IEEE Access
Multidisciplinary ⋮ Rapid Review ⋮ Open Access Journal

Received November 28, 2018, accepted January 8, 2019, date of publication January 21, 2019, date of current version February 14, 2019.

Digital Object Identifier 10.1109/ACCESS.2019.2893971

Using a Google Glass-Based Classroom Feedback System to Improve Students to Teacher Communication

TELMO ZARRAONANDIA, PALOMA DÍAZ, ÁLVARO MONTERO, IGNACIO AEDO, AND TERESA ONORATI

DEI Lab–Computer Science Department, Universidad Carlos III de Madrid, 28911 Leganés, Spain

Corresponding author: Telmo Zarraonandia (tzarraon@inf.uc3m.es)

This work was supported in part by the Spanish Ministry of Economy and Competitivity through the PACE Project under Grant TIN2016-77690-R, and in part by the Spanish Ministry of Science and Innovation through the CREAx Project under Grant TIN2014-56534-R.

ABSTRACT The use of augmented reality (AR) to support the learning process has been extensively researched but its use to support the teaching practice has just started to be explored. In this paper, we present a communication system that makes use of a pair of Google Glass to provide the teacher with a constant and private flow of information on the students' current knowledge. The proposed system allows the information sent by the students through their mobiles to overlap with the teachers' live vision of the class. Compared to other feedback systems like clickers or backchannel systems, this AR prototype avoids teachers diverting their gaze and interrupting the class to access the students' feedback. This supports the constant monitoring of potential comprehension problems that might otherwise be overlooked. With the aim of obtaining insights on the teachers' and students' views of the system, we conducted two studies during which the system was used in real classroom settings. The results of both studies suggest that the AR system could report benefits in terms of better communication between students and teachers, and a more adequate rhythm of the class. Also, the use of the AR system in the classroom does not necessarily constitute an element, which will distract and disrupt educational activity.

INDEX TERMS Augmented reality, computer-mediated communication, educational technology.

I. INTRODUCTION

Augmented Reality (AR henceforth) is foreseen as a potential useful resource in teaching and learning, assuming that educational experiences can be improved by increasing the real world with digital information in many different ways. Most current research is focused on examples of the usage of AR to support specific learning processes [12], [19] and on the unique learning affordances of AR, including the capacity to learn on realistic environments, and support kinaesthetic learning or face-to-face communication in collaborative learning [9], [10]. In this research, we focus on the other side of the coin: the use of AR to augment the teacher's view during the lecture. Feedback systems like clickers [6] or backchannels [8] are used in the classroom to improve and speed up the communication among students and teachers. In this paper, we propose overcoming some of the limitations of the current feedback systems by making use of AR technology, and more specifically AR glasses. This type of device can be used to augment the teacher's view superimposing the responses collected from the students as symbols or graphs. This amplified view allows teachers to visualize the feedback gathered from the students directly, without diverting their gaze to look at a computer or a smartphone screen. This could be especially useful for backchannels, since the information students send at any point of an explanation are immediately visible to the teacher, so that they are more difficult to miss. In addition, the AR technology allows teachers to access the feedback privately, as opposed to other systems' implementations that publicly display the responses on the classroom projection screen, which could influence the students' responses and facilitate situations of abuse [2].

In [20] we already investigated whether an AR-based classroom feedback system could overcome the reluctance of some students to ask questions or communicate their difficulties in following a teacher's explanation. The results of the

The associate editor coordinating the review of this manuscript and approving it for publication was Jun Huang.

experiments carried out to test that prototype were encouraging, suggesting that this type of system could improve the teaching practice. However, as the AR glasses available at that time were too cumbersome and intrusive, it was not possible to evaluate the system during its use in real classroom settings on a daily basis. Since nowadays there are AR glasses that overcome the ergonomic limitations of the previous devices it is now possible to continue the research to further investigate the potential benefits of this system, so that they can be definitively confirmed or discarded in longer term experiments.

In this paper, we present our research on using an AR system to support communication in the classroom by providing the teacher with a constant and private flow of feedback on the current level of knowledge of the students. Research was aimed at obtaining insights on both the teachers' and students' views of the system. Following this objective, we asked 20 teachers from university and secondary educational centers to use the system in at least one of their classes and give us feedback. In addition, we conducted a long-term study during a university course in which the AR system was used for 7 weeks of an introductory course on programming, so we could test whether positive attitudes went beyond the first impact with a new technology. The results of two studies conducted indicate that teachers and students appreciated the benefits that the system can report in terms of a better communication and a better adaptation of the rhythm of the class.

The rest of the paper is organized as follows: in the next section, we summarize some relevant related works in the area, and briefly describe the previous prototype of the AR system and the results of its evaluations. Next, we present the new version, its architecture and the functionalities it supports. In the next section, the research methodology and the results of the experiments carried out are described and discussed. We conclude the paper discussing the limitations of the work, conclusions and on-going works.

II. LITERATURE REVIEW AND PREVIOUS WORK

The technology used for gathering feedback from the students in the classroom is usually classified into two major groups: Audience Response Systems (ARSs) and digital backchannels. The objective of the ARSs, also known as Classroom Response Systems (CRSs), is to allow the teacher to collect anonymous responses to multiple choice questions formulated at specific points of the explanations. The responses collected are usually displayed on the projection screen as histograms [6]. The use of ARSs in the classroom has been the subject of extensive research [13]. Among its many advantages, the ability of students to contribute anonymously, thus avoiding the embarrassment of being judged by their peers or the tutor, stands out. This seems to be a key factor in the increase of students' participation [6], [17] and engagement [2], [6]. From the perspective of the teacher, ARSs can help to support contingent teaching, adapting the explanations based on the misconceptions identified in the answers collected [3], [6], [14].

Digital backchannels permit the students to provide more expressive feedback at any time of the lecture, and not only as a response to the teacher's request. Depending on the system, this feedback can take the form of questions or comments on the lecture content, votes or responses to posts from other students, messages referring to the lecture's presentation (e.g. pace of lecturing), or indications of being lost, for example [1], [4], [8], [16]. The benefits of digital backchannels are not so well studied as those of ARSs. Some studies suggest that backchannels which permit students to post questions anonymously could increase their engagement [1], [5], and the number of questions asked in class [1], [2], [16]. However, students might also misuse these backchannels [2], [4], [8] to publish off-topics or inappropriate posts, thus disrupting the class. Only a few studies [1], [4] report on the outcomes of using backchannels for sending feedback to a teacher on her explanations, to indicate whether the pace was too fast or too slow, for example. In the case of the study described in [1], both students and teachers highly appreciated this functionality. On the contrary, in the experiment described in [4] the feedback buttons were barely used by the students. Finally, some studies have also analyzed the risk of distracting the students from the class [1], [4], [8]. Most results suggest that the backchannel did not constitute an element of distraction [1], [8] although there are some exceptions [4].

To investigate the potential benefits of AR-based feedback systems, we developed an AR system named ALF (Augmented Lectures Feedback System) that aimed to support communication in the classroom. The system allowed a lecturer equipped with a pair of AR glasses (Vuzix Wrap 920 AR eyewear) to visualize symbols on top of the student's head that depicted their status with regards to the current teacher's explanation, or their answers to the questions he/she formulated (Fig. 1). Students choose their status and send responses using their mobile phones. The results of an experiment carried out in lectures and presentations were promising [20] and suggested that the system could improve the communication of students' difficulties to the teacher and help the teacher to better adapt the rhythm of the class to their current knowledge. However, the models of AR glasses which were available at the time were still very heavy and cumbersome. This impeded evaluating the effectiveness of the system when used on a daily basis.

III. THE ALF GLASS SYSTEM

The ALF Glass system (ALF-G) adapts the functionalities of the previous ALF system to the Google Glass. The ergonomic design of this device makes its use in a classroom environment possible. However, as opposed to other models of AR glasses that augment a wide range of the user's field of view, the Google Glass restricts the area of augmentation to an upper corner of the user's vision. Due to this limitation, the new version of the ALF system displays the data collected from the students summarized in the form of diagrams, and not individually. As in the previous versions of the system, this data could correspond to feedback about students' level

FIGURE 1. Teacher's view of the class through the ALF system.

of understanding of the teacher's explanations as well as to the answers to the teacher's questions.

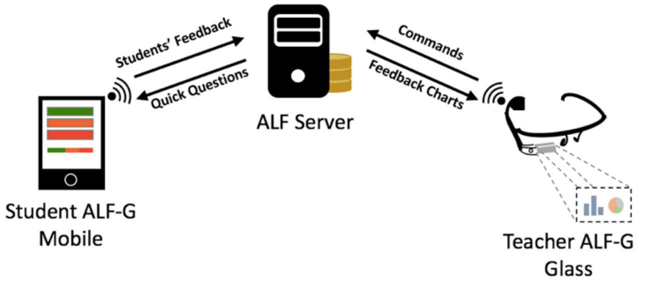

FIGURE 2. Modules of the ALF Glass System.

Fig. 2 depicts the architecture of the system. As shown in the figure, the system is composed of three modules: *ALF-G Mobile*, for collecting the students' feedback and responses, *ALF-G Teacher*, for visualizing the information in the glasses and controlling the system, and *ALF-G Server*, which manages the communication between the different devices and stores the feedback in a database.

The right-hand side of Fig. 3 depicts a screenshot of the ALF-G Mobile app. This module was implemented as a Web application so that it can be used without installing any software in the students' cell phones. As shown in the picture, the app is composed of one single page divided into two areas. The uppermost area allows students to select their level of comprehension on the current explanation. Students can indicate whether they are lost (red cross symbol), whether they understand the explanation (green check symbol) or whether they have questions to ask (question mark symbol). The activation of this last symbol would indicate to the teacher that she should stop at some point to deal with the questions the students might have. The lowermost area is only displayed upon the activation on the teacher's side. She can formulate questions indicating possible answers that the students vote on using the "option buttons." The teacher can configure the system to show or hide a bar diagram of the other students' responses, so all students can also be aware of the responses of the rest of the class. Also, if the student does not update the feedback for a long time the page displays a reminder.

The information collected from the students is stored in the ALF-G database. This module also generates and updates two data charts, a *feedback chart* and a *responses chart* that are displayed in the teacher's Google Glass (left hand side Figure 3). The *feedback chart* is a pie chart permanently displayed on the glasses that summarizes the students' status. The *responses chart* is only displayed when the teacher activates a question swiping backward (yes or no question) or forward (multiple choice question) on the touch located on the side of the glasses. Tapping on the touchpad makes the *responses chart* disappear again and resets the *feedbackchart*. Fig. 4 depicts the teacher's view of the class through the glasses.

IV. EXPERIMENTS: ANALYSING THE TEACHERS' AND STUDENTS' PERCEPTIONS

In this section, we describe and present the results of the research carried out with the aim of investigating the perceived benefits and weaknesses of the system. More specifically, and considering the related work presented in section 2, the research focused on three specific potential benefits: improvement of the communication of students' difficulties; improvement of the adaptation of the pace of the class; and, improvement of students' engagement. Concerning potential drawbacks, two aspects were analyzed: the capability of the technology to distract students and to disrupt the teacher's activity.

In order to investigate these issues, we conducted two studies. The first one aimed to understand the teachers' perspective and the second one to provide insights into the students' perception of the system.

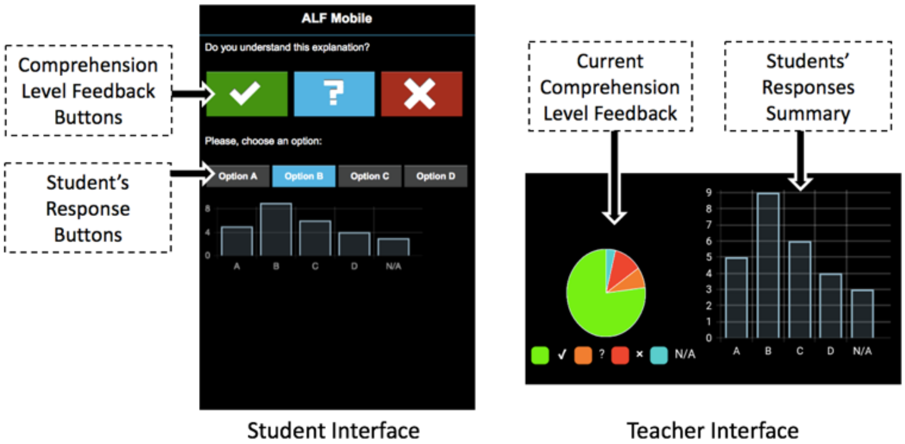

FIGURE 3. ALF-G students' view (left hand side) and ALF-G teacher's view (right hand side).

FIGURE 4. Teacher's view of the class through the glasses.

A. FIRST STUDY: ANALYSING THE TEACHERS' EXPERIENCE USING ALF-G

The first study aimed to gather insights into the teachers' opinions on ALF-G's potential benefits and drawbacks. With this purpose, we asked 20 teachers from different educational centers and disciplines to use the ALF-G in one of their regular lectures.

1) PARTICIPANTS AND APPARATUS

20 teachers participated in the study. 8 of them used the ALF-G in lectures of Bachelor degrees in law (1), political science (1), computer science (7), and telematics engineering (3). Another 8 used it in classes of medium and higher vocational training courses in electricity (2), administration and finances (2), network systems management (2) and informatics (2). Finally, the last 2 used it in high school maths (1) and history (1) courses. The ages of the teachers ranged from 30 years to 57, most of them being between 35 and 45. The size of the classes varied from 15 to 40 students, and in most cases, they were between 20 and 30 students. The duration of the classes was 2 hours for the Bachelor degrees classes (10 classes), and 1 hour for the other ones (10 classes).

Concerning the apparatus used, students used their own mobile phones to access the ALF-G web site, whereas the teacher utilized a pair of Google Glass. Only 2 participants had tried the Google Glass before.

2) PROCEDURE

Before each lecture a member of the research team trained the teacher on how to use the system and explained the different functionalities it offers. Then, at the beginning of the class the teacher introduced the system to the students, who practiced sending questions and status with their mobiles from around 5 minutes. We asked the teachers to use the system as an ARS, for collecting the students' responses to their questions, as well as a backchannel, enabling the students to provide

TABLE 1. Summary of the responses to the questions on class dynamics.

Question		M	SD
Q1	The system helps me to adapt the rhythm of the class to the students' necessities	4.35	0.75
Q2	The system improves the communication between students and teachers in the	4.20	0.77
Q3	Having to update their status in the app makes the students more engaged in the class	3.95	0.69
Q4	The system distracts the students	2.35	1.18
Q5	The system disrupts my activity	2.10	1.33

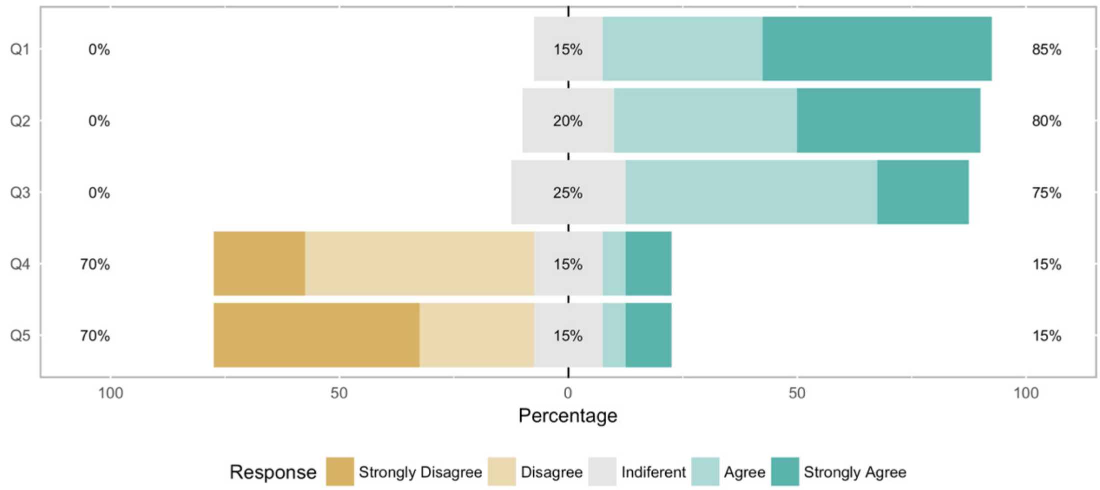

FIGURE 5. Frequency diagram of the responses for the questions on the Class Dynamics.

constant feedback about their level of understating on the lecture content. At the end of the classes, the teachers were asked to fill a questionnaire about the experience and they were also briefly interviewed.

3) DATA COLLECTION MECHANISMS

The instruments used in the evaluation aimed at providing quantitative and qualitative data on the teachers' opinions about the system. Quantitative data were obtained from the items in Table 1. The teachers were asked to rate the list of potential benefits and disadvantages using a 5-point Likert scale of agreement. Qualitative data were obtained from three open questions included to give the teachers the opportunity to explain if they think this technology could change somehow the way they teach, if they wanted to count with it in the next classes and provide comments and suggestions.

In addition, and to understand better the teachers' answers to the questionnaires, semi-structured interviews were conducted at the end of the classes. In these interviews the teachers were asked to give a general overview of the experience, to elaborate their answers to the questionnaire, and to provide advice and recommendations on how to improve the system.

4) RESULTS

We collected 20 responses to the questionnaires. Descriptive analysis was performed on the questionnaire data using the mean and standard deviation values and the frequencies distributions. For the responses to the open questions and the transcriptions of the interviews content analysis was used [11].

a: TEACHERS' VIEWS ON THE IMPACT OF ALF GLASS IN THE CLASS DYNAMICS

Table 1 depicts the mean and standard deviation of the responses to the questionnaire on class dynamics, and Figure 5 a frequency histogram of the answers. Questions Q4, Q5 and Q6 should be interpreted in the opposite way since they were reverse coded in order to avoid the acquiescence bias that happens when participants adopt an automatic behavior and mark answers without even reading the question [18]. As shown in Figure 7, the responses suggest that teachers valued the system very positively. Most of them agreed in that the system helps to adapt the rhythm of the class (85%), improves the communication (80%), and makes the students more engaged in the class (75%). It is necessary to note that none of the teachers disagreed with these statements. With regards to the potential drawbacks, 70% of the teachers did not considered that the system disrupts their activity or distracts the students, whereas a 15% agreed with these shortcomings.

b: TEACHERS' OPINIONS

We collected 17 answers to the question "*Do you think the system could change the way you give your classes?*." 12 teachers responded affirmatively, 3 negatively, and 2 explained that to exploit the system opportunities it would be necessary to modify the way they prepare their classes. According to their responses the instruction process could change due a better adaptation of the explanations and rhythm of the class (4 subjects), an increment in students' participation (3 subjects) and a better feedback from the students (2 subjects). It's worth noting here that 2 out of the 3 teachers who responded negatively also acknowledged some benefits that the system might report. As one of them stated "*I don't think it would change the way I teach, but I will use it to identify the key moments in the explanations in which the students change their answers, the instants in which their mental model change*."

For the question "*Would you like to use the system in your classes regularly?*" we collected 18 positive and 1 negative answers. In addition, 1 subject explained that he/she would like to use it but only during some specific parts of the class.

Among the suggestions, 2 subjects proposed to provide teachers with an historical of the students' feedback responses. This would help them to analyses the class latter on, identifying what went wrong and what really worked.

During the interviews, most teachers reiterated that the major benefit of the system is providing immediate information about students' current knowledge. This can help to increase awareness of comprehension problems that might be overlooked otherwise. As one of the teachers described "*... in the middle of an explanation I noticed that most of the circle was red. This was abit of a shock, as I always assumed that the students followed this part of the class effortlessly. I have never stopped to check at that point of the class before*." In addition, one of them mentioned that the system could help to compare the effectiveness of different ways of explaining the same concept: "*The system allows to identify the precise moment in which the students grasp the concept explained. I could try to explain the same concept in two different ways in two classes, and I would know in which one the students grasped the explanation earlier. This is something difficult to know right now*."

5) DISCUSSION

In general, the responses from the teachers were very positive. There was almost a general consensus in that the system helps to improve the communication in the class, to adapt the explanations, and even to keep the students engaged. In general, most of the teachers acknowledged the opportunities that the system could open up for improving their activity in the classroom due to a better awareness of the students' current knowledge. With regards to the drawbacks, for most of them, the distraction of the students was not a major concern, and the device did not seem to disrupt their normal activity. These results are very encouraging, especially considering that only 2 teachers had tried the Google Glass previously, and that not all of them had a technical background.

B. SECOND STUDY: ANALYSING THE STUDENTS' VIEWS

In order to gather insights about students' opinions about ALF-G we conducted a second study during the regular classes of a university course.

1) PARTICIPANTS AND APPARATUS

The study took place during an introductory course on Computer Programming of a Bachelor on Biomedical Engineering at University Carlos III of Madrid that is taught in the first semester of the first year of the degree. Since the study was run in a realistic environment, that is, in regular classes, a in-group study in which all students are exposed to the same conditions was chosen. Also, and in order to be able to compare the use with ALF-G with other options, the system was used in the second half of the course, so that students were exposed first to traditional lectures. At this point, it is important to remark that this study was run with first year students who are not already used to the university lectures, teachers and even mates. That makes it quite difficult to achieve a great degree of participation, since students are often embarrassed to ask questions in an unfamiliar and unknown environment.

The duration of the course was 14 weeks, and the number of students enrolled was 70. The teaching methodology included weekly lectures in a standard classroom and practice sessions in a computer lab. The duration of both types of session was 2 hours. The ALF-G system was used in the last 7 lectures of the course. Previously, and to make sure that students knew how to use it, the system was introduced in some short activities during practice sessions. With regards to the apparatus, the students used their own mobile phones to access the ALF-G functionalities, whereas the teacher utilized a pair of Google Glass. The responses and status collected during the class were displayed on the glasses screen, and the teacher controlled the different system functionalities tapping and scrolling the touchpad of the glasses.

2) DATA COLLECTION MECHANISMS

To allow comparison of the students' opinions about normal lectures and ALF-G augmented lessons we conducted two surveys. The first one was filled in after the first 7 weeks of classes, during which lectures were given in a traditional way, and the second one was distributed after the last 7 weeks of classes, that is, after the teacher and students were exposed to ALF-G lectures (see Fig. 6). In both surveys the participants were asked to provide feedback on the class dynamics in the form of 5 point Likert-scale answers. As shown in Table 2, participants were asked to indicate their level of agreement with some statements about the adequacy of the pace of the classes (Q1), their comfort level when communicating their

FIGURE 6. Experiment description.

TABLE 2. Summary of responses and Mann-Whitney U test for the questions on the class dynamics.

Question		Survey	M	SD	Mann-Whitney U
Q1	The pace of the class is inadequate for me (too fast, too slow for me)	PRE	2,40	1,07	U=1.163,500, ρ= 0,010
		POST	1,88	0.84	
Q2	I feel comfortable asking questions [using the app to ask questions]	PRE	3,51	1,30	U=1.943,000, ρ = 0.034
		POST	4,05	0.94	
Q3	I feel engaged in the class	PRE	3,55	1,04	U=1.787,000, ρ = 0.234
		POST	3,83	0.82	
Q4	Having to use the app distracts me from the class	POST	2,01	1,02	

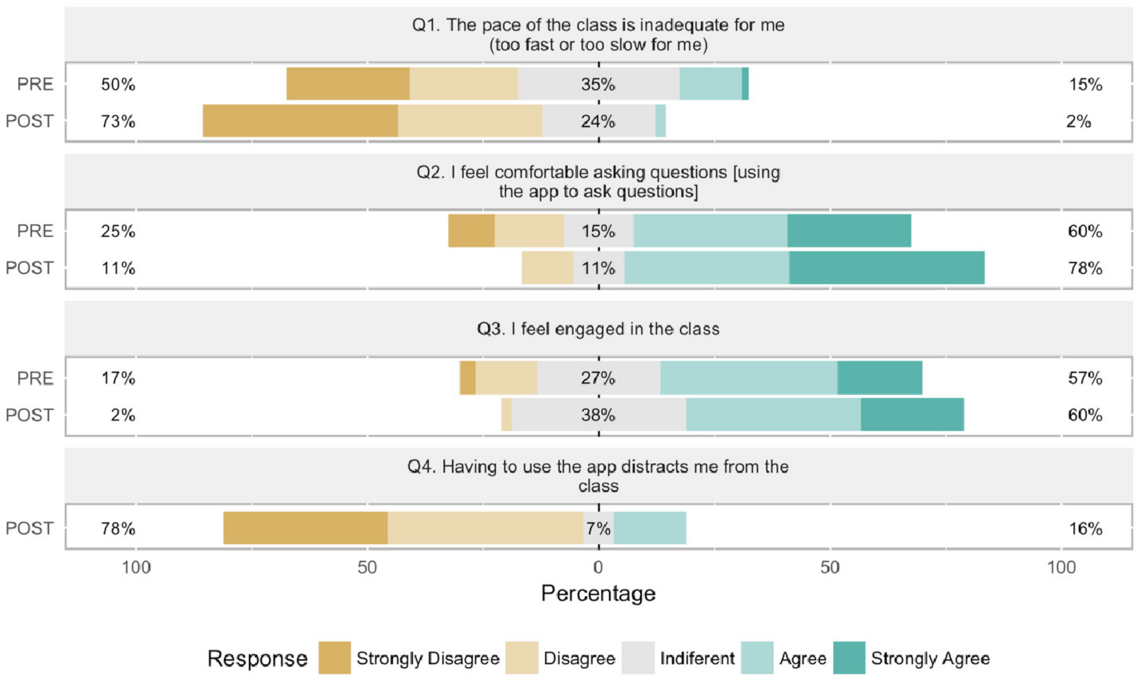

FIGURE 7. Frequency of the responses for the questions on the Class Dynamics.

difficulties (Q2), and their engagement in the classes (Q3). In the second survey Q2 and Q3 were adapted to specifically refer to the use of the system. Also, the second section included a fourth item (Q4) gathering feedback on the distraction that the interaction with the app might cause. Both surveys ended with some open-ended questions that made it possible to provide additional explanations, comments and suggestions.

At the end, we collected 60 responses for the first survey, and 53 for the second one. In both cases the surveys were anonymous since a disclosure of the respondent identity could influence their answers.

3) RESULTS

a: THE IMPACT OF ALF GLASS IN THE CLASS DYNAMICS

Table 2 and Figure 7 summarize the mean and standard deviation of the responses to the questionnaire on class dynamics, and the distribution of the responses, respectively. It is important to point out that the responses to Q1 and Q4 should be interpreted in the opposite way respect to the other questions, since they were reverse coded. Q4 was only included in the second questionnaire since it explicitly focuses on the use of the app.

As shown in the diagram, the number of students who responded negatively to the three questions Q1, Q2 and Q3 decreased considerably in the post survey. In the case of Q1, inadequacy of the pace, the percentage of students decreased from 15% in the normal lecture to 2% in the ALF-G lecture. Similarly, for Q2, the percentage of students who did not feel comfortable when asking questions changed from 25% in the normal lecture to 11%, in the ALF-G lecture. Finally, concerning Q3, the number of students who did not feel engaged with the class was reduced from 17% to 2%. However, only in the case of Q1 and Q2 did this translate into a notable increment of positive responses. The positive responses for Q1 went from 50% to 73%, for Q2 from 60% to 78%, but for Q3 they only changed from 57% to 60%. The overall mean of the responses improved by 0,52 for Q1, 0,54 for Q2 and 0,28 for Q3 (see Table 1). To determine whether the differences in the results for the items Q1, Q2 and Q3 were statistically significant we applied the Mann-Whitney Wallis test. A statistically significant difference was found for Q1 (U=1.163,500, $\rho = 0, 010$) and Q2 (U=1.943,000, $\rho = 0, 034$), whereas no statistically significant difference was found for Q3 (U=1.787,000, $\rho = 0, 234$).

Finally, only 15% of the students reported getting distracted by the app (Q4), whereas for almost the rest of the class (77%) this was not an issue. In this case the mean of the responses was M=2,01 and SD=1,02.

b: STUDENT'S OPINIONS

As commented above, the questionnaires included a set of open-ended questions that students could use to explain their answers or provide any additional comment. The responses to the questions in the first survey revealed that very often the causes for not communicating difficulties to the teacher were related to speaking in front of their pears: *"I don't want to draw attention to myself," "I feel a little "silly," "I never want to be 'the dumb one'"* or *"I don't want to speak in front of my fellow students"*. In addition, some of them also reported to preferring not to interrupt the teacher ("*I don't want to interrupt so that the class can proceed more fluidly*") or to let him know about their difficulties *("I don't want the teacher to know that I don't understand something," "The teacher might think that I don't work enough"*).

In the second questionnaire students were asked to provide their general opinion about the application, and to provide comments and suggestions. Many of the responses collected were encouraging. (*"It is a good idea," "It is helpful when I don't understand something," "I think it is a nice, interactive and fun way to learn*, *and to let the teacher know how good or bad I am doing"*). However, some students reported not liking to use their mobiles in class ("*It is not comfortable to have the mobile phone on all the time in class*," " *Whenever I want to participate I have to pick up the phone, find the application... it takes too much time," "The phone goes into downtime when you are not using it. It would be better if it were installed on another device"*). Among the students who did not consider the application useful, some reported not to be sure about the reaction of the teacher to their interactions. As one of them stated: "*I push the question button but I'm not sure if the teacher is going to stop or if he is going to care if just one person is not following the explanation."*Some others explained they prefer to address the teacher directly ("*I think it's easier to raise your hand and ask the teacher*"). With regards to potential improvements, some students proposed being able to send the teacher specific questions.

C. DISCUSSION

The results of the study suggest that, from the perspective of the students, the use of a system like ALF-G could report some benefits, particularly to those students who feel embarrassed to interact publicly with the classroom, confirming what teachers said in the first study. In particular, more students were satisfied with the pace of the class and reported feeling comfortable when communicating their difficulties to the teacher. However, overall, students' opinions on these issues seem not to improve greatly. With regards to the student's engagement, the third benefit analyzed, the data collected doesn't identify any clear enhancement. Finally, and regarding the potential drawbacks, most of the students indicated that the app did not distract them from the class, though less disruptive mechanisms might be envisioned to avoid problems when the cell phone is locked, like using more simple notification systems that can be used in other devices like smart watches.

The student's profiles might play an important role in their attitude to the system. Those students who in the first questionnaire reported to be reluctant to communicate their problems due to shyness and fear of public exposure might find the system more useful. On the contrary, for the students who usually participate in class, the system offers little benefits over raising their hands and asking questions directly. In addition, it is necessary to note that some students seemed to feel a bit intimidated and distrusted a system which might help to identify who were experiencing difficulties, or that it could be used to record with the camera their actions in class. The use of wearable devices like the Google Glass can provoke privacy concerns [15] that need to be addressed before this technology is fully integrated in daily activities like teaching. A better explanation of the system's performance at the beginning of experiment might have helped to reduce suspicion, but in any case, this is a brand new technology users might need to live with and experience to have a more positive and trustful attitude.

V. THREADS TO VALIDITY

There are some limitations of the studies presented here that need to be highlighted. Firstly, it is necessary to note that the two studies focus on the opinions of participants, be they students or teachers. We believe that this is the best way to assess subjective perceptions as the adequacy of the rhythm of the class, or the willingness to participate. In any case, the collection and comparison of the number of students' interventions with and without the system could help to confirm some of the conclusions presented. Also, the difficulty of controlling the wide range of variables that can influence the results of the experiments carried out in the context of a classroom should be acknowledged [7]. For instance, the perception of the rhythm of the class could have been influenced by the section of the course in which the system was used, as by the end of it the students might have grown used to the subject difficulty and to the teacher's personality. In any case, it is necessary to note the results obtained are consistent in both studies, and even the students perceptions confirm the opinions gathered from teachers in the first study, who agreed in considering the system beneficial for improving communication and class adaptation. In addition, the opinions collected in the first study correspond to teachers who used the system in one single class, so integrating the system into a whole course might provide different results. Also, the profile of the participants in the second study, engineering students, could have influenced their positive attitude towards that system. In any case, the results are encouraging, and suggest that AR could improve current classroom communication systems' implementations, providing a more seamless way of delivering the feedback gathered from the students to the teacher.

VI. CONCLUSIONS

We have presented a novel configuration of a communication system for the classroom that makes use of AR technology. As opposed to other backchannels and ARS systems that require the teacher to periodically check the responses of the students on a computer screen or to publicly display in them on the classroom display, the ALF-G system makes it possible to visualize the feedback overlapping digital information to the teacher's view of the classroom. This provides a constant and private flow of information on the students' level of comprehension of the explanations which would be difficult to achieve by other means. The results of the study suggest that this could report benefits in terms of better communication between students and teachers and a more adequate rhythm of the class. Also, that the use of the system in the classroom does not necessarily constitute a distraction from or and disruption of educational activity.

Finally, it is necessary to note the original version of the AR device used in the studies, the Google Glass Explorer Edition, was discontinued. However, Google has recently released a new version designed for industrial applications, and there are other models of AR Glasses available in the market, as Epson Moverio or Vuzix M100 Smart Glasses. Therefore, it is reasonable to expect that in the future AR devices ergonomic enough for use in a classroom environment. The results of the study are relevant as they provide evidence of the positive attitude of students and teachers towards this technology, and of the benefits of its use for educational purposes.

REFERENCES

[1] D. Baron, A. Bestbier, J. M. Case, and B. I. Collier-Reed, "Investigating the effects of a backchannel on University classroom interactions: A mixed-method case study," *Comput. Educ.*, vol. 94, pp. 61–76, Mar. 2016.

[2] G. Bergtrom, "Clicker sets as learning objects," *Interdiscipl. J. E-Learn. Learn. Objects*, vol. 2, no. 1, pp. 105–110, 2006.

[3] C. A. Brewer, "Near real-time assessment of student learning and understanding in biology courses," *BioScience*, vol. 54, no. 11, pp. 1034–1039, 2004.

[4] F. Bry and A. Y.-S. Pohl, "Large class teaching with backstage," *J. Appl. Res. Higher Educ.*, vol. 9, no. 1, pp. 105–128, 2017.

[5] J.-F. Bussières, M.-É Métras, and G. Leclerc, "Use of Moodle, ExamSoft, and Twitter in a first-year pharmacy course," *Amer. J. Pharmaceutical Educ.*, vol. 76, no. 5, p. 94, 2012.

[6] J. E. Caldwell, "Clickers in the large classroom: Current research and best-practice tips," *CBE Life Sci. Edu.*, vol. 6, no. 1, pp. 9–20, 2007.

[7] L. Cohen, L. Manion, and K. Morrison, *Research Methods in Education*, Abingdon, U.K.: Routledge, 2013.

[8] H. Du, M. B. Rosson, and J. M. Carroll, "Augmenting classroom participation through public digital backchannels," in *Proc. 17th ACM Int. Conf. Supporting Group Work*. New York, NY, USA: ACM, 2012, pp. 155–164.

[9] M. Dunleavy, C. Dede, and R. Mitchell, "Affordances and limitations of immersive participatory augmented reality simulations for teaching and learning," *J. Sci. Educ. Technol.*, vol. 18, no. 1, pp. 7–22, 2009.

[10] M. Dunleavy and C. Dede, "Augmented reality teaching and learning," in *Handbook of Research on Educational Communications and Technology*. New York, NY, USA: Springer, 2014, pp. 735–745.

[11] H.-F. Hsieh and S. E. Shannon, "Three approaches to qualitative content analysis," *Qualitative health Res.*, vol. 15, no. 9, pp. 1277–1288, 2005.

[12] H.-K. Jee, S. Lim, J. Youn, and J. Lee, "An augmented reality-based authoring tool for E-learning applications," *Multimedia Tools Appl.*, vol. 68, no. 2, pp. 225–235, 2014.

[13] R. H. Kay and A. LeSage, "Examining the benefits and challenges of using audience response systems: A review of the literature," *Comput. Edu.*, vol. 53, no. 3, pp. 819–827, Nov. 2009.

[14] G. E. Kennedy and Q. I. Cutts, "The association between students' use of an electronic voting system and their learning outcomes," *J. Comput. Assist. Learn.*, vol. 21, no. 4, pp. 260–268, 2005.

[15] V. G. Motti and K. Caine, "Users' privacy concerns about wearables," in *Proc. Int. Conf. Financial Cryptogr. Data Secur.* Berlin, Germany: Springer, 2015, pp. 231–244.

[16] M. Ratto, R. B. Shapiro, T. M. Truong, and W. G. Griswold, "The activeclass project: Experiments in encouraging classroom participation," in *Designing for Change in Networked Learning Environments*. Amsterdam, The Netherlands: Springer, 2003, pp. 477–486.

[17] K. Siau, H. Sheng, and F. F. H. Nah, "Use of a classroom response system to enhance classroom interactivity," *IEEE Trans. Educ.*, vol. 49, no. 3, pp. 398–403, Aug. 2006.

[18] B. Weijters and H. Baumgartner, "Misresponse to reversed and negated items in surveys: A review," *J. Marketing Res.*, vol. 49, no. 5, pp. 737–747, 2012.

[19] S. C.-Y. Yuen, G. Yaoyuneyong, and E. Johnson, "Augmented reality: An overview and five directions for AR in education," *J. Educ. Technol. Develop. Exchange*, vol. 4, no. 1, pp. 119–140, 2011.

[20] T. Zarraonandia, I. Aedo, P. Díaz, and A. Montero, "An augmented lecture feedback system to support learner and teacher communication," *Brit. J. Educ. Technol.*, vol. 44, no. 4, pp. 616–628, 2013.

TELMO ZARRAONANDIA received the degree in computer science from the Universidad de Deusto and the Ph.D. degree in computer science from the Universidad Carlos III de Madrid, where he is currently an Associate Professor. He has been a Visiting Researcher with the Universidad Federal do Rio de Janeiro and the Universitá degli Studi di Salerno, Italy. He has published several scientific papers in international journals and conferences related to the fields of computer supported education and interactive systems. His research interests include technologies to support education and learning, videogame design, mixed reality environments, and interactive systems.

PALOMA DÍAZ is currently a Full Professor with the Computer Science Department, University Carlos III de Madrid. She is currently the Head of the DEI Lab Research Group, Universidad Carlos III de Madrid, where she focused on the design of interactive systems applied to different domains such as emergency and crisis management, e-learning, or cultural heritage. Her main research interests include interactive systems engineering, collaborative systems, visualization, and ubiquitous computing. Concerning the topics of this chapter, she has led projects on interactive and educational systems modeling, and on the definition of conceptual frameworks for the co-design and production of serious games supporting children informal learning. She has been a Visiting Scholar with the Information Science and Technology College, PSU, the MAGIC Lab, The University of British Columbia, and the VISUS Institute, University of Stuttgart.

ÁLVARO MONTERO received the bachelor's degree in computer science and the M.Sc. degree in computer science and technology from the Universidad Carlos III de Madrid, in 2012 and 2013, respectively, where he is currently pursuing the Ph.D. degree with DEI Lab. His current research interests include augmented reality, augmented environments, and end-user development. He has been a Visiting Researcher with Human Interface Technology Lab New Zealand, University of Canterbury, in 2017.

IGNACIO AEDO received the bachelor's and Ph.D. degrees in computer science from the Universidad Politécnica de Madrid. He is currently a Full Professor with the Universidad Carlos III de Madrid, Escuela Politécnica Superior. His research interests include hypermedia, interactive systems in education, web systems, electronic books, development methodologies, and information systems for emergency situations. Since 1990, he has been involved in the field of interactive systems. He was a Visiting Researcher with CSCL, IST Pennsylvania State University (2007–2008), and MAGIC Lab, The University of British Columbia (2011). He is currently the Chair of a Group Vision Grant of technologies for the collaboration, the Co-Chair of the IEEE ICALT 2008, 2009, 2010, and 2012, the Subdirector of the Culture and Technology Institute, and the Deputy Vice-Chancellor of faculty and departments.

TERESA ONORATI received the B.Sc. and M.Sc. degrees in computer science from La Sapienza Università di Roma and the Ph.D. degree in computer science from the Computer Science Department, Universidad Carlos III de Madrid (UC3M), where she was involved in modeling the semantics of several knowledge domains for improving the accessibility of critical information, in 2013. She is currently a Visiting Professor with the Computer Science Department, UC3M. As a member of the DEI Interactive Systems Research Group, UC3M, she is involved in several research projects about the role of technology for improving citizen collaboration and participation in critical situations. She has been a Visiting Researcher with the Researcher Center, Inria, Paris, Saclay, France, where she has been involved in large display interaction, and she has been with the GEOVista Research Center, Penn State University, PA, USA, where she has been involved in visual analytics for geographic information. Her research interests include semantic modeling, visual analytics, and information visualization for supporting a better understanding of how information and people sentiments propagate within a complex data ecosystem.