognitive load emanating from using MIXAP will be lower than the median value (Likert = 3).
- *Transfer:*
  - **H6:** There will be no differences between the partner and non-partner teachers in terms of usability, ease of use, emotional experience, and cognitive load.
  - **H7:** There will be no differences between participants' age and discipline in usability, learnability, utility, emotional experience, and cognitive load.

5.2 Participants

The participants were 39 (N=39) teachers [Age: 26-30 = 1, 31-35 = 1, 36-40 = 3, 41-45 = 15, 46-50 = 12, $>$ 50 = 7; Discipline: STEM = 22, Non-STEM = 7, Computer Science = 1, Other = 9]. We divided teachers into two groups: the pilot group (P) with 12 teachers and the non-pilot group (NP) with 27 teachers. The pilot teachers were familiar with the MIXAP. We recruited the non-pilot teachers during a local workshop, and they were not familiar with the MIXAP prior to the study. All teachers voluntarily participated in the study without compensation and signed a consent for using and analyzing their data for research.

5.3 Educational AR Activities

We prepared four different AR activities[10] for teachers to create using MIXAP (see the example, Figure 3). One activity involved augmenting a book with multimodal resources. Another activity involved associating images. The third activity involved validating an image. And, the final activity involved creating a learning cluster or a path from the first three activities.

5.4 Apparatus

We used three apparatuses: MIXAP, paper sheets of the four activities, and different props. We installed MIXAP on 12 tablets (Samsung SM-X200, SM-T500, 11 inches, 2G RAM, 32G Hard Drive). We printed out the steps to create the four activities on paper. We selected a set of props: cards from the Dixie game, books, and posters, which we provided the participants with to create resources for AR activities, such as markers, images, and videos.

5.5 Procedure

The procedure consists of three steps. We first introduced the study and the four AR activities to the teachers. Then, we asked the teachers to create the four activities (see example in Figure 3). And, finally, we asked the teachers to answer a questionnaire[11].

5.6 Data Collection and Analysis

We collected 39 responses to the questionnaire from the participants; 12 responses from the partner group and 27 responses from the non-partner group. For the usability (**H1-2**), we used the 10 SUS questions [Q1-10] to assess the total SUS score as well as ease of use [Q1,2,3,5,6,7,8,9] and learnability [Q4,10] (Brooke

[10] https://drive.google.com/file/d/11I4vJTB-GgW1Xtmb-sAL0gWPiWVyksUL/view
[11] https://forms.gle/GP1NCaEpAtihzqbY6

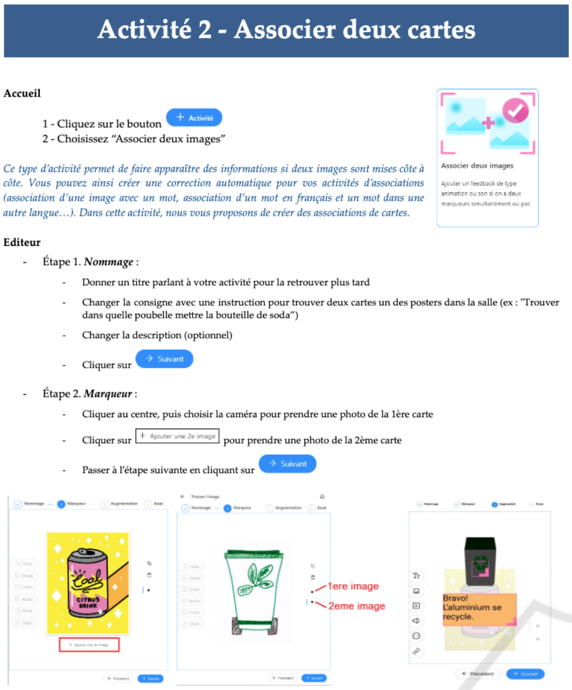

Figure 3: An example of the AR activity that the teachers created to associate two cards. We introduced this activity to the teachers as: *"This type of activity allows you to visualize augmentations if two images are visible in the scene at the same time (e.g., side by side). You can thus create an automatic correction for your association activities (e.g., an association of a picture with a word, an association of a word in French with a word in another language, etc.)"*

et al., 1996; Lewis and Sauro, 2009). We formulated the question [Q15] along with an open-ended question [Q16] to assess the utility (**H3**). For the acceptability (**H4-5**), we formulated [Q12,14] to assess emotional experience and [Q11,13] to assess the cognitive load. For transfer (**H6-7**), we analyzed the variance of responses with respect to the factors **Group** and **Demographics** (Disciple and Age). Questions were on a 5-point Likert scale, except for [Q16].

6 RESULTS

We report and interpret our results using both p-values for statistical significance and Effect Sizes for quantifying the main difference (small: $<$ .3, moderate: .3 - .5, large: $>$ .5), with a 95% confidence interval (Robertson and Kaptein, 2016). We used a nonparametric Wilcoxon test for One-sample tests of participants' Likert responses. We used nonparametric factorial analyses of the variance of participants' Likert responses using the Aligned Rank Transform (ART) (Wobbrock et al., 2011).

6.1 Overview

Overall, almost all participants completed the activities at about the same time. Figure 6 summarizes the responses to the questionnaire, highlighting participants' positive reactions to the tool.

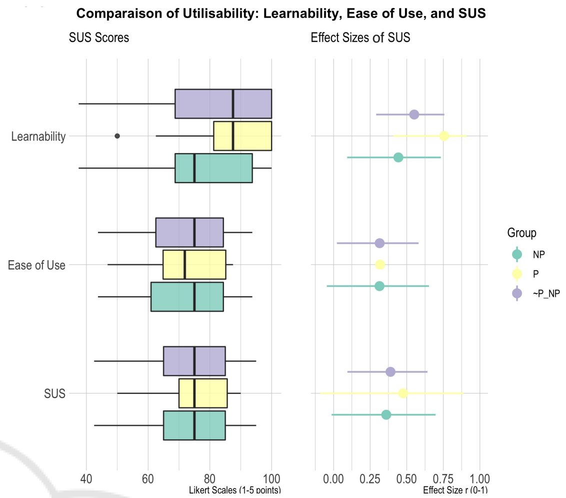

Figure 4: Utilisability: On the left is a boxplot with median, min-max, and outliers; right is effect sizes with 95% confidence intervals.

6.2 Usability

We followed (Brooke et al., 1996; Lewis and Sauro, 2009) and calculated scores (on a scale of 0 to 100) for SUS [Q1-10], ease of use [Q1,2,3,5,6,7,8,9], and learnability [Q4,10].

As illustrated in Figure 4 (legend P_NP), the mean SUS score for all participants was 73.91, which is above the standard SUS average of 68 points and is classified as "good." A one-sample Wilcoxon test showed that teachers' scores were significantly higher than 68 points, with a medium effect size for total SUS (p = .015, r = .389), a medium effect size for ease of use in hand (p = .049, r = .315), and a large effect size for learnability (p = .009, r = .756).

Analysis by Group showed that the difference was not significant for SUS, with a medium effect size for the pilot (P) group (p = 0.107, r = 0.476) and a trend toward significance for the non-pilot (NP) group (p = 0.062, r = 0.360). The difference in ease of use was not significant with a mean effect size for both groups: P (p = 0.288, r = 0.318) and NP (p = 0.104, r = 0.314). In contrast, the difference between the groups for learnability was significant, with a large effect size for the P group (p = 0.022, r = 0.756) and a medium effect size for the NP group (p = 0.022, r = 0.443).

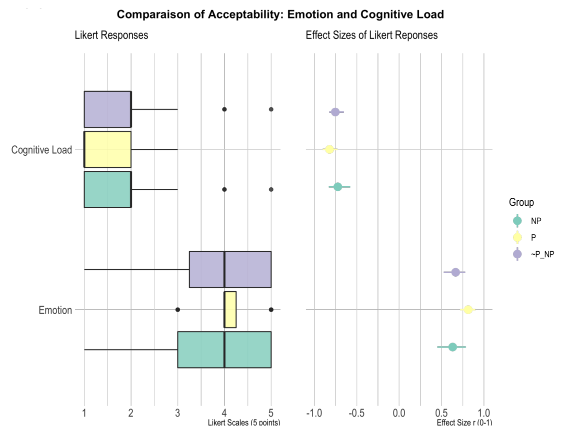

Figure 5: Acceptability: On the left is a boxplot with median, min-max, and outliers; on the right are the effect sizes with the 95% confidence interval.

6.3 Utility

We performed a one-sample Wilcoxon test to assess whether the utility [Q14] is greater than the median value of 3. For the data combined from both groups, the utility was not significant with a small effect size ($p = 0.25$, $r = 0.186$). Analysis by Group showed that the difference in utility was significant for the pilot group (P) with a large effect size ($p = 0.043$, $r = 0.598$) and not significant for the non-pilot group (NP) ($p = 0.684$, $r = -0.084$). Some teachers elaborated on new features they would like to have in the tool, such as, for example, an AR activity capable of recognizing multiple markers automatically and displaying augmentations; adding videos to sheets and interactive menus; or exploring details in large image markers. Others have elaborated on technical issues such as accuracy, stability, or responsiveness of the augmentations. These elements can have an impact on the participants' perceived utility.

6.4 Acceptability

As illustrated in Figure 5, a one-sample Wilcoxon test showed that Likert responses were significantly different from the median with a large effect size for emotional experience [Q12,14] ($p < 0.001$, $r = 0.666$) and a large (negative) effect size for cognitive load [Q11,13] ($p < 0.001$, $r = -0.827$). Analysis by Group showed that the difference in emotional experience was significant with a large effect size for the pilot (P) ($p < 0.0001$, $r = 0.814$) and non-pilot (NP) groups ($p < 0.0001$, $r = 0.631$). Similarly, the cognitive load was significantly lower than the median value of 3 with a large effect size for the pilot (N) ($p < 0.0001$, $r = -0.898$) and non-pilot (NP) groups ($p < 0.0001$, $r = -0.825$).

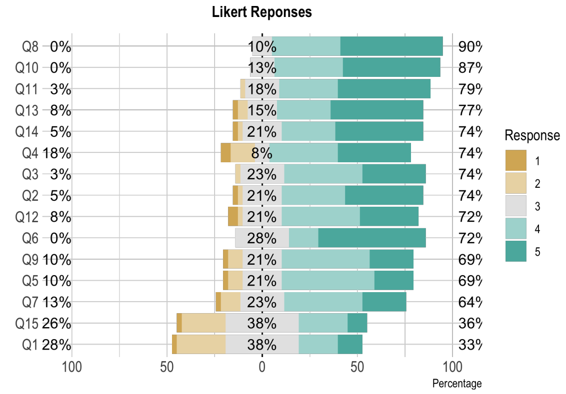

Figure 6: A summary of Likert responses of all the participants.

6.5 Transfer

We conducted a non-parametric factorial analysis of the variance of Likert responses using the ART procedure Wobbrock et al. (2011). The analysis showed that there was no significant difference in responses between the levels of the Category: usability, learnability, utility, emotional experience, and cognitive load (p = n.s) with respect to the participants' Group ($p = .180$), Age ($p = .889$), and Discipline ($p = .520$).

7 DISCUSSION

We first summarize our results on the main effects of the authoring approach. We then discuss our results concerning the design and use of AR authoring tools in classrooms.

7.1 Impact of AR Authoring Approach

The analysis of SUS scores validates **H1**. The ease of use and the learnability were significant, validating **H2**. Thus, the usability of MIXAP is quite reasonable and comparable between pilot and non-pilot teachers. Both groups were able to create all four activities at about the same time. The acceptability of the tool is important, participants showed positive reactions (also observed during the experiments). The emotional experience was significantly strong, validating **H3**. Since we propose authoring workflows with incremental steps and intuitive interactions, the cognitive load was significantly low, validating **H4**. Regarding the transfer, the factorial analysis of variance showed no significant difference between the pilot and non-pilot teachers, validating **H6** and **H7**, which shows that this approach may be beneficial for a wider audience of teachers. In contrast, the perceived utility was significantly high only for the pilot group, partially validating **H5**. In our next iterations, we will further examine the utility aspects, particularly the questions of (1) the appropriation and (2) the longitudinal impact of our approach. We believe teachers will appropriate better the tool as we plan to provide them with video tutorials and resources to support them in creating educational AR content.

7.2 Participatory Design of AR Authoring Tools

An authoring tool aims at providing a wide range of functionalities to support a wider audience of users with different technological familiarities —while allowing them to (1) create artifacts without programming and (2) appropriate the tool easily (Lieberman et al., 2006; Ez-Zaouia et al., 2022). In this sense, a participatory design with teachers allowed us to identify pedagogical needs that we were able to transpose into small building blocks to enable users in creating AR activities using user-friendly interactions. The transfer analysis showed that this approach is viable. Even though the tool was only designed based on 19 pilot teachers, the evaluation with 27 non-pilot teachers showed that there was no difference between the pilot and non-pilot teachers in terms of ease of use, learnability, usability, emotional experience, and cognitive load. Similarly, there were no differences in the age and discipline of the participants.

That said, the participatory approach also poses some challenges. Combining various users' needs without making an authoring tool too complex can be a difficult task. This constraint requires making design choices such as selecting, validating, and even rejecting some needs (e.g., needs that are specific to a context of use or that do not meet common needs or risk making the tool more complex for the majority of teachers). The constraint is even more severe when the needs have been identified in the form of complete pedagogical scenarios or activities. Some teachers may have difficulty identifying their needs in the tool —as they had expressed them during the participatory design, which could negatively impact their perception of the tool's utility. Our analysis of utility supports this point. Some teachers did not identify their needs in the tool in an explicit way. An authoring tool requires an appropriation effort from the end-users to adapt its functionalities to meet unique needs.

7.3 Integration of AR Authoring Tools in the Classroom

Beyond the technical aspects, creating AR activities *by end-users* poses a cognitive difficulty. This difficulty stems from the fact that end-users have little familiarity with AR content creation. This type of production has not yet become a convenient task compared to, for example, multimedia productions using Google Docs or Powerpoints. Teachers may find it difficult to develop instructional activities in AR or to adapt their traditional activities to immersive AR learning. In addition, teachers may not have training in multisensory and experiential learning. Even if an authoring tool removes the technical barrier, creating this type of content requires skills, such as principles of multimedia, coherence, multimodality, and personalization (Yang et al., 2020).

Potentially, a library of educational activities where teachers can find, create and share AR activities can help address the above challenges. Our approach goes in this direction and aims at proposing small building blocks that teachers can use and combine in an easy manner to create more advanced activities or even new activities that they have not thought of. For example, in the context of learning to associate concepts in a collaborative mode, a teacher was able to create an original activity where learners combine AR with tangible artifacts: books, post-its, images, and cards to complete. Learners in pairs visualize multimodal augmentations of a book, identify associations related to the augmentations, and paste post-its and images on the card. The teacher was able to appropriate the tool while using everyday artifacts in the classroom and was able to create an immersive environment for learning associations of concepts. Sharing these types of activities among teachers can help in the successful integration of AR authoring tools in classrooms.

Another important aspect that can improve the appropriation of AR authoring tools by teachers is learning analytics (e.g., dashboards). We believe providing teachers with feedback about learners' experiences, such as emotional state (Ez-Zaouia et al., 2020; Ez-zaouia and Lavoué, 2017), progression and engagement (Ez-zaouia. et al., 2020) can support them in fine-tuning AR activities for their classrooms best.

8 CONCLUSION

AR offers an interesting environment to facilitate multisensorial, immersive, and engaging learning. However, creating AR activities is far from an easy task. We examined an "authoring tool" approach to making AR less technical and more accessible to non-expert teachers. We presented our process for designing MIXAP in an iterative, participatory design approach with pilot teachers. We evaluated our approach with 39 teachers. The results are very encouraging to further explore this approach, especially the analysis of usage, appropriation, and activities created by teachers in their classrooms. We hope that our work provides researchers and designers with ideas for the design and use of AR-authoring tools to democratize AR for education.

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