Augmented Reality Educational Applications: Let's Find out What Students and Teachers Need!

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ABSTRACT. While the number of augmented reality educational applications (AREAs) has increased in the recent decade, the actual uptake of AREAs in real-life contexts has been low. Our systematic review showed that little attention was paid to the teacher's perspective of AREAs. A handful of studies with teachers showed that the lack of equipment and inadequate support hindered the AREA uptake. However, these studies had a severe limitation: many of the participating teachers did not have any interaction experience with AR. Hence, we conducted a survey targeting teachers with actual experience of deploying AR in teaching. Results showed that teachers held positive views about the educational values of AR and wanted to use it more for teaching. To meet this goal, certain factors need to be improved: quality devices, teacher training, user experience of AREAs, and coverage of AR content. We derived teacher requirements to address the identified needs.

KEYWORDS: augmented reality / education / teacher / survey / user experience / requirement

APLICACIONES EDUCATIVAS DE REALIDAD AUMENTADA: DESCUBRAMOS LO QUE NECESITAN ESTUDIANTES Y PROFESORES

RESUMEN. Si bien el número de aplicaciones educativas de realidad aumentada (AERA) ha crecido en la última década, la aceptación real de AERA en contextos de la vida real ha sido baja. Nuestra revisión sistemática expuso que se prestó poca atención a la perspectiva docente de las AERA. Una serie de estudios con docentes mostró que la falta de equipo y el apoyo inadecuado fueron los principales factores que obstaculizaron la aceptación de AERA. Pero, estos estudios tienen una serie de limitaciones, como, por ejemplo, que muchos de los docentes participantes no tienen ninguna experiencia de interacción con la realidad aumentada (RA). Por lo tanto, ser realizó una encuesta dirigida a docentes con experiencia real de despliegue de RA en la enseñanza. Los resultados mostraron que los profesores tenían opiniones positivas sobre los valores educativos de la RA y querían utilizarla más para la enseñanza. Para cumplir con este objetivo, es necesario mejorar ciertos factores: dispositivos de calidad, formación del profesorado, experiencia de usuario de las AERA y cobertura de los contenidos de RA. Finalmente, identificamos los requisitos de los docentes para abordar las necesidades identificadas.

PALABRAS CLAVE: realidad aumentada / educación / profesor / encuesta / experiencia de usuario / requisito

1. INTRODUCTION

Augmented Reality (AR) has three defining characteristics: it combines real and virtual content; it is interactive in real-time; it is registered in 3D (Azuma, 1997). These characteristics render AR technology particularly attractive and valuable for educational uses. For instance, AR can visualize concepts in 3D that are difficult to be explained in 2D (e.g., molecular structures), and it can also enrich the learning experience with an immersive mixed reality setting (e.g., roaming animals in the wilderness). In the recent decade, the number of AR educational applications (AREAs) has visibly increased, thanks to advances in mobile technology (Ibáñez *et al*., 2018), making it easier to deploy AREAs in various contexts - within as well as outside school premises (e.g., Hsiao *et al*., 2016; Fujitsu & Intel, 2021).

Nevertheless, only a few studies exploring teachers' views exclusively on deploying AREAs can be located (Tzima *et al*., 2019; Alkhattabi, 2017; Putiorn *et al*., 2018; Alalwan *et al*., 2020). All four studies had two common concerns: the teacher participants involved had no, or little experience in using AR applications, and the scale of the individual study was limited to a particular region of a single country that is Greece (Tzima *et al*., 2019), Saudi Arabia (Alkhattabi, 2017; Putiorn *et al*., 2018; Alalwan *et al*., 2020), and Thailand (Putiorn *et al*., 2018). Specifically, in (Tzima *et al*., 2019) and (Alkhattabi, 2017) none of the 20 and 200 participants, respectively, have ever used AREAs in teaching. In (Tzima *et al*., 2019), given that only 50% of the participants have heard about AR apps and 15% used one, the validity of their responses to questions on the challenges of implementing AREAs is questionable. In (Alkhattabi, 2017) a set of generic Likert-scale questions were posed to participants, such as whether they would accept using AR applications in an e-learning environment without specifying the context of use (e.g., subject). The soundness of their findings was also debatable. In (Putiorn *et al*., 2018), 38 pre-service teachers of different training (e.g., languages) were asked to evaluate an AREA on astronomy for secondary school students; the mismatch between the background knowledge of the teachers and the AR content could have confounded the outcomes. Using semi-structured interviews and systematic qualitative data analysis, (Alalwan *et al*., 2020) was methodologically sounder than (Tzima *et al*., 2019; Alkhattabi, 2017; Putiorn *et al*., 2018). However, its narrow focus on science teachers only (29 from different schools) is a limitation.

Given the observations identified in the above reviews, we were motivated to design and conduct a survey to analyse the usage of AREAs from the teacher's perspective. The survey was designed with the following characteristics to address the aforementioned drawbacks: (a) Only teachers with actual AR experience in teaching were invited to take part; (b) Teachers with various disciplines were eligible to take part as long as they met the criterion (a); (c) The geographical spread was expanded well beyond one country; (d) both close- and open-ended questions were included in the survey.

Overall, the main research goal of our survey is to understand teachers' perceptions and UX with AREAs in a range of educational contexts. Our main contribution is identifying

teachers' experience-based needs and requirements for enhancing AREAs and thus their uptake, thereby unleashing the potential of this emerging technology. Note that a high-level summary of our survey's findings is presented as a poster in a conference (Heintz *et al*., 2021), and the details, which are not included in the poster, are reported in this paper.

2. BACKGROUND

Several systematic literature reviews (SLRs) on AREAs have been conducted (e.g., Ibáñez *et al*., 2018; Garzón *et al*., 2020; Pellas *et al*., 2019) since 2000 when the work on AREA emerged. Overall, three consistent findings on the educational effectiveness of AREAs can be identified from these SLRs: (i) the use of AR can result in learning gain to a moderate extent; (ii) increased motivation is the salient mediating variable contributing to the positive learning effect of AR; (iii) STEM is the most common domain for AREAs.

However, most of these reviews address primarily their educational impacts rather than their usability and user experience (UX), which are critical qualities for determining the acceptance and adoption of AR as an educational tool. Usability is defined as "The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use" (ISO 9241-210, 2019). Going beyond usability, UX emphasizes on user effect and sensation and the meaningfulness of interaction with technology (Law *et al*., 2009). We were then motivated to perform an SLR on AREAs designed for K-12 education by following the related guidelines and principles (Moher *et al*., 2009), focusing on the usability and UX aspects of AREAs.

While the complete results on the interaction quality of AREAs from the student perspective are documented in (Law *et al*., 2021), the results from the teacher perspective are yet to be reported. The related data on teachers are so meager that there is little to present. There are two teacher-specific aspects. First, concerning the perceived quality of the AREAs, 36 out of the 48 papers did not take any measure with teachers. The other papers had the following observations: Teachers can engage students better with AR (n=3) (e.g., Squire, 2007); Teachers can present better learning content in AR (n=5) (e.g., Wojciechowski & Cellary, 2013); Teachers have a positive experience with the AR app (n=4) (e.g., Joo-Nagata, 2017), and the AR app supports teaching tasks (n=1) (Lu & Liu, 2015). Second, concerning AREA's effectiveness on teaching, 46 out of the 49 reviewed in our SLR did not specify it at all. The two papers addressing this aspect reported the effects of monitoring individual students' progress (Hsu, 2019) and having a variety of tools for different learning situations (Alakärppä *et al*., 2017). It is surprising to note the limited attention ascribed to teachers' perception of AREA and the impact of these educational tools on them. This observation stimulated us to conduct the teacher survey, of which the process and results are delineated in the following.

3. METHOD

Survey structure. Our empirical study aimed to know the current AR usage patterns of teachers and elicit their user requirements for AREAs. We created a homegrown survey to address the shortcomings we identified in the current work (see Introduction). The survey design was inspired by related work and similar surveys (Sáez-López *et al.*, 2020; Ghavifekr *et al.*, 2016). It was also based on our expertise in AR and HCI. Its details are given below.

Introduction and Section 1: Demographics. Having used AR for teaching is a prerequisite to participating in the survey. This screening criterion is outlined on the start page to ensure the participating teachers are aware of this fact. The introduction page asks for the teachers' consent to have their anonymous responses being used for research. The six demographic questions are the type of school they teach at, gender, age, country of residence, main teaching subject, and years of teaching experience.

Section 2: General AR Usage for Teaching. A statement on AR with pictorial examples is first presented. This is to ensure that participants have a similar understanding of AR. Then they are asked to describe their reason for using AREAs, frequency and duration of usage, conditions of usage (i.e., class size, hardware), confidence in using them, and how the usage can be increased.

Section 3: Most Recent AR Usage for Teaching. Participants are asked to name the AR app that they have recently used and describe the app usage, and the app itself comment on the perceived usefulness and user experience of students and teachers with the app, the domain and topic of the app covered, and the age group of the students using it.

Survey distribution. The research work underpinning the survey was run under the auspices of the project ARETE (https://www.areteproject.eu/). The survey was implemented with the open-source survey tool LimeSurvey. Initially developed in English, the survey was translated into Dutch, German, Greek, Italian, and Spanish. The survey was publicized in the news section of a project's website and social media channels. The project partners distributed the survey to their networks of teacher and school contacts. Nonetheless, the low response rate was low; we re-advertised our call for participation through these channels several times.

4. RESULTS AND DISCUSSION

Like most user-based studies, our survey was severely affected by the pandemic. The number of responses was relatively low, despite repeated attempts to promote it. Altogether there were 1746 visits to the survey website, but only 65 responses were complete. While we cannot identify actual reasons for the high incompletion rate, we speculate that many of the visitors considered themselves ineligible when they read the following statement at the beginning of the survey: "*This survey targets educators who have used AR in their teaching. If you have*

never used AR before for educational purposes, your input will not be required." If our speculation were true, it would imply that only 3,7% of the teachers whom we sampled had experience in deploying AR for educational purposes. One may argue that this could be an artifact of our sampling strategy. Nonetheless, the low percentage is not surprising because the actual usage of AREAs in everyday teaching is still a nascent phenomenon.

4.1 Demographic Data

The 65 complete responses came from 17 countries and two unspecified ones, with seven countries having only one respondent (Figure 1). This unusual distribution might be related to the low adoption of AREA in real-life teaching. In the sample, 35 teachers were in secondary schools, 27 in primary schools, one in an infant school, and two in further education colleges.

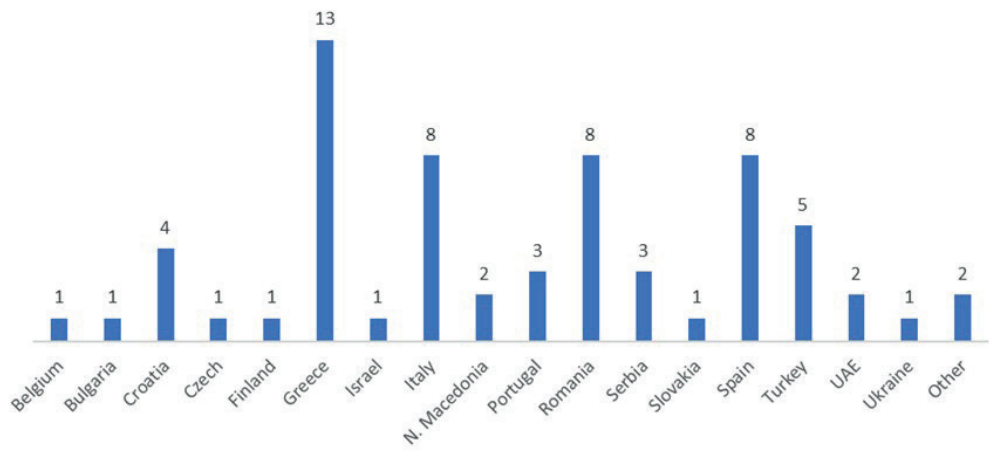

Figure 1. Distribution of the country of residence of the teacher respondents
Own elaboration

The gender distribution with 44 females and 21 males is higher than a typical ratio of 3:1 in the teaching profession. In terms of age-group, the distribution is as follows: 31-40 (n=20), 41-50 (n=26), 51-60 (n=16), >60 (n=3). Regard to teaching subjects, most of respondents reported teaching mostly STEM subjects, and most of the primary school teachers said to teach more than one main subject. The average teaching experience in years was 17.2 (SD =7.02, Range= 4-45).

4.2 General AR Usage for Teaching

Rationale. In response to why they had used AR as part of their teaching (Note: they could choose more than one reason), the majority of the respondents (n=52) chose the option *out*

of curiosity. The two other frequent options were *following the recommendation of colleagues* (n=12) and *being drawn attention to it by students* (n=8). A handful chose the option *following the guidelines of the ministry of education* (n=3) *or school board* (n=3). The rest chose a different reason (n=8). Some elaborated their rationales such as "*I wanted to try something new*" (T271), "*I believe it may have the potential to stimulate learning*" (T254, translated from Italian), "*To teach my students to create augmented reality applications.*" (T366).

Usage. Teachers were asked about their years of AR experience (Table 1). Concerning the usage frequency, ten teachers used AREAs for teaching weekly or fortnightly (i.e., active), 26 teachers between monthly and every three months (i.e., moderately active); 22 teachers used only every six months or less (i.e., less active).

Table 1
Distribution of teachers' AR experience

Duration	< 1 year	1-2 years	3-4 years	> 4 years	Not specified
Number	15	20	14	7	9

Own elaboration

As a follow-up question, the teachers were asked whether they wanted to use more AR for teaching; 57 indicated "yes", 4 selected "no" and 4 teachers were unsure. Example reasons why teachers were unsure about using AR more often for teaching were because "*It is not easy for my students to keep attention alive*" (T492), "*...not sure if it is a pedagogical advance*" (T305), and "*...there are a lot of AR apps out there that are not so good*" (T1290).

Needs. Several significant needs for increasing the usage were identified, including (a) Financial constraints and lack of training. T1444 remarked that "*in my school, there are no tablets for students, they use their mobile phones. Moreover, my colleagues are not keen on using ICT and do not encourage students. I am the only one that pushes for this" (T1486); "Regular training on what is new would also be very useful."; (b) Restrictions (e.g., time, legal); T1476 commented that "actually more than the lack of apps, there is a lack of readymade materials, which would considerably reduce time spent in creating AR activities suitable to foreign language teaching."; (c) Limited availability of quality materials;* T1292 remarked that "*There has only been two really good apps for AR and now are no longer supported so I find the current AR apps on the market quite limited to exchange learning.*"

Experience in the classroom. In the sample, most teachers used smartphones for teaching with AR (n=51), followed by tablets (n=33), desktop or laptops (n=23), and in very few cases, game consoles (n=3) and VR glasses (n=1). In four cases, teachers mentioned they needed to bring their own devices to the classroom to teach with AR, and six teachers had to ask their students to bring their own smartphones or tablets to learn with AR. The average number of students per class in this sample was 23 (SD= 5.64, range= 12 - 40). Most teachers rated their

confidence in using AR for teaching as high (n = 24) or very high (n = 7), with only a few teachers still struggling (with their confidence being very low, n = 3; low, n = 7).

In responding to the question of how AR apps could be changed to further improve their confidence in using AR for teaching, teachers provided various responses, which can be categorized into four aspects: Access (n = 6), Training (n = 11), Content (n = 23) and Technical.

Enhancement (n = 14). Responses about Access include "*By creating repositories with easy access*" (T247); "*Applications that can be installed on PC Desktop for use in the classroom because not all students have modern personal devices to work with them*" (T337). In this sample, most teachers explained that they need more suitable contents to use AR for teaching because the contents often do not align well with the curricula or with the cognitive level of their students. "*Including pre-made activities and templates*" (T299); "*By knowing exactly what they include, how they work, how they relate to the curriculum and in which classes it is best to apply*" (T1387). Another topic frequently mentioned by teachers was the need for applications to be fast, reliable, and compatible with more than one operating system. For instance, "*Devices that can handle AR as the students get frustrated or give up waiting for the graphics to load, being able to manipulate objects on a small screen, etc. The answer would be to have an app that would work with tablet devices*." (T1292). With less emphasis, teachers also claimed to need more training and guidance to be more confident while using AR apps for teaching and better access to equipment and free AR apps.

4.3 More Recent AR Usage for Teaching

Software. In response to which AR applications teachers had used most recently, various names were mentioned, with the most popular ones being Quiver (n=11), GeoGebra (n=7), and HP Reveal (n=5). The other applications mentioned twice are: *Architect by Twinkle, Aurasma, Curioscope, iSolarSystemAR, Merge Cube, Metaverse, SchoolAR*. The most common domains covered by the AR apps were Mathematics (n=19), Biology (n=18), Physics (n=16), and Informatics (n = 16); some less common ones were PBIS = positive behavior intervention and support; n =4), history (n=4) and physical education (n=3). In total, 53 out of the 65 teachers said to have used an AR application to teach at least once in the last year.

Experience. The respondents reported that they had used the AR apps with students of different age groups, ranging from 11-13 years old (n=28, 43%), followed by two age groups: 8-10 years old (n=13, 20%) and 14-16 years old (n=14, 21.5%). A small number of classes had students between 5-7 years old (n=3, 4.6%) or students older than 17 years old (n=6, 9.2%). On average, students spent 43 minutes using the AR apps the last time they had an opportunity to do so. Students used the AR software mostly in the classroom (n=53, 82%), but some used it somewhere else in their schools (n=7, 11%), at home (n=11, 17%), in a museum (n=5, 8%), outdoors (n=5, 8%) or elsewhere (n=2, 3%). About the usage method, the more

common ones are students working in groups while sharing a device (n = 35) and the teacher presenting the AR app in front of the class (n = 35). Less common methods are students working in groups with each having a device (n=13) and students working individually with a device (n=9). These results confirmed the observation about the inadequate infrastructural support provided by schools.

Most teachers perceived the AR software as fairly useful (n=20), very useful (n=29), or extremely useful (n=13) to support students to learn a topic. Examples of positive comments are:

- "*Students were active, moving around, searching for answers. They were highly motivated to finish the hunt. All the students worked on math problems trying to solve them in order to proceed. Only 1-2% students did not solve the problems. Comparing to 20-25% when they didn't use the app it is a great success*" (T77);
- "*this is motivating and a very practical educational way of learning*" (T234);
- "*It is a learning experience that is hard to replicate and it is easy to resource*" (T1290);
- "*Through the use of AR, I was able to visualize knowledge. The children learned through playful learning, which piqued their interest, made them look forward to the next application and be happy. In addition, they showed that they better understand and assimilate the concepts of the lesson.*" (T1444).

Two teachers rated the AR software as "slightly" and one as "not at all usefu*l*". Examples of negative comments are:

- "*Beyond the initial surprise, then they lost interest as soon as they saw that it was to explain part of the functioning of the body*" (T211);
- "*A little difficult to use*" (T260);
- "*There is always the risk that students could be interested in other things*" (T492).

Moreover, teachers also considered that the overall student experience while using the app was positive (n=38, 58%) or very positive (n=24, 37%); only a few teachers were neutral on their response (n=3, 5%). When asked to elaborate on this answer, some responses of teachers were:

- *"They liked it very much. They learned several things that were not in the textbook. Many children bought similar books for their own home." (T240);*
- *"It was a pleasant and at the same time constructive teaching and learning experience" (T339);*
- *"Students had fun and the overall experience was positive" (T305);*
- *"Also weaker students were engaged and contributed learning about their town ... It was for them "strange" to actually see some important people who lived in our town" (T1476).*

Teachers also rated their own overall use experience as positive (n=40, 61%) and very positive (n=22, 34%) for the most part; with only a handful of teachers being neutral about their experience (n=3, 5%). Teachers selecting "neutral" explained that they were:

- *"...not familiar using AR during teaching and would like to learn more" (T348);*
- *"...not sure that it really contributes much" (T305).*

5. TEACHER REQUIREMENTS

Based on the above survey results, user (teacher) requirements have been derived and grouped into three types, namely, functional requirements (i.e., what the system should do), non-functional requirements (i.e., quality in use that the system should satisfy), and organisational and pedagogical requirements (i.e., enabling teachers to deploy AR as educational tool). In the following, the three lists of requirements are presented with each being illustrated by a quote from a teacher participant as an example.

Functional Requirements (FR)

- **FR1:** AR apps should support different styles of presentation (e.g. teacher to class, students in groups, or students individually).
  - "*I only have my own tablet to show groups of AR children on various topics*"
- **FR2:** AR apps should be available in different languages.
  - "*... have support in multiple languages*"
- **FR3:** AR apps should offer user-specific instructions and help options.
  - "*More instruction how to use, and learning scenarios for teaching*"
- **FR4:** AR apps should be flexible and allow customization.
  - "I would like to develop my own content and add it to the application"
- **FR5:** AR apps can work offline.
  - "*I expect an offline version but I think it's impossible*"

Non-Functional Requirements (NFR)

- **NFR1:** All functionalities in AR apps should be and stay free of charge.
  - "*The app would be improved if it became free for content creation*"
- **NFR2:** AR apps should be fast and always available.

  - "*Be faster and require less memory to run*"
- **NFR3:** AR apps should recover from errors immediately.
  - "*Devices that can handle AR as the students get frustrated or give up waiting for the graphics to load, being able to manipulate objects on a small screen, etc.*"
- **NFR4:** AR apps should be usable and learnable.
  - "*Create easy-to-use, intuitive tools; select item, overlay content, and run*"
- **NFR5:** AR apps should support teachers to develop AR-based learning content and design learning activities with AR.
  - "*To prepare a lesson plan using AR it takes me 2-3 weeks to find suitable apps and 2-3 weeks more to 'build' a lesson...*"
- **NFR6:** AR apps should offer up-to-date, clear and clean sequences and user interfaces.
  - "*More elements could be incorporated to enhance student engagement and apply exploratory approaches*"
- **NFR7:** AR applications should be portable and need to run in any major mobile or desktop operating system.
  - "*I would make some apps usable on all systems in the same way in order to guarantee their use on students' personal devices in the BYOD logic*"

Pedagogical and Organisational Requirements (POR)

- **POR1:** School management should care about providing the appropriate infrastructure and hardware/equipment, including the Internet and mobile devices to run AR apps (tablets, smartphones), and ease regulatory constraints.
  - "*I know AR is really good for teaching different subjects, but I do not have the hardware I need*"
- **POR2:** AR activities should be short enough to fit in a lesson (~45 minutes).
  - "*Lack of time in classroom programming to work with AR hardware available in primary school*"
- **POR3:** AR apps should be gathered, categorized, and published in highly accessible and searchable online repositories.
  - "*It would help a lot if all the applications were gathered somewhere with short instructions and per lesson*"

- **POR4:** A broader coverage of up-to-date and ready-to-use AR educational resources, which should be creative and have high educational utility.
  - "There could be more resources that would help teachers to save the time and give them idea to apply in the classroom"
- **POR5:** Projects should offer more training and support.
  - "I think there is a need for new educational seminars for improving AR skills, new workshops and webinars"
- **POR6:** Building a community of practice for teachers using AR educational tools to discuss the related pedagogical issues.
  - "Also a teachers blog or resource pages where teachers could share tips, ideas, worksheets, lesson plans with AR would be appreciated"

6. CONCLUDING REMARKS

Overall, we conclude that the teachers have had a positive experience of AR and have been motivated to deploy them to a great extent. The functional and non-functional requirements identified (Section 5) can be relevant factors for designers and developers to consider when creating AREAs. To address the pedagogical and organisational requirements, it is necessary to mobilize professional bodies. It is also important to negotiate with the policymakers to invest sufficient resources in requisite infrastructure and equipment.

Regarding the future development of AREA, one promising direction is holographic AR, which can create a strong immersive experience by generating 3D stereoscopic images with head-mounted devices (HMD) and supporting natural user interface interaction through gesture recognition. Nonetheless, an intriguing observation is that none of the teacher participants mentioned using holographic AR with HMD in the description about their most recent experience of using AR for teaching. There are several possible explanations for the observation: One is that the samples of the surveys are too small to cover a broad coverage of usage. Another one is that respondents may consider the use of HMD is more for virtual reality than AR applications. Yet another plausible reason is that HMD and holographic equipment such as Hololens or Google Glass is too expensive for regular schools to purchase. Presumably, many teachers have not had holographic interaction experience. It would be challenging for them to envision innovative uses of emerging AR technology for educational purposes. We plan to organise workshops where teachers will be given opportunities to have first-hand holographic AR experience and explore its potential educational usage for our future work. It is critical that visionary use scenarios with the new AR tech are envisaged by the critical stakeholder – teachers – to ensure the real-life relevance of the scenarios and their actual implementation and uptake.

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