Review of Web-Based Audience Response Systems Used in Higher Education

Elina Michaelidou

Master of Science
Cognitive Science
School of Informatics
University of Edinburgh
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Abstract

Audience Response Systems (ARSs) are frequently used in education to support discussion, increase participation and enhance active learning. At the moment, there is a wide selection of ARSs on the market that differ in price, features offered and technology used. For this reason, it is essential to identify which design elements of ARSs cause the above benefits. This could facilitate the selection of an ARS to be used in an educational setting as well as to guide the future design of ARSs. This project aims to review the web-based ARSs used in higher education with a focus on usability and design guidelines.

Initially, the literature was reviewed on the uses, benefits and challenges of ARSs and a list of design guidelines that enforce the benefits coming from their uses and minimise the challenges was derived. Next, a systematic review was performed to identify ARSs and evaluate them according to the identified design guidelines. For this project, only web-based ARSs were considered that are free of charge, have a free trial period or are accessible via an educational license. An overall score was calculated for each ARS, and the overall best three ARSs were selected to be used in a usability evaluation. The usability evaluation consisted of a study with academics to examine the teacher's interface and a study with student's to test the students' interface. The teachers' study involved an observation, a questionnaire and a semi-structured interview for each ARS, while the students' study involved an observation and two questionnaires for each ARS. The outcomes of the study included quantitative results from the questionnaires that give an indication of general usability and a list of comments that participants made regarding their interaction with the ARS. Based on the comments and suggestions, a list of additional design guidelines was derived.

The final list of design guidelines can be used by educational institutions as comparison criteria when selecting an ARS to use in their classrooms, as well as by designers and software engineers as advice to follow when designing an ARS.

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Chapter 1

Introduction

1.1 Motivation

There is a plethora of educational software that can be used today in classrooms to facilitate every step of interaction between teachers and students [73]. The adoption of computers in classrooms in all the stages of education has opened doors to opportunities for the creation of different types of educational tools that focus on a variety of functions and support different educational paradigms. Tutorials, simulations and tests are just three examples of categories that software can facilitate their creation [81], while more complex tools such as collaborative digital tools and learning management systems also exist [40]. In higher education, specialised software is developed to support unique disciplines, students' needs and pedagogical methods. In this project, the focus is on web-based Audience Response Systems.

A web-based Audience Response System (ARS) allows a teacher to pose questions to students who can then respond using their personal devices. The results are collected using a WiFi internet connection and are presented back to the class in a summarised form. Such software can engage and motivate students to participate in the class [46, 64]. Moreover, they promote active learning, which is an essential component of contemporary pedagogy [50, 51]. The development of web-based ARSs is based on the trend of students bringing their own devices to class (Bring-Your-Own-Device principle; BYOD), like laptops, tablets and mobile phones. This considerably reduced the cost of the software and increased their acceptance rate among students and teachers [57]. As a result, several ARSs have appeared on the market and teachers and universities have to choose from a range of software. However, these tools can vary in the functionality offered and usability, i.e. how easy the interface is to use both

for teachers and students. Thus, choosing the best option can be very time consuming and considering how little time academics have, it is important to provide them with a review on ARSs currently available and a guide on features to look for when selecting an ARS in order to promote healthy classroom practices.

1.2 Aims, Objectives and Research Questions

The aim of this project is to evaluate a selection of web-based ARSs used in higher education in terms of design guidelines and usability.

As described in [79], the objectives of this project are to:

- review the design guidelines and any other criteria that ARSs should follow;
- compare a selection of web-based ARS in terms of the above criteria;
- perform a usability study on the best ARSs as identified in the systematic review;

The above will help to answer the following research questions [79]:

1. What are the expected educational aims from the use of ARSs?
2. What are the design guidelines that ARSs should follow in order to ensure the above educational aims and to support a comparison of web-based ARSs?
3. How do ARSs compare in terms of the defined criteria?
4. What is the usability of the best three ARSs identified from the above comparison?
5. What design elements can be added to improve the functionality and usability of the overall best ARSs as well as of future ARSs.?

This project directly addresses the above research questions, and the answers can potentially identify which ARSs could have the most impact on students and teachers that want to use them [79]. Additionally, the results of this project aim to become a guide for teachers and universities who consider using an ARS in their classes. Firstly, it could help them decide if they need to use an ARS by looking at the benefits and challenges, compare different brands in terms of functions that are related to positive educational outcomes and finally inspect the usability of the best three ARS. At the same time, the results could also be used by software designers when developing an

ARS, because it can give them advice and design guidelines that they should follow to create teacher and student-friendly systems. Lastly, this project aims to be an addition in the academic literature since there does not exist a recent review on this topic.

1.3 Outline

This project is structured as follows:

- Chapter 2 details the **background** knowledge required for this project as well as a literature review of previous work.
- Chapter 3 explains the **methodology** that is followed to complete this project.
- Chapter 4 presents the specific uses of **ARSs in higher education** as well as their advantages, disadvantages and a list of design guidelines that they should follow. This chapter addresses Research Questions 1 and 2.
- Chapter 5 describes in detail the **systematic review** that was performed to select and evaluate a selection of ARSs based on a set of criteria. This chapter answers Research Question 3.
- Chapter 6 outlines the details of the **usability evaluation** performed on the three highest-scoring ARSs from the systematic review and responds to Research Questions 4 and 5.
- Chapter 7 provides a **conclusion** to the project, shares a **discussion** on the work undertaken and gives suggestions for **future work**.

Chapter 2

Background

2.1 Audience Response Systems

An *Audience Response System* (ARS) is a piece of software that allows the collection of responses from the audience to a question posed to them, and the immediate presentation of results [75]. ARSs can be used in different contexts like education, business meetings, and TV game shows, but **in this project, only ARSs used in higher education are considered**. Therefore, in this case, the *audience* refers to students attending a live class (either in a classroom or via distance learning), and the question poser refers to their teacher. The term *teacher* here is used to describe all the academic staff who deliver a lecture, no matter their position. The term *class* is used to represent lectures of any-size and other settings used for educational learning. Similarly, the word *classroom* refers to a lecture theatre and any other places where students have lessons.

ARSs are also known by a variety of other terms with the most popular being *student response systems* (SRSs) and *classroom response systems* (CRSs). Dangel [51] mentions that the use of each name represents a slightly different focus point. To be more specific, the term audience suggests that students are viewed as a mass which is controlled by the teacher, the use of the term student brings attention to individual students, and the term classroom represents the more collaborative approach of learning in groups. Other names that can be used to describe an ARS are *personal response system*, *electronic voting system* [67], *electronic response system* [46], and *group response system* [50]. To refer specifically to web-based ARSs the terms *web-based*, *smartphone*, *online*, *cloud-based* or *software-based* can be appended in front of the names mentioned above (e.g. "online classroom response system"). **For the purposes of this project, all synonymous names will carry equal weight** and avoid confusion

only the term ARS will be used.

There are different types of ARSs based on the devices that students use to respond to questions and the way that their responses are collected. Jagar, Petrovi and Pale [65] separate ARSs into clicker-based, SMS-based and web-based. In short, *clicker-based* require students to purchase a keypad to respond to questions, *SMS-based* allow students to submit responses by sending text messages, and *web-based* allow students to respond using any web-enabled devices. Appendix A describes the evolution of ARSs and explains the characteristics of each of the three main types of ARSs, i.e. clicker-based, SMS-based and web-based ARSs. Lastly, ARSs can also specialise in different audiences within education (secondary school, high school) and special cases, such as supporting game-based learning methods and the flipped-classroom paradigm. **In this project, only web-based ARSs used for general purposes in higher education were considered**.

The primary reason that this type was chosen is that there are numerous systems to compare that are accessible for free, hence minimising the cost required for this project for which no funding is available. Besides, web-based ARSs exhibit the same set of benefits as their previous versions and in addition, they overcome most of their challenges. For a complete discussion of benefits and challenges refer to Chapter 4.

2.1.1 Web-based Audience Response Systems

Web-based ARSs do not require any specific hardware to be purchased and usually do not require any software to be installed [77]. Teachers can prepare and present questions using a web-interface. To access this interface, teachers usually need to create an online account. This would allow their questions to be saved on the ARS company's servers and hence they could access them from any device with an internet connection. Some pieces of software do not require teachers to use an online interface, but instead, they offer them presentation software plugins that they can install on their device. This can somehow limit teachers because they would need to use the specific presentation interface that a plugin supports to prepare and present the questions. Another way that they can prepare questions if a web-interface is not available is by using a mobile application. Again, teachers would need to have a device that runs the software and has the minimum hardware requirements for which the app was created. Lastly, there is a small minority of web-based tools that ask teachers to download a standalone software to prepare and present the questions, which is again limited by the operating system(s)

for which it was designed. During class, the teacher can present the questions either using the web-interface or using some other presentation software, and students can then answer them using any web-enabled device. Students usually can answer using just a browser, but a small number of tools require students to download an app to respond to questions. The responses are sent via a WiFi connection on some cloud software, where they are being summarised and presented using some kind of visualisation. After class, the teacher can use the ARS to view and download the results.

The use of web-based ARSs in classrooms is encouraged by the number of students who have access to a web-enabled mobile device such as laptops, tablets and phones and subsequently bring them to class. More specifically, 88% of students in the UK used a web-enabled device in 2018 [52], while in the USA in the same year 91% of students had access to a laptop [56]. The additional advancement and broader availability of wireless internet connection in university classrooms [76] set the footing stones of the wide adoptions of web-based ARSs .

2.1.2 Audience Response System Design

ARSs need to be designed in a way to support both teachers and students. Hence, a different interface is needed for each type of user. The *Teachers' Interface* is designed to be used and accessed only by teachers who use it to create and set up questions, initiate a presentation and view the results. The *Students' Interface* is designed to be used only by students, who use it to respond to questions. Teachers can also use it to test if the interface suits their students and also to try the tool. In addition to this, all tools have a *presentation screen* to present the questions and results to students during a class. Everything that happens on the presentation screen can be visible both to teachers and students, as long as the screen is connected to a projector. Because the screen is controlled by the teachers, it is part of the teachers' interface. Some tools also feature a separate screen that is visible only to the teacher who can see live results coming in before presenting them to the rest of the class and can adjust the controls of the presentation.

Students can find the questions that their teachers asked and subsequently respond to them by connecting to a classroom environment. A *classroom environment* or *session* for short is the online gateway that students use to send their responses to the cloud server for further processing. There are different ways that students can access a classroom environment. The most popular way is by using a URL. This URL usually

consists of the ARS domain name followed by a unique code for each session. Some ARSs provide students with a shorter domain name which they can access quickly. There, students are asked for an access code, which is usually a few letters/digits long. An alternative way to connect to a session is by scanning a QR code that is presented on the screen. However, this requires a working (back) camera on the student's device and specific software to interpret it. In the case that students use a mobile app, they usually, need only an access code to connect to a classroom environment.

2.1.3 Audience Response System Questions and Results

ARSs are used to create a number of activities; some ARSs only have a limited number of options available, while others are more flexible. These activities are usually queries to a topic under discussion, and for simplicity, they will be called *question types* throughout this project. The most popular question types are single/multiple-choice questions and polls. The difference between a *question* and a *poll* is that a question usually has a correct answer set up by the teacher, while a poll does not. Appendix B has a long list of question types than an ARS should support.

Results can also be displayed in a variety of ways, but many systems offer few options. The most popular ones are bar charts for single/multiple-choice questions and lists for open-ended questions. Many ARSs also offer word clouds to represent short answers to open-ended questions. A *bar chart* is a display of results across two axes. On one axis, the possible answers to a question are given, while on the other axis, a bar is drawn to represent the number of students who gave that answer. The bars can be horizontal or vertical. Bar charts are frequently used because they are proven to be easy to understand and interpret, while at the same time they provide an accurate representation of the responses and facilitate comparisons of the different answer groups [90]. A *word cloud* is a collection of words shown on the screen that vary in size based on the number of times that a word appeared in the responses. [78] Word clouds are useful as they can point directly to the most popular topics the audience mentioned [60].

2.2 Methods for data collection

A *systematic review* is a collection, evaluation and analysis of *all* studies that appear under a specific topic [68]. It is a form of secondary study as it uses material from

primary sources. It differs from a literature review to the point that a *literature review* aims to summarise a collection of studies relevant to a topic, while a systematic review looks at all related studies.

There are a number of steps that need to be followed to perform a systematic review. Before conducting the search for primary studies, a set of eligibility criteria that describe what requirements a paper needs to satisfy along with a search strategy need to be defined [71]. After the search is completed, the necessary information needs to be extracted from all papers that satisfy the eligibility criteria. Lastly, the results need to be presented in some form. The above steps are described in detail in the PRISMA statement (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) [71] which was also followed for the systematic review that was performed in this project. A full description of PRISMA can be found in Chapter 5.

A *usability evaluation* examines how usable an interface it is to its intended users for their needs and in the intended context [45]. There are four ways to conduct usability evaluation: using automatic, empirical, formal and informal methods [80]. *Automatic methods* involve a programmable way to test an interface; *empirical methods* involve human participants or human-computer interaction (HCI) experts; *formal methods* involve usability models, and *informal methods* involve colloquial methods and techniques. In this project, ARSs were evaluated using empirical methods. There are three types of empirical evaluation methods: inquiry, inspection and testing [54]. *Usability inspection methods* require HCI experts to evaluate the design of an interface based on a set of defined metrics [80]. Possible methods are *heuristic evaluation* (checking if a system satisfies a set of informal rules) and *cognitive walkthrough* (testing if the steps needed to perform an action are clear and intuitive). *Usability inquiry methods* require human participants to comment on what they think about a system [54]. A few example methods are *interviews/focus groups* (a researcher asks questions to a participant/group of participants about their experience with a system) and *questionnaires* (participants are asked to respond to a predefined set of questions). Interviews are further separated into structured, semi-structured, and unstructured [93]. *Structured interviews* involve a specific set of questions that need to be posed to all participants in the same order, *unstructured interviews* do not follow a strict structure and can take any form based on the topics under discussion, while *semi-structured interviews* offer a balance between the two by allowing both planned and unplanned questions. *Usability testing* requires participants to perform a set of tasks while being supervised by a researcher who collects data about their interaction with the system

[62]. Two example methods are *observation* (a participant performs a set of tasks, and a researcher inspects their interaction) and *think-aloud* (a participant is requested to perform a set of tasks while describing aloud their actions).

Another way to quantitatively evaluate an interface is to use the *System Usability Scale* (SUS) questionnaire [48]. The SUS consists of ten predefined questions that assess a system in general. Each question can be answered on a 5-point Likert scale from Strongly Disagree to Strongly Agree. Participants are asked to interact with the system, before completing the questionnaire.

2.3 Methods for data analysis

The SUS questionnaire responses are analysed by converting the Likert scale responses to numerical values: 1 for Strongly Disagree, 2 for Disagree, 3 for Neither Agree Nor Disagree, 4 for Agree and 5 for Disagree [48]. Then, each even-numbered question (representing negative questions) has its numerical value subtracted from 5, while each odd-numbered question (representing positive questions) has its numerical value reduced by 1. The new values are added and then multiplied by 2.5. The resulting number is the final SUS score that ranges from 0 to 100. However, this number itself cannot be used to describe how usable a system is. For this reason, a number of interpretations were derived from subsequent studies on SUS, such as letter grade scales, acceptability ranges and adjective scores [42]. *Letter grade scales* describe a system using letter grades that follow the margins being used for school tests (A $\geq$ 90, B $\geq$ 80, C $\geq$ 70, D $\geq$ 60 and F otherwise) [42]. *Acceptability ranges* describe a system as Acceptable if it has a SUS score above 71, High Marginal if its SUS score is greater than 63, Low Marginal if the score is above 51 and Not Acceptable otherwise [43]. *Adjective rating scales* characterise a system based on data points in the SUS scale as Best Imaginable (100), Excellent (85), Good (74), Ok (52), Poor (39) and Worst Imaginable (25) [42].

Interview data (i.e. screen recordings) can be analysed using thematic analysis. *Thematic analysis* is a "method for identifying, analysing and reporting patterns (themes) within data" [47]. The first step requires the transcription of audio recordings and the generation of initial themes. Next, transcripts need to be coded based on the themes, which are later revised to ensure that they match the data. Lastly, each reference to a theme is gathered to facilitate results reporting. NVivo [20] is a tool which can be used to perform a thematic analysis.

Chapter 3

Methodology

This chapter is about describing which methods were used throughout this project. Below, there is an overview of the steps and methods that were followed.

1. **Literature review of the benefits and challenges associated with the use of ARSs in higher education:** The first step was to perform a literature review on ARSs in general, and more specifically with regards to their advantages and disadvantages. The aim of this step was to identify which are the expected educational aims from using an ARS in a class and hence replying to Research Question 1. The results of the literature review can be found in Chapter 4.

2. **Literature review of the design guidelines of ARSs:** The second step was to review design guidelines about ARSs to determine which features lead to the benefits identified in step 1. This list of design guidelines would be used in the next part of the project as the criteria to which the ARSs found in the systematic review were compared. The aim of this step was to respond to Research Question 2. The results of the literature review can be found in Chapter 4.

3. **Systematic review of web-based ARSs used in higher education:** The following step involved the preparation of a systematic review. The PRISMA statement [71] (Section 2.2 in Chapter 2 provides a definition) was used as it provides an extended set of steps to follow when completing a systematic review. After preparing the review, it was time to perform the required searches. The results were filtered based on some selection criteria defined in the previous step. The final list of ARSs was compared using the evaluation criteria as defined in the previous step. The aim of this step was to respond to Research Question 3. The results of the systematic review comparison can be found in Chapter 5.

4. **Usability evaluation of the top three performing tools:** The final step was to perform a usability evaluation of the ARSs that satisfied the most evaluation criteria during the systematic review step. Two usability studies were designed for this purpose: one for teachers and one for students. The teachers' study was conducted with academics from the University of Edinburgh and involved an observation, a questionnaire and a semi-structured interview. The observation was selected because it allowed the simulation of a typical interaction with the tool, which would not have been possible with another method such as a think aloud. The questionnaire was to collect some general information about their interaction, and it was preferred instead of an interview, to allow time for the researcher to prepare for the next part of the study. A SUS [48] questionnaire was used for this purpose (Section 2.2 in Chapter 2 defines SUS and the way the collected data were analysed). The interview was selected to discuss with the participants their interaction with the tool and to expand on topics they wanted to mention (something that would not be possible with a simple questionnaire). The interviews were audio-recorded with the participants' consent and the collected data were thematically analysed using NVivo [20].

   The students' study was conducted with UK students and consisted of an observation and several questionnaires (including the SUS questionnaire). Student participants would be in groups of three; hence, questionnaires would be the most appropriate way to collect information about the student's interaction with the tool. Interviews would have been inconvenient and time-consuming for students to wait for each other, while a focus group would not have been possible due to the small number of participants in each session. Allowing a larger number of participants in each study would have been impractical as not many students were willing to participate. The results collected were analysed in a similar way as the teacher's study. This step aimed to reply to Research Question 4. A description of the usability evaluation can be found in Chapter 6.

5. **Creation of a list of additional design guidelines based on the findings of the usability evaluation:** The final step is to create a list of additional design guidelines that ARSs should follow, based on the outcomes of the usability studies with teachers and students. The aim of this step was to answer Research Question 5. The final list can be found in Chapter 6.

Chapter 4

Audience Response Systems in Higher Education

The first part of the project was to perform a literature review on ARSs, their benefits and challenges. The results of this research are summarised in this chapter. Chapter 2 described three types of ARSs: clicker-based, SMS-based and web-based ARSs. Below there are some advantages and disadvantages regarding their use, along with a list of design guidelines they should follow. The aims of this literature review are: a) to help identify specific features of ARSs that cause those benefits and help avoid the challenges based on their possible uses, b) to enforce the reasoning of choosing to focus this project only on web-based ARSs. Overall, this chapter aims to respond to Research Questions 1 and 2.

4.1 Benefits of Audience Response Systems

The educational benefits of using an ARS in the classroom are well documented in the literature. Most academic studies agree on the observed benefits, especially on the encouragement of active learning [64, 51]. *Active learning* can be defined as "any instructional method that engages students in the learning process" [84]. This can happen mostly during different class activities that move away from students being just passive listeners to a teacher, such as when responding to ARS questions.

By design, ARSs provide features which facilitate the job of the teacher when asking questions to a large group of students. Firstly, they allow teachers to ask questions during lectures [63], and they facilitate a fast and accurate collection, analysis and display of responses from all students [67, 64, 58, 63]. All the above are not possible to

do using only the traditional methods of hand and card raising. In addition, ARSs encourage all students to participate regardless of where they sit in the lecture theatre or their character since they do not need to raise their hand and speak in front of a group of people [91, 82, 59, 58, 89].

The immediate presentation of results allows both students and teachers to get feedback on different aspects. In a multiple-choice question setting where there is a single correct answer, students can immediately see if they have replied correctly [86]. They can also see, where they stand in the class as compared to their classmates [67, 64, 91, 55, 59]. In the same setting, the teacher can immediately see how well students understand the taught concepts and adjust the pace of the lecture accordingly [67, 64, 50, 55, 51, 58, 66]. According to Gennaro [81], questions posed at the beginning of the lecture help the teacher understand the level of student's background knowledge, questions posed during the lecture help to alert and engage students with the taught material, and questions posed at the end of the lecture help the teacher see what students learned during the lecture. In an open question setting, where students are asked their opinion on a topic, their responses can act as a starting point for a class or peer discussion [67, 46, 64, 82, 51, 66], thus improving the interaction between the teacher and the students and between the students themselves [50, 82, 59, 51].

The responses collected can be either anonymous or not, depending on the ARS used. Answering anonymous questions encourages shy and reluctant students to participate without fear of embarrassment if they give the wrong answer [67, 64, 59, 58, 89]. When ARSs are not used in anonymous mode (either because they do not provide one or because of teacher's choice), they can be used for attendance taking [67, 64, 50] and for grading students based on their responses [86]. Furthermore, the use of ARSs can lead to more honest responses. This can happen because ARSs can hide the responses of other students until all the students have replied. In this way, students cannot be influenced by what other students think is the correct answer [67, 46, 58]. At the same time, this feature decreases the pressure to respond in the same way as the majority of students, as is the case with hand-raising [67, 46, 58].

As mentioned earlier, ARSs provide a number of benefits on educational outcomes. For example, ARSs are reported to increase students' attendance, attention, participation, engagement and interaction [67, 46, 64, 91, 50, 82, 55, 59, 51, 58, 89, 66]. In addition, they are reported to promote active learning and improve the quality of learning [67, 64, 91, 50, 55, 51, 66] since teachers can plan their lectures to suit their students' needs based on the immediate feedback they get [67]. Furthermore, ARSs

allow teachers to try new pedagogical strategies [66] and emphasise "time on task" (i.e. the amount of time to sufficiently cover a topic) [51]. Some studies even report that the use of ARSs led to an increase in students' understanding and retention of knowledge and as a result, they can lead to an increase in students' examination grades [46, 64, 50, 66]. This may be because the questions posed during the lecture can help students understand which parts of the lecture are the most important and hence focus their attention on that topic [91, 82]. Other studies mention that ARSs increase the interactivity between the teacher and the students [50, 82, 59, 51] and as a result, students are more satisfied with that course [50]. However, the degree of observing the above benefits depends on the way and frequency that teachers use an ARS in class.

4.2 Challenges of Audience Response Systems

Despite the numerous benefits described above, ARSs are accompanied by some challenges based on how they are used in class. This is true for all types of ARS. However, some challenges were mostly observed in the older versions of ARSs, and are reduced considerably as newer versions evolve. As can be seen below, web-based ARSs solved most of the problems that teachers and universities experienced with clicker-based ARSs.

To begin with, studies report that the use of an ARS in class reduces the amount of time available for new content delivery [67, 50, 51, 66]. Teachers also need to spend more time when preparing their lectures in order to create questions to ask students [67]. Besides, some teachers require further training to gain the ability to create questions and interpret the feedback that will lead to the benefits mentioned above [67, 46, 55, 51]. Some students report that they do not like ARSs when they are used for grading, attendance taking, and in general when ARSs are not used in the anonymous mode because they feel that they are monitored all the time [67]. Also, some students feel that they are not given enough time to answer the questions, and others mention that some of their classmates do not respond honestly and professionally to the questions asked [63]. Lastly, without appropriate training and support, the use of any type of ARS in class can be a "steep learning curve" for all involved members (universities, teachers and students) [66].

The most frequently cited disadvantage of clicker-based ARSs was their cost to buy and maintain them [77, 65]. Clickers represented a significant percentage of the expenses, and in some cases, it was the students that had to purchase them [50, 59].

This practice received a lot of negative comments form students. In contrast, web-based ARSs have minimal costs as there is no specific hardware required to use them; hence, no maintenance costs and students can use their existing devices. In addition, in clicker-based ARSs there were frequent signal errors with clickers, which resulted with responses not being registered (this was especially a problem when those responses received class credits) and very frequent calls to the support team [51, 66]. Since web-based ARS use a Wi-Fi connection to send the responses, this version is considered to be more reliable in general.

Web-based ARSs may have solved many problems of the previous versions; however, they also introduced some new ones. The most important ones are the dependency on internet availability in all classrooms with enough bandwidth to support a large number of students [69], and the requirement that students possess an internet-enabled device [74]. Also, there are concerns over the safe and anonymous exchange of students' responses over the internet [69]. Fortunately, most of these problems are minimal since a Eurostat report [52] shows that 88% of UK students have a smartphone, and most university classrooms provide students with a high-speed internet connection [76]. Lastly, the problem over internet safety can be solved when https connections are used, and no IP addresses are stored with students' responses [69].

4.3 Design Guidelines of Audience Response Systems

From the review of the benefits and challenges, an extensive list of design guidelines that an ARS should follow was derived. It is separated into two sections: Teacher's Interface and Student's Interface. Below there is a short overview of the design guidelines for each interface. Appendix C includes the complete list along with justifications that explain the benefit(s) that each point supports or the challenge(s) that it avoids.

4.3.1 Teacher's Interface

When teachers decide to use an ARS, they also agree to spend some time before their classes to plan what questions to ask and how to ask them. Therefore, an ARS needs to provide them with all the necessary functions to implement what they want. The following design guidelines were created to match the different phases of the teacher's interaction with an ARS. A complete list of design guidelines for the teachers' interface can be found in Appendix C.1.

- **Question Preparation:** ARSs should be support multiple question types [57], as well as accept questions from the audience. They should also allow for integration of questions with content slides via the web interface. Free presentation software plugins for the most popular presentation software should also be provided [44].

- **Question Settings:** ARSs should allow teachers to set up questions to adjust to their needs. Important settings include the ability to a) set a timer for each question [57], b) specify whether to allow or disallow a student to update a response after submitting; c) specifying whether to allow or disallow a student to reply more than once; d) specify whether a response to a question is mandatory or not; e) scoring student's responses based on a correct answer [49, 44]; and f) save questions for future use [83].

- **Results Settings:** Teachers should be able to change how the results are presented before or during a presentation. It is recommended that multiple-choice questions results in a bar chart, while open-ended questions result in a word cloud. Equally important, is the ability to change the default visualisation type as well as the colours of the visualisation [83]. An ARS should also allow for automatic moderation of open-ended question responses and for hiding students' identity when presenting the results to the class. Lastly, teachers should be able to specify whether to allow students' responses to be hidden to the class or not during voting [57, 65].

- **Presentation Screen:** ARSs should have an additional screen for teachers during questions and results presentation, while the presentation screen itself should show the total number/a percentage of students who have already responded [83] and should allow the teacher to manually stop accepting responses even if a timer is set [65].

- **Results Manipulation:** Teachers should be able to store students' responses for all questions asked as well as access them at some point in the future. Also, teachers should be able to see the total number/percentage of students who responded [83] and how much time students required to answer each question. Moreover, teachers should be able to download/email the student's responses for analysis with another software. Lastly, they should be able to delete all questions and responses from the ARS.

- **General:** ARSs should allow the creation of unlimited sessions and unlimited number of questions per session. Also, they need to be able to be used in classrooms with more than 100 students. Online help for teachers should also exist [81], along with free mobile applications for the most popular mobile platforms.

4.3.2 Students' Interface

Despite students only interacting with the ARS for a very short amount of time, as they only have to respond to questions, it is still important to be provided with good user experience. The following design guidelines aim to do exactly that. A complete list of design guidelines for the students' interface can be found in Appendix C.2.

- **Anonymity:** An ARS should support anonymity by not requiring students to log in, provide a name or an email [65].
- **Connect to a classroom environment:** ARSs should allow students to connect to a classroom environment using a URL, a QR code or a URL along with an access code [69].
- **Presentation of questions:** ARSs should show one question at a time, use a secure connection (https) to transfer students' responses [69] and inform students that their response has been submitted.
- **Presentation of results:** ARSs should display the overall results to students' devices [59], along with some personal results for each student.
- **General:** ARSs should provide online help for the students' interface [81], and free mobile applications for the most popular mobile platforms [75].

4.4 Conclusion

In this chapter, a description of the benefits and challenges of ARSs in general and specifically of their various versions was given. Next, a detailed list of design guidelines that an ARS should have was presented. The design guidelines follow the pattern of giving control to the teacher to design the questions as well as enforcing anonymity. The design guidelines can be used as a starting point when designing an ARS, as well as criteria for selecting one to use. In the next chapter, these guidelines will be used to compare a selection of web-based ARSs.

Chapter 5

Systematic Review

5.1 Introduction

The main part of this project was the implementation of a Systematic Review on web-based Audience Response systems used in higher education, aiming to respond to Reseach Question 3. For this reason, the PRISMA statement [71] (for a definition refer to Section 2.2 in Chapter 2) was used to prepare the steps of the systematic review. Below, there is a detailed description of the steps taken, along with the presentation of results.

5.2 Aims and Objectives

The objectives of this systematic review were to a) identify all ARSs that satisfy a set of eligibility criteria; b) derive a set of comparison criteria to evaluate these ARSs; c) evaluate the ARSs against these criteria; and d) identify the best three ARSs (i.e the ones that satisfy the most of the comparison criteria).

5.3 Methods

This review followed a modified version of the PRISMA framework [71]. Each of the seven steps which were relevant for the review is described in detail below.

5.3.1 Eligibility criteria

Only the following types of search results were considered: a) ARS websites, b) research or review articles on ARSs in higher education, c) GitHub pages about projects relating to ARS, d) market research websites that list ARSs and e) description pages of mobile app stores. Informal websites, such as blogs and wiki-style sites, were not included.

The results on academic literature had to be dated in the last five years (i.e. since 2014). The year 2014 is a result of the preliminary research, which showed that web-based ARSs started to be used widely at around that period of time.

The inclusion criteria for the ARSs require the tool to a) be in English; b) be fully developed and ready for use (i.e. not a prototype); c) be able to be used in higher education; d) have the basic functionality of an ARSs as defined in Section 2.1 in Chapter 2; e) match the definition of web-based ARSs as given in Section 2.1 in Chapter 2; f) have a secure account creation/download page (https); e) have a free application to download for all major platforms if a download is required that was last updated within the last two years; and f) be free of charge, have a free trial period that does not require credit card details or be accessible via a University of Edinburgh license.

5.3.2 Information Sources

Google [8] and Google Scholar [11] were the primary databases that the search was conducted. These two databases were chosen as the most comprehensive and relevant as Google [8] could point to the ARSs' official web pages and other supportive material, where Google Scholar [11] could point to academic literature from different sources.

5.3.3 Search Strategy

Due to a large number of results that were returned by both Google [8] and Google Scholar [11] and the limited amount of time to perform the systematic review, it was essential to limit the results using filters. Preliminary research showed that there is an extensive collection of words/phrases that describe ARS (some example synonyms are given in Section 2.1 in Chapter 2). For this search, it was decided that the three most popular ones would be used, i.e. "audience response system", "student response system" and "classroom response system".

For Google [8] the following filters were applied: a) search using the keywords to describe ARSs in quotation marks (e.g. “audience response system”); b) include only English results by modifying the search settings; c) turn off the default emission of similar entries; and d) ignore all the Ad references as well as references to Scholarly articles that appear in the results.

For Google Scholar [11], the following filters were applied: a) search using the keywords to describe ARSs in quotation marks (e.g. “audience response system”) followed by the conjugate AND, and the phrase higher education in quotation marks (e.g. “audience response system” AND “higher education”); b) refine the date range to include results that are up to five years old (i.e. from 2014 to 2019); c) include only English results; and d) exclude references to patents and citations.

All the searches were performed from Edinburgh, United Kingdom in July 2019.

5.3.4 Software Selection

This is a renaming of “study selection” item from PRISMA [71] to better reflect that this systematic review was of software tools.

Initially, the results returned were checked to see if they are of the required type. Then, they were checked to see if they contain an ARS brand name. If there was no reference to an ARS, the result was discarded as being out of scope. If an ARS was mentioned, then the procedure below was followed.

If the resource was an ARS website, that ARS was checked against the inclusion criteria for ARSs mentioned above. If it passed all the criteria, then an entry for that ARS was created in the spreadsheet. If the resource was of another type, it was searched to see if it includes any redirect links the official ARS web page. If a redirect link existed, it was checked against the criteria mentioned above, and the ARS was noted in the spreadsheet or discarded depending on the result. It should be noted here that the ARS name was first checked in the spreadsheet to see if a decision was already taken for that ARS or not to avoid duplicate work. Appendix D includes a diagram of search process.

5.3.5 Software Evaluation

This section describes the “data collection process” and “ data items” steps of PRISMA [71] to better reflect the comparison step.

The ARSs that were identified in the previous steps were evaluated based on a set of evaluation criteria. These criteria were derived from the design guidelines presented in Section 4.3 in Chapter 4. The criteria are separated into two big categories: teachers' interface and students' interface and are for evaluating the respective interfaces. The teachers' criteria are separated in before class, during class, after class and general features, while the students' criteria are separated in before voting, during voting, after voting and general features. Each sub-category is relevant for the respective interactions of each user group.

Data were collected for each ARS by interacting with them. An account was created for each ARS (there were no ARS that did not have a web-interface in the final list; hence, no downloads were necessary) to test its functionality. To test the before class features, sample questions were created to find out which question types were supported along with what settings they offered. Then, the questions were activated, and sample responses were given to produce visualisations of the results and check the during class features along with the students' interface. After that, the session page was revisited to mimic an after-class interaction. Lastly, any other information that was necessary to fill the evaluation of that ARS was searched using the tool's help page.

5.3.6 Synthesis of results

A score was given to each ARS based on the results of the evaluation. For each criterion met, the ARS received one point, and the final score was obtained by summing up all the points. Individual scores for the teacher's and students interface were also calculated to facilitate discussion.

5.4 Search Results

Six searches were conducted in total in both databases using the three keywords. The number of results of each search performed can be found in Table 5.1.

After checking the above 3823 results, 318 ARSs were retrieved. From those, only 34 passed the eligibility criteria, as most of the references were for clicker-based ARSs or of tools that were developed within a university and no download link could be found. Of the 34 selected ARSs, only 25 were included in the final comparison table. These nine tools were discarded during the evaluation stage for two reasons: a) six of them had bugs that prevented the evaluation from taking place in full; and b)

Database	Keyword	No. Results	Date last searched
Google [8]	“audience response system”	367	July 2nd, 2019
Google [8]	“student response system”	329	July 3rd, 2019
Google [8]	“classroom response system”	309	July 5th, 2019
Google Scholar [11]	“audience response system” AND “higher education”	982	July 9th, 2019
Google Scholar [11]	“student response system” AND “higher education”	980	July 11th, 2019
Google Scholar [11]	“classroom response system” AND “higher education”	856	July 13th, 2019

Table 5.1: Systematic Review Search Results

three had problems with the account creation process. The final list of ARSs found was categorised based on their version used.

Partial Version: In this version, only some of the features that an ARS offers are available free of charge. This could either be with or without a time limit. None of the ARSs below had a time limit for the partial version features to be accessible (they all had a free version). The final list of the partial version ARSs are Poll Everywhere [24], Wooclap [37], Mentimeter [19], UMU [34], Socrative [30], Slido [29], Crowdpurr [6], Quiz-maker [28], Meeting Pulse [18], VoxVote [35], Kahoot! [16], Glisser [7], GoSoapBox [13], Imakiku [14], TapToSpeak [31], OnlineTED.com [21] and IQPolls [15].

Full Version: In this version, all of the features that an ARS offers are available free of charge. This could either be part of a limited trial version, because the tool is free by design, because it is open source or because it was accessible via an educational/University of Edinburgh license. The final list of the full version ARSs are: TopHat [33], ARSnova [3], Pingo [22], Zeetings [38], Q-ARS [27], Teachably [32], AuResS [4] and Answer Garden [1].

5.5 Evaluation of Search Results

The comparison of ARS showed that the overall best three ARS are Wooclap [37] (67%), Poll Everywhere [87] (65%) and Mentimeter [19] (59%). Figure 5.1 shows an overview of the comparison results. Below, there is a summary of the results per user

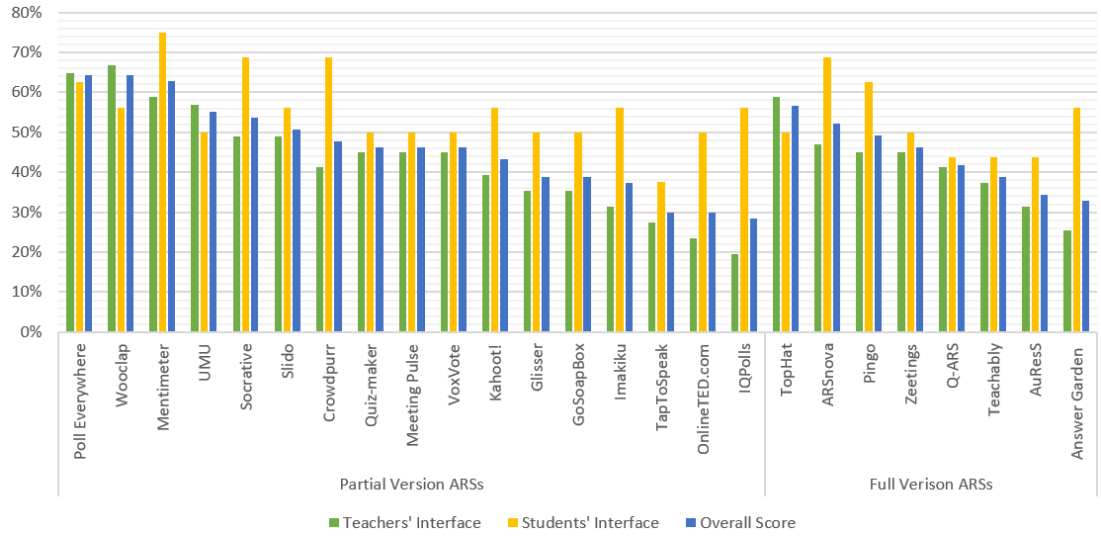

Figure 5.1: Comparison results of the ARS identified in the systematic review.

interface.

5.5.1 Teacher's Interface

The highest-scoring ARSs in the teacher's interface were Wooclap [37] (67%), Poll Everywhere [24] (65%), Mentimeter [19] (59%) and Top Hat [33] (59%). Regarding presentation preparation, Wooclap [37] was the only tool that satisfied all the possible question types, while all three ARSs scored the same in the settings available (67%). Unfortunately, all four ARSs, scored averagely in the presentation of questions (PE: 40%, WC: 60%, MM: 60%, TH: 40%), mostly because they do not provide a dual-screen during the presentation. On the other hand, Poll Everywhere [24] and Mentimeter [19] scored high regarding the presentation of the results (83%). In terms of results manipulation, all ARSs but Top Hat scored averagely, (PE: 63%, WC: 63%, MM: 50%, TH:75%). Lastly, the three free-version ARSs scored poorly in the general category of features, as no tool offered a mobile app for teachers and they all had different limitation regarding the maximum number of sessions, questions per session and students supported. To be more specific, Poll Everywhere [24] and Wooclap [37] only supports 25 and 30 students per session, respectively, while Mentimeter [19] only supports two questions per session. Top Hat [33] did not have such limitations.

The remaining ARSs scored average to low in most categories. It is worth mentioning that Slido [29], Crowdpurr [6], Meeting Pulse [18] and Zeetings [38] scored highly (80%) regarding the presentation of questions, a category where the top-performing

ARSs scored averagely. The only free version ARS that has no limitations in the number of students, questions and sessions supported is Kahoot! [16]. This ARS also, along with UMU [34] and Socrative [30] are the only ones that offer a mobile app for teachers. Lastly, it is worth noting that all ARSs apart from Answer Garden [1] support single-choice polls while most tools also support open-ended queries.

The comparison tables of the teachers' interface can be found in Appendix E.1.

5.5.2 Students' Interface

The highest-scoring ARSs in the students' interface were Mentimeter [19] (80%), Socrative [30] (69%), Crowdpurr [6] (69%) and ARSnova [3] (69%). Overall, most ARS (20 out of 24) satisfied all the criteria about anonymity, while Top Hat [33] was the only ARS that required students to log in before connecting to a classroom environment. Regarding the ways to connect to a session, Mentimeter [19] and Wooclap [19] were the only ARSs that allowed students to connect using any of the recommended methods. Additionally, most tools (21 out of 24) satisfied all the criteria about the presentation of questions, with no tool using a non-secure connection. On the other hand, not many tools performed well in the presentation of results, with only five out of 24 ARSs getting all the points and an additional 11 tools only satisfying one of the two criteria. Similarly, only eight ARS provide a help page for students and only five out of 24 offer students a mobile application.

The comparison tables of the students' interface can be found in Appendix E.2.

5.6 Conclusion

This chapter described a systematic review on web-based ARSs used in higher education, followed by a comparison. The results of the comparison can be used by teachers and universities when deciding which ARS to use. The overall best three ARSs when considering both teacher's and students' interfaces are Poll Everywhere [24], Wooclap [37] and Mentimeter [19]. These three ARSs will be used in the next part of the project, which is a usability evaluation.

Chapter 6

Usability Evaluation

6.1 Introduction

This chapter presents the usability studies that were performed to evaluate the best performing ARS identified in the systematic review (see Chapter 5). The overall highest-scoring ARSs were selected for a usability evaluation. The three ARSs are: Poll Everywhere (PE) [24], Wooclap (WC) [37] and Mentimeter (MM) [19]. To evaluate the above ARSs, two usability studies were designed: one for teachers and one for students to test the respective interface. Each study is described below. The aim of this chapter is to respond to Research Questions 4 and 5.

This research has received an ethics approval from the School of Informatics, The University of Edinburgh, according to the Informatics Research Ethics Process, RT number 2019/803019.

6.2 Teachers' Study

Below there is a description of the aims and objectives of the study, the participant recruitment process, the methods and materials used, the data collection and analysis methods and an overview of the results.

6.2.1 Aims and Objectives

This study was aimed at collecting teachers' perspectives on the usability of the top three ARSs and to collect suggestions on how to improve them in terms of usability and functionality.

The objectives of the study were to identify which ARS: a) provided teachers with the best user experience; b) was the most challenging to use; c) provided the best question creation experience; d) provided the best presentation experience; and e) provided the best after-class experience.

6.2.2 Participants

For this study, academics from the University of Edinburgh were recruited via the supervisors' contacts. Ideally, the participant should not have used any of the three ARSs as a teacher, but previous experience with another ARS was not an issue. It was expected that a small number of academics would be willing to participate; hence, it was decided that all of them would be asked to interact with all ARSs to collect enough data. This meant that each session had to last for at least one hour. To eliminate the learning effect, each participant would be shown the tools in a different order.

Six academics volunteered to participate in the study. Their details and the order that the ARSs were presented to them can be found in Table 6.1. Participant names were hidden to preserve their anonymity, and instead, a Participant Identification code (P. ID) is used throughout this chapter.

P. ID	Academic position	ARS Experience	Last time used an ARS	ARS Order
TP1	University Teacher	No experience	-	PE, WC, MM
TP2	Univesrsity Teacher	TopHat [33]	Last semester	WC, PE, MM
TP3	University Teacher	No experience	-	MM, WC, PE
TP4	Lecturer	Google Forms [9]	Last month	PE, MM, WC
TP5	Research Fellow	No experience	-	WC, MM, PE
TP6	University Teacher	Plickers [23]	Last semester	MM, PE, WC

Table 6.1: Participant profiles along with the order that the ARSs were shown to them.

6.2.3 Methods

During the study, participants were asked to perform a set of tasks, respond to a general questionnaire and then participate in a semi-structured interview to discuss in detail their interaction with the ARS. This procedure was repeated for each ARS. In the end, teachers were asked to compare the tools in a final interview.

Observation: The first part of the study for each ARS was an observation. The teacher was asked to perform a set of tasks using each of the ARSs using the re-

searcher's laptop. Their interactions were screen recorded upon their consent to allow for further analysis. Besides, the researcher was also taking notes of any important observations or comments that the participant made during their interaction.

The tasks that participants were asked to complete cover the three main phases of a typical interaction with an ARS: a) before class, b) during class and c) after class. The same set of tasks were given for all ARSs so that the results were comparable. An overview of the tasks is given in Table 6.2, while the full list of tasks that participants were given can be found in Appendix F.4.

Task 1 asked participants to create two questions, a multiple-choice one and an open-ended one and adjust their settings. Some of the settings that were asked were available by default for some tools, and this was indicated to them.
Task 2 asked participants to present the questions they had created in Task 1 and the results. At this point, the researcher acted as a student and provided some sample responses to the questions the participant created, so that some results could be produced.
Task 3 asked participants to browse the results one more time and download an overall report. For some tools, the overall report was only available in the premium version, so instead an individual report for each question was acceptable.

Table 6.2: Overview of teachers' tasks

Questionnaire: The questionnaire was based on the System Usability Scale (SUS) [48] and was asking general questions about the participant's interaction with the system. Participants were given to complete a paper version of the questionnaire.

Interview: During each teacher's study, there were five interview sessions: a) a very brief initial interview which asked participants about their past experience with ARSs; b) an "experience" interview after they interacted with each ARS to comment on specific aspects of their interaction; and c) a final interview to compare the three ARSs. All interview sessions apart from the initial interview were audio recorded upon participants' consent to allow for further analysis.

6.2.4 Materials

The materials used in each study are given in Table 6.3. A copy of the participant information sheet, consent form, researchers script, the teachers' tasks, questionnaire and the interview questions can be found in Appendix 6.2.

A *participant information sheet* that includes important information about the study.
A *consent form* that the participant should sign before beginning the study.
A *researcher's script* to ensure that all participants are given the same information.
A list of *teacher's tasks* that the participant had to complete during the observation.
Three copies of the *SUS questionnaire* for the participant to complete.
A *list of the interview questions* for the researcher to ask the participant.
A *pen* for the participant to use when needed and for the researcher to take notes.
Some *paper* for the researcher to take notes during the observation and the interview.
A *laptop* device that has a screen recorder installed.
A *mouse* device in case the participant prefers to use rather than the laptop's trackpad.
An *audio recorder* to record the interviews.

Table 6.3: The materials required to run the teachers' study.

6.2.5 Study Procedure

Each session was run based on a researcher's script. Initially, the participant was given a short introduction about ARSs and the study procedure. Then, they were asked some questions about their previous experience (if any). Afterwards, an ARS was shown to them one at a time, and they were asked to complete a set of tasks while being observed. Their interactions were recorded using a screen recorder and note-taking. Next, they were asked to complete a SUS questionnaire [48]. The last part was an interview about their interactions with the tool. This procedure was repeated for the two remaining ARSs. In the end, the participant was asked to compare the three ARSs in a final interview. After the study, if the participants asked, they were shown how to find some of the features that they could not find during the observation.

6.2.6 Results Analysis

The screen recordings were used to identify common problems that participants experienced while interacting with the ARSs.

The SUS [48] results were analysed using the recommended method as described in Section 2.3 in Chapter 2 to get a final score. The score was then interpreted using the acceptability ranges defined in Section 2.3 in Chapter 2, which classifies a system as *Acceptable*, *High/Low Marginal* or *Not Acceptable* based on its SUS score [43].

The qualitative results collected from the audio recordings were analysed using a

thematic analysis as described in Section 2.3 in Chapter 2. NVivo [20] was used to create themes and match them to specific parts of the interview transcriptions. A mixture of top-down and bottom-up approaches were used to create the themes. Initially, themes were extracted from the topics asked in the interview questions and then more themes were created to match comments specific to a sub-topic of the discussion.

The final NVivo [20] node hierarchy that describes the themes found in the transcribed text consists of four super-nodes, one for each ARS and one for comparing them: Poll Everywhere [24], Wooclap [37], Mentimeter [19] and Comparison. The Comparison node has a sub-node for each question asked in the comparison interview along with a general one. Each ARS node has four sub-nodes, one of each phase of the teachers' interaction with the ARS and a general one: Before Class, During Class, After Class and General. Before Class has sub-nodes for Question Creation and Settings; During class has sub-nodes for Presentation screen and Results Presentation; After Class has sub-nodes for Results Viewing and Results Downloading; General has sub-nodes for Interface, Expectations and Comparisons. Each of the sub-sub-nodes (except Expectations and Comparisons) are separated into Positive, Negative and Suggestions. Sub-nodes for specific settings and suggestions that were common among participants were created under the corresponding node. The complete structure of the NVivo [20] nodes can be found in Tables G.1 and G.2 in Appendix G.1.1.

6.2.7 Results

From the observations, it can be seen that all participants experienced difficulties with adjusting the settings of each question, especially in Poll Everywhere [24] and Mentimeter [19]. Participants were particularly confused when they were asked to set up a timer for these tools. While some of them were able to find this feature for Mentimeter [19], no one could find it in Poll Everywhere [24]. Another common mistake that involved Wooclap [37] and Mentimeter [19] was that participants instead of adding another question to the same session, they created a new one which was not necessary. One participant also overwrote the first question to create the second one, and only realised it during the presentation. A common problem for Poll Everywhere [24] was that participants did not recognise that the screen they were using to set up the question was also the presentation screen, while for Wooclap [37] and Mentimeter [19] three participants could not find how to exit the presentation. Additionally, for two participants, it was not clear how to move to the next question during the presentation when using

Mentimeter [19]. Lastly, all participants experienced some sort of problems with at least one ARS while trying to view and download the results.

The SUS scores for each ARS along with their acceptability range score can be found in Table 6.4. The average scores for the three ARSs are very similar and are all considered Low Marginal. Mentimeter [19] is the ARS with the highest overall score of 82.5, which is considered Acceptable. Mentimeter [19] also has the highest average score (61.67). The ARS with the lowest overall score is Poll Everywhere [24] with 35, which is considered Not Acceptable. Poll Everywhere [24] also has the highest number of Not Acceptable scores with four out of six being less than or equal to 50.

P. ID	Poll Everywhere [24] Score		Wooclap [37] Score		Mentimeter [19] Score	
	Raw score	Acceptability	Raw score	Acceptability	Raw score	Acceptability
TP1	40	Not Acceptable	**77.5**	Acceptable	75	Acceptable
TP2	65	High Marginal	55	Low Marginal	**82.5**	Acceptable
TP3	45	Not acceptable	**42.5**	Not Acceptable	**42.5**	Not Acceptable
TP4	**35**	Not Acceptable	65	High Marginal	**42.5**	Not Acceptable
TP5	**80**	Acceptable	45	Not Acceptable	60	Low Marginal
TP6	50	Not Acceptable	75	Acceptable	67.5	High Marginal
Average	52.50	Low Marginal	60	Low Marginal	**61.67**	Low Marginal

Table 6.4: Teachers' SUS [48] scores, along with their acceptability scores of the top three ARSs (green for highest scores and red for lowest scores per ARS).

During the interviews, it was revealed that participants were not very satisfied with their experience, as it can already be seen from the above scores.

Poll Everywhere [24]: There were many negative comments about this ARS starting the labelling and visibility of buttons which was found to be confusing by many participants. TP3 mentions that "there is nothing to support you to create a quiz". The main problem of this ARS was that there were a lot of things to control, and participants were lost looking for them. Characteristically, TP2 mentioned that it "had lots of good options, I thought once you found them". Moreover, four participants commented negatively about the many options that exist on the presentation screen, with TP4 commenting "so students will see me clicking activate and deactivate [...] that's something that doesn't need to be shown [...] it's not like the students will gain anything from it being on the screen". Also, while participants noted that it was hard to find a summary of the results after the presentation, TP4 liked the existence of raw

results without a visualisation applied to them.

Wooclap [37]: The comments that this ARS received were mostly positive, starting with the question creation process and TP1 noting that "it's good that you only have those settings which are available for you for each type of questions so that it's not confusing". Regarding the presentation screen, some participants mentioned that it was clean enough to be used in class, while others noted that the colours were not appropriate. There were mixed reactions regarding the downloading of the results. This can also be explained by the fact the there were three different ways to complete this task with one involving an error message. Clearly, the participants who experienced this message were not happy, but even the only participant who arrived at the visually appealing page of the results was not very satisfied because the button to get there was hidden in a settings menu. Characteristically, TP5 comments: "settings is something that you expect some parameters to set, [...] actions like exporting something or generating a report are underneath a button which is called settings [...] seems to be completely not intuitive".

Mentimeter [19]: This ARS received mostly positive comments like: "I liked the fact that you can make a whole presentation by adding slides, that's great" (TP1), but there were also some negative experiences. Specifically, a third of the participants were confused by the name "presentation", as they were expecting something related to "question". Although participants experienced a few problems during the presentation, most of them had positive things to say. Most participants had no problems finding the correct button to download the report, while TP4 comments that a way to access raw data as a table of numbers would be useful. Lastly, there were a couple of negative comments regarding layout not being very clear and buttons that were not labelled appropriately. In the end, TP2 expressed her interest in the full version of the tool as "there were some good options".

A common suggestion for all the ARSs made by TP5 and TP6 was the addition of a separate screen during the presentation, to de-clutter the main presentation screen and allow more options to the teacher.

Overall, academics believed that Wooclap [37] provided the best user experience. On the other hand, Poll Everywhere [24] was referred by most participants as the most challenging one to use. In each specific category the best ARSs were Mentimeter [19] for question creation, Wooclap [37] and Mentimeter [19] for presentation experience, Poll Everywhere [24] and Mentimeter [19] for after-class experience, while most participants would consider using Wooclap [37] and Mentimeter [19] in their classes.

These findings came from the final comparison interview. The results per participant can be found in Table G.3 in Appendix G.1.1.

6.3 Students' Study

Below, there is a description of the aims and objectives of the study, the participant recruitment process, the methods and materials used, the data collection and analysis methods and an overview of the results.

6.3.1 Aims and Objectives

This study was aimed at collecting students' perspectives on the usability of the top three ARSs and collect suggestions on how to improve them in terms of usability and functionality.

The objectives of the study were to identify which ARS: a) provided the best user experience; b) was the most challenging to use; c) provided the best connection to classroom experience; d) provided the best way to respond questions; and e) provided the best way to view the results.

6.3.2 Participants

For this study, students from UK higher education institutions were recruited using the researcher's contacts, and they were asked to bring a web-enabled device with them. Previous experience with using an ARS to create or respond to questions was not an issue. It was expected that a small number of students would be willing to participate, hence it was it decided that students would be in groups of three (to simulate a lecture environment; no interaction with the other students was necessary) and that all groups would be asked to interact with all ARSs to collect enough data. This meant that the study had to be about half-an-hour long. To eliminate the learning effect, each group would be shown the tools in a different order.

Nine students volunteered to participate in the study; therefore, forming three groups. Their details, along with their preferred device to respond to questions and the order that the ARSs were presented to them can be found in Table 6.5. Similarly to the teachers' study, participant names were hidden to preserve their anonymity and instead, a Participant Identification code (P. ID) is used throughout this chapter.

P. ID	ARS Experience	Last time used an ARS	Preferred Device	ARS Order
SP1.1	TopHat [33]	Last semester	Smartphone	PE, WC, MM
SP1.2	Mentimeter [19]	Last academic year	Smartphone	PE, WC, MM
SP1.3	TopHat [33]	Last semester	Smartphone	PE, WC, MM
SP2.1	Mentimeter [19]	Earlier this academic year	Smartphone	WC, PE, MM
SP2.2	TopHat [33]	Last academic year	Smartphone	WC, PE, MM
SP2.3	TopHat [33]	Last academic year	Smartphone	WC, PE, MM
SP3.1	Mentimeter[19], TopHat [33]	Last semester	Laptop	MM, WC, PE
SP3.2	Mentimeter [19]	Last semester	Smartphone	MM, WC, PE
SP3.3	Mentimeter [19]	Earlier this academic year	Smartphone	MM, WC, PE

Table 6.5: Participants' profiles, along their preferred device to respond to questions and the order that ARSs were shown to them.

6.3.3 Methods

During the study, participants were asked to respond to a set of questions using each ARS, and then complete two questionnaires to comment about their interaction both in general and in relation to the tasks they had to do. In the end, students were asked to compare the tools in a final questionnaire.

Observation: The first part of the study was an observation. Students were asked to connect to a classroom environment using one of the ARSs and then respond to two questions using their personal devices: a) a multiple-choice question which had a correct answer and b) an open-ended question where participants could submit as many answers as they wanted. The researcher was taking notes of any important observations or comments that the participants made during their interaction.

Questionnaire: During each students' study, there were seven questionnaires to complete: a) a SUS questionnaire [48] to gather general information about the ARSs; b) an "experience" questionnaire to collect more specific information about their interaction with each ARS and any comments or suggestions that students had; and c) a final questionnaire to allow students to compare the ARSs and provide some demographic data. Students completed all the questionnaires using their personal devices.

6.3.4 Materials

The materials used for each students' study can be found in Table 6.6. The participant information sheet, consent form, the researcher's script for the students' study, and the questionnaire questions can be found in Appendix F.

A *participant information sheet* that includes important information about the study.
A *consent form* that the participant should sign before beginning the study.
A *researcher's script* to ensure that all participants are given the same information.
A list of *questionnaire links and QR codes* that the participants can use to complete the questionnaires using their devices.
A *pen* for the participant to use when needed and for the researcher to take notes.
Some *paper* for the researcher to take notes during the observation.
A *laptop* device to show the questions to students.
An *HDMI* cable to connect the laptop to a projector, if the room of the study allowed so that all participants could easily see the screen.

Table 6.6: The materials required to run the students' study.

6.3.5 Study Procedure

Each session was run based on a researcher's script. Initially, each group of participants was given a short introduction about ARSs and the study procedure. Then, they were shown the first ARS and were asked to connect to the classroom environment. Once everyone was connected, they were shown the first question (multiple-choice) and were given some time to respond. When all the students had responded, they were shown the second question (open-ended), and they were asked to provide more than one responses. After their interaction with the ARS, they were provided with a link to complete the SUS questionnaire [48] and then the experience questionnaire. The same procedure was repeated for the other two ARSs. In the end, participants were given another link to complete the final questionnaire.

6.3.6 Results Analysis

The results from the observations were used to identify any common problems that participants experienced while interacting with the ARSs.

The SUS results were analysed using the recommended method [48] as described in Section 2.3 in Chapter 2 to get a final score. The score was then interpreted using the acceptability ranges [43] defined in Section 2.3 in Chapter 2, which classifies a system as *Acceptable*, *High/Low Marginal* or *Not Acceptable* based on its SUS score [48].

The results collected from the experience questionnaire were scored based on students' responses and were used to create a final score in percentage form for each ARS. To be more specific, students were asked to rate specific parts of the tools. They were given five options: Excellent, Above Average, Average, Below Average, Poor. The number of students that selected each rating was summed and then multiplied by the total number of participants. That value was transformed to a percentage and was used in conjunction with the other results to determine which is the best ARS.

Participants' comments to the open-ended questions at the end of the experience questionnaire were analysed using thematic analysis as described in Section 2.3 in Chapter 2. The NVivo tool [20] was used to match the text to nodes. Each node represents a theme. The themes were extracted using a mixture of top-down and bottom-up approaches. Initially, the topics asked in the questionnaire were used to create a theme and then, more themes were added to match individual sub-topics.

The final NVivo [20] node hierarchy that describes the themes found in the comments of all questionnaires has three super-nodes, one for each ARS: Poll Everywhere [24], Wooclap [37] and Mentimeter [19]. Each ARS node has four sub-notes, one for each kind of interaction with the ARS: General, Replying to Questions and Results Presentation. General has sub-nodes for Connection Experience and Interface; Replying to Questions and Results Presentation have sub-nodes for Multiple-Choice and Open-Ended. Each sub-sub-node is separated into Positive, Negative and Suggestions. The complete structure of the NVivo nodes can be found in Table G.11 in Appendix G.

6.3.7 Results

There were no issues during the observations. All students could complete the tasks.

The SUS scores for each ARS, along with their acceptability value, can be found in Table 6.7. Mentimeter [19] is the tool with the highest score overall, with one student scoring 100 and average score of 80.83, which is considered Acceptable. Mentimeter's [19] lowest score is also on the High Marginal range, while Wooclap's [37] lowest score is on the Low Marginal range with 57.5 and Poll Everywhere's [24] is on the Not

Acceptable range with 50. Mentimeter [19] also has the highest number of Acceptable scores (seven out of nine) when compared to the other two. On the other hand, Poll Everywhere [24] is the only tool which has a Not acceptable score. In general, Poll Everywhere [24] and Wooclap [37] have very similar scores when considering their averages (71.94 and 71.39, respectively).

P. ID	Poll Everywhere [24] Score		Wooclap [37] Score		Mentimeter [19] Score	
	Raw score	Acceptability	Raw score	Acceptability	Raw score	Acceptability
SP1.1	70	High Marginal	65	High marginal	82.5	Acceptable
SP1.2	**95**	Acceptable	**90**	Acceptable	87.5	Acceptable
SP1.3	80	Acceptable	75	Acceptable	**65**	High marginal
SP2.1	85	Acceptable	87.5	Acceptable	72.5	Acceptable
SP2.2	92.5	Acceptable	62.5	Low marginal	70	High marginal
SP2.3	70	High Marginal	82.5	Acceptable	82.5	Acceptable
SP3.1	52.5	Low Marginal	62.5	Low marginal	**100**	Acceptable
SP3.2	52.5	Low Marginal	**57.5**	Low marginal	87.5	Acceptable
SP3.3	**50**	Not acceptable	60	Low marginal	80	Acceptable
Average	71.94	Acceptable	71.39	Acceptable	**80.83**	Acceptable

Table 6.7: Students SUS [48] scores, along with their acceptability scores of the top three ARSs (green for highest scores and red for lowest scores per ARS).

When considering the scores from the experience questionnaire, Mentimeter [19] also gets the highest score overall with 84%. However, this is not true for the individual categories, where Poll Everywhere [24] is ahead by getting the highest score in four out of six categories. Wooclap [37] gets the lowest average score out of three (80%), but since all the scores are relatively high and similar, all the tools seem to be perform equally well when compared to the teacher's interface. An overview of the scores can be found in Table G.8 in Appendix G. A more detailed descriptions of how these scores were derived can be found in Tables G.5, G.6 and G.7 in Appendix G.

Note: One student participant did not submit their experience questionnaire for Mentimeter [19]; hence, only the percentages can be used for comparison and not the absolute scores since there is a difference in the number of participants for that ARS.

In terms of the students' final questionnaire, the preferred ARS for most students is Mentimeter [19], followed by Wooclap [37]. Mentimeter [19] is considered to provide the best user experience to more than half of the participants, while the remaining

students prefer Wooclap [37]. Most students said that no tool was challenging to use, but two selected Poll Everywhere [24] and one selected Wooclap [37]. In all other categories, Mentimeter [19] was selected as the best tool by getting four votes per category, while the other five votes are distributed in the other two tools. The results can be found in Table G.9 in Appendix G.

When students were asked to compare the three ARSs they used in the study with the ARSs they had used in the past, Mentimeter [19] seems to be preferred by students who had experience with the same tool. On the other hand, students who had experience with Top Hat [33] showed a slight preference towards Wooclap [37] and rated Mentimeter [19] and Poll Everywhere [24] in about the same way. This comparison can be found in Table G.10 in Appendix G.

Lastly, when students were asked to provide comments about the ARSs and suggestions on how to improve them, it was frequently asked a) to show the final result on the students' device; and b) to improve the submission instructions for the open-ended question, so that it is clear that multiple responses are allowed. Regarding Poll Everywhere [24], it was mentioned that asking for a username caused confusion. Comments specific to Wooclap [37] included a) improving the on-screen feedback for open-ended responses; b) providing more space for the open-ended question response field; and c) improving the connection to classroom experience when using a URL as the short code is difficult to type. Lastly, comments regarding Mentimeter [19] were to a) improve the way that the correct option to the multiple-choice question is displayed; and b) only show one text-box to submit an answer to the open-ended/word cloud question.

Finally, it is worth noting that most students used their smartphones to respond to questions and that most of them chose to connect using a URL, even though other options were available. This can be seen in Table G.4 in Appendix G. Smartphones are also most students' preferred way to respond to question as Table 6.5 shows.

6.4 New design guidelines

Based on the results of the above studies, the following additional design guidelines were derived.

Teachers' Interface: Most of the teachers' suggestions on things to improve were already included in the design guidelines, it was just the case that these ARS did not include them or they included them in their premium version. To summarise them here, teachers asked for: a) structured process to guide the question creation process;

b) two presentation screens (one to be displayed to the class and one for the teacher); c) preview of raw results through the web-interface; d) download of an overall report of results for all the questionnaires; e) better labelling of the buttons; and f) cleaner interfaces, but at the same time with enough features.

Points b) and d) are already included in the design guidelines. From the above, the following new design guidelines can be created: a) option to create questions following a tutorial integrated in the interface; b) availability of raw results (students' responses presented in a simple table without any visualisations applied to them); c) intuitive button names, with visible labels. In the case of icons, a meaningful description should be given when hovering over them; and d) clean layout without too many menus that can become confusing, but still containing the maximum possible functionality.

Students' Interface: Student's comments were mostly specific to each ARS as can be seen in Section 6.3.7, but still, some degree of generalisation is possible. Similarly to the teachers' interface, some features that students suggested were already included in the design guidelines; it just happened that the tool did not include them or were available if the student provided an email. From their suggestions, the following design guidelines were derived: a) provide a meaningful access code to connect to a classroom environment; b) do not ask for any identification information while trying to connect to a classroom environment; c) show timer on student's device, if one is set; and d) provide submission instructions and any special requirements (e.g. allowed to submit more than once) on the students' device.

6.5 Conclusion

This chapter presented a usability study on the teachers' and students' interface for three ARSs: Poll Everywhere [24], Wooclap [37] and Mentimeter [19]. In the study, participants were asked to perform some tasks and then comment on their interactions. The results showed that teachers were mostly dissatisfied with their experience, while most students found the tools acceptable. Mentimeter [19] was, overall, the most favourable ARS, followed by Wooclap [37]. Participants' comments showed some suggestions on how to improve the three ARS. From those suggestions, some new design guidelines could be extracted that can be used when designing an ARS. A complete list of design guidelines can be found in Appendix H.

Chapter 7

Conclusion

7.1 Answers to Research Questions

This project has answered the research questions described in Chapter 1 as follows:

Research Question 1: Using ARSs in higher education can result in numerous benefits such as an increase in students' attention, attendance and participation [67] while encouraging active learning [51]. A full description of the educational aims from the use of an ARS can be found in Chapter 4.

Research Question 2: ARSs need to be able to a) support different question types that can be adjusted to match the teachers' needs; b) allow the teacher to define how the results should be presented; c) provide a clear presentation screen with enough controls; and d) allow the manipulation of the responses after the session. From the students' perspective, ARSs need to a) allow them to connect easily and anonymously to a classroom environment; and b) present them the questions asked along with the results. Besides, ARSs should provide online help and mobile applications. A full description of the design guidelines for ARSs can be found in Chapter 4.

Research Question 3: 24 ARSs were compared in terms of the above criteria, and the results showed that not many tools satisfy many of them. The comparison is described in Chapter 5, and the comparison tables can be found in Appendix E.

Research Question 4: The best three ARSs from the comparison were rated averagely by the academics who used the teachers' interface, while students who used the students' interface rated them better. Chapter 6 describes the teachers' and students' usability studies and presents their results.

Research Question 5: Results from the usability studies showed that teachers want to be provided with a) a structured way to create questions; b) raw results; c) improved

button names; and d) a clean layout, while students want a) meaningful access codes; b) fully anonymous mode; c) timer presented on their device; and d) clearer submission instructions. Chapter 6 has an overview of the additional design guidelines.

7.2 Discussion

Despite the limited amount of time available to complete this project, a substantial amount of work was performed. Initially, a review of the literature allowed the exploration of ARSs in-depth and the understanding of what they require to be usable in the classroom. The systematic review made possible the identification of a vast amount of ARSs, which were then evaluated based on criteria. PRISMA [71] made the process easier by providing a list of steps to follow, which need to be clearly defined before starting the review.

In addition, some improvements could be made in the usability study. Firstly, a larger number of participants would allow for a more significant collection of results and suggestions and a broader representation of user types. However, this would require an enormous amount of work to analyse each session and possibly a group of researchers would be required. This would facilitate the extraction of quantitative results from the screen recordings during the teachers' study such as time, number of clicks, number of pages and number of errors to complete a task. This was originally the purpose of the screen recordings in this study as well, but due to time constraints, this could not be completed, and only high-level data could be extracted.

7.3 Future Work

The results of this project can provide the basis for future work. The comparison tables can be augmented to include an evaluation of the full version of those ARSs that were compared based only on their partial version which was available for free. This can provide a more accurate representation of the capabilities of each tool and an improved guide for universities, that can usually afford to invest in the full version of software to provide a better experience to students. In addition, these criteria can be adjusted for specific disciplines. Examples include options to format text to look like program code or support mathematical formulas for complex equations. Last but not least, The final list of design guidelines can be used to create some prototypes or even a working system of an ARSs that satisfies all of the mentioned criteria.

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Appendix A

Evolution of Audience Response Systems

This Appendix should be read in conjunction with Chapter 2.

The first audience response systems started appearing in 1950s to replace hand raising as an effort to increase engagement in large lecture theatres [39]. The first version of ARSs required no electronic equipment and it was meant to facilitate the collection of responses from students. In this version, students were given paper response cards with the letters A, B, C and D, and they are asked to raise each of them when being asked a multiple choice question. Then the teacher counted the A, B, C and D responses, and then comments on the results [58].

Although this card raising method has some advantages over hand raising, it still has similar limitations. More precisely, card raising discourages students to vote with the majority since all students are asked to raise their cards at the same time (not per each option as in the hand raising method) and it is not easy to see what other students have responded. However [58] mentions that in their study students were not responding immediately and were waiting to see what other students responded. Lastly, even though the teacher can count the responses easier, this method still does not produce accurate results. Because of the extra burden of creating and distributing the cards, this method was not widely adopted [85].

With the wider adoption of technology in classrooms, electronic ARSs started appearing in the market. These systems consisted of three main components: the response keypads or "clickers" to be used by students to submit responses, the response receiver to collect students' responses, and dedicated software to aggregate and present the results [58]. The software had to be installed in all the computers that would use the

system. The same is true for the response receiver which accepted infrared (IR) signals and later radio frequency (RF) signals. Systems using RF signals allowed a larger number of students to respond [44]. The clickers were purchased either by university or by each student, but each case had different advantages and disadvantages.

The problem of purchasing hand-held devices was solved using a so-called SMS-based ARSs. In these ARSs students could use their own mobile phones to send an SMS with their response. This version was encouraged by statistical results showing that many students carry a mobile phone with them and also by the small cost of sending an SMS (zero cost in some carriers). A response receiver was still needed and consisted of SIM enabled modems to collect the responses, which were then summarised and presented to students via some presentation software [70]. Although this version did reduce the cost of purchasing clickers, it introduced other disadvantages which discouraged their wide adoption.

The next and current generation of ARSs solves many of the problems of the older versions and takes advantage of the availability of wireless internet services in classrooms besides the wide adoption of mobile devices. This ”web-based” version of ARSs does not require the purchase and installation of specific hardware. Clickers are replaced by students' own handheld devices, initially internet-enabled PDAs and iPods and later smartphones, tablets and laptops. A response receiver is not needed, because the responses are sent via Wi-Fi to some cloud server, which also summarises the results which are later presented using a web-interface [77]. Access to this online interface to present the questions and the results can be free of charge or upon paying a license fee, depending on the brand.

Appendix B

Definitions of terms related to Audience Response Systems

This chapter includes definitions of the question types that an ARS should support and should be read in conjunction with Chapter 2.

- A *single-choice poll* is a query that has a number of options as possible answers but the audience c*an only select one* of them. None of the options is selected to be the correct one.
- A *single-choice question* is a query that has multiple options as possible answers but the audience *can only select one* of them. At least one of the options need to be selected as the correct one.
- A *multiple-choice poll* is a query that has multiple options as possible answers and the audience *can select more than one* of them. None of the options is selected to be the correct one.
- A *multiple-choice question* is a query that has multiple options as possible answers and the audience *can select more than one* of them. More than one options need to be selected as correct.
- An *image single-choice poll* is exactly the same thing as a single-choice poll, but possible options are images.
- An *image single-choice question* is exactly the same thing as a single-choice question, but possible options are images.

- An *image multiple-choice poll* is exactly the same thing as a multiple-choice poll, but possible options are images.
- An *image multiple-choice question* is exactly the same thing as a multiple-choice question, but possible options are images.
- An *open-ended poll* is a query that provides a text-box for students to write their answer. It can require either a short answer or a longer one. The size of the answer required usually matches the size of the text box shown to students to fill in their answers. Sometimes open-ended polls that require a short answer are called *word clouds* and only those that require a longer answer are called open-ended. Here, the term open-ended will be used to describe both types of answers, and where a distinction on the length of the answer will be given where necessary. Since this is a poll, no correct answer is specified by the teacher.
- An *open-ended question* is similar to the above with the only difference that the teacher specifies a correct answer. Depending on the tool, the are different ways to match students answers to the correct one. For example, some allow cases to be ignored, while others allow for some variations on the exact words used. In some cases the teacher needs to check the responses manually.
- A *sorting problem* is a query that provides students with a list of options and asks to sort/rank them. Depending on the tool, a teacher may be able to select a correct combination or not.
- A *matching problem* is a query that provides students with two list with a number of options in each list and asks them to match the items of the first list to the items of the second list. Usually a correct configuration is provided.
- An *image query* asks for students to respond to a question by selecting a point(s) in an image given to them.

Appendix C

Design Guidelines for Audience Response Systems

This Appendix should be read in conjunction with Chapter 4.

From a further review of the benefits and challenges, an extensive list of design guidelines that an ARS should follow was derived. It is separated into two sections: Teacher's Interface and Student's Interface. Next, to each guideline, there is justification that explains the benefits that it offers or the challenges that it avoids.

C.1 Teacher's Interface

When teachers decide to use an ARS, they also agree to spend some time before their classes to plan what questions to ask and how to ask them. Therefore, an ARS needs to provide them with all the necessary functions to implement what they want. The following design guidelines were created to match the different phases of the teacher's interaction with an ARS.

Question Preparation: The following guidelines are related to the creation and setting up of the questions to present during a class.

Support of multiple question types [57]: ARSs should support multiple question types to satisfy different teachers' needs. This also avoids complaints that existed in clicker-based ARS regarding the limited question types that were available. [53]. Below, there are the recommended question types that an ARS for education should have to support different needs [83]. All questions types are defined in Appendix B.

- Single-choice polls
- Multiple-choice polls
- Single-choice questions
- Multiple-choice questions
- Open-ended questions
- Sorting problems
- Single-choice image polls
- Multiple-choice image polls
- Single-choice image questions
- Multiple-choice image questions
- Matching problems
- Image questions

Support of questions from the audience: This point is about allowing students to ask questions to the teacher using the ARS. The questions submitted are visible to the teacher, who can then address them when appropriate. This helps to create a more inclusive environment where everyone can ask questions no matter where they sit in the class or how loud they speak (if a microphone is not available) and to support further discussions [58, 66].

Integration of questions with content slides via the web interface: In an ARS, questions are usually presented to students in a slide format, with one question following another. The ability to also integrate content slides (i.e. slides with explanatory or other material such as videos, images and text) with the questions either by uploading a preexisting presentation or creating some slides using the web interface, allows teachers to be more organised during the lecture [91].

Existence of free presentation software plugins [44]: Instead of uploading their slides on the web-interface, some teachers may prefer to create the questions using their preferred presentation software. In this case, some ARSs offer plugins for different software that allow this integration. The most frequently used presentation software according to [41] that a plugin should exist for are: PowerPoint [25], Google Slides [12], Keynote [17] and Prezi [26].

Question Settings: The following are important settings to questions that allow teachers to plan their classes accordingly and also to adapt each question to the specific demands of a situation.

Setting a timer to each question [57]: The ability to set a timer to automatically stop collecting responses is important to allow teachers to implement the time-on-task principle [51].

Specifying whether to allow or disallow a student to update a response after submitting: Allows teachers to control how students respond to questions based on the objectives of the course [91].

Specifying whether to allow or disallow a student to reply more than once: Allows teachers to control how students respond to questions based on the topic under discussion [91].

Specifying whether a response to a question is mandatory or not: This feature is mostly used when questions are presented in a questionnaire format. However, it can still help students by providing them with feedback on which questions are important [51].

Scoring student's responses based on a correct answer [49, 44]: This feature is mostly used when ARSs are used for grading purposes and not in anonymous mode. However, even in anonymous mode grading can still be useful because it can help students assess which topics are the most important based on the scores that the teacher gave to each question and also the teacher can assess the overall level of students [51].

Saving questions for future use [83]: This point also helps the teacher stay more organised and prepare better lectures [91].

Results Settings: Teachers should be able to change how the results are presented before or during a presentation. Below, there are a number of settings that ARSs should have to make the results understandable to students.

Multiple-choice questions should at least result in a bar chart: Bar charts are a simple and understandable way to visualise multiple-choice results [90].

Open-ended questions should at least results in a word cloud: Word clouds are a simple and understandable way to present results to open-ended questions, especially to those questions that require only a few-words-long answer [60].

Ability to change the default visualisation type: Although the above two visualisation types are the easiest to interpret, it is essential to allow for possible changes in the visualisation type to accommodate teacher's needs and focus points for different scenarios [83].

Ability to change the colours of the visualisation: This setting is important to make the results accessible to colour blinded people [83].

Automatic moderation of open-ended question responses: When students can reply to open-ended questions, theoretically, they can submit whatever response they want. Hence, it is essential for some moderation to take place. The simplest way to do this is for the teacher to approve/disapprove responses manually when necessary [87], but in large classes, this can be impractical. In these cases, automatic moderation is preferred, to check each response for inappropriate language automatically, so that a

healthy discussion is enforced.

Hiding students' identity when presenting the results to the class: Not all ARSs have anonymity as their default mode. Some tools ask students to provide an optional username at the beginning of their interaction with the system. This username can be later used in the presentation of the results, so it is important that the teacher can select to hide the students' names to preserve their anonymity [64, 59].

Ability to specify whether to allow students' responses to be hidden to the class or not during voting [57, 65]: This feature avoids the problem of students being influenced by the majority when responding to questions by hiding the responses [58], while at the same time it allows the teacher to change disable it to support other class activities.

Presentation Screen: The presentation screen is the only part of the teacher's interface that is displayed to the students. This happens when the teacher connects their device to the classroom projector. Whatever controls are on the presentation screen, the students will also be able to see. Therefore, it is important to have a basic selection of controls on the screen, which are useful to the teacher but do not obstruct the presentation of the question or the results to students.

Existence of an additional screen for teachers during questions and results presentation: Having a separate interface to present questions and results means that the teacher has more control in regards to the presentation in a separate screen. The second screen is only visible to the teacher who can adjust the presentation settings, start and stop accepting responses, see students' responses as they are coming in, without students noticing. The benefit of this feature is that students can see a cleaner interface. [44]

Showing the total number of students who have responded [83]: By knowing how many students have already responded to a question, the teacher can adjust the time required before stop accepting responses.

Showing the percentage of students who have responded [83]: Similar to the above, but in this case, a percentage is shown based on the number of students who have connected to the classroom environment and the number of students who have already responded.

Ability to manually stop accepting responses even if a timer is set [65]: Allows the teacher to manually stop accepting responses to questions so that students do not accidentally provide answers to those questions when it is not required. Also, by overwriting the timer, the teacher can gain time for discussion or further clarifications [51].

Results Manipulation: Teachers need to be able to manipulate the results in some form after the class. This is to allow further analysis or comparison of students' performance over time.

Ability to store students' responses for all questions asked: It is important that students' responses to individual questions can be stored so that they can be accessed by the teacher at the end of the class [74].

Showing the total number of students who have responded [83]: To keep track of how many students participated in each session. The number of students participating can also show some indication about students' attention during class: the more participants, the more people are interested in the course (no matter what they have responded).

Showing the percentage of students who have responded [83]: Similar to the above, but in this case, a percentage is shown based on the number of students who have connected to the classroom environment and the number of students who have responded.

Showing how much time students required to answer each question [83]: This can help the teacher identify any particularly challenging topics.

Ability to access results from previous sessions: Accessing older results allows the teacher to monitor students' learning and understanding over time. [64, 51]. This should not be confused with the first point in this category, which only represents responses from a single session.

Downloading responses for analysis with another software [65, 57]: The teacher needs to be able to download all the responses in a format which can be used by other software if they want to analyse the results further or keep them for longer if they wish to stop using the ARS.

Emailing responses for analysis with another software [65, 57]: The teacher needs to be able to email the responses to themselves if they are using a shared device and want to avoid downloading them on that machine.

Deleting all questions and responses: The teacher needs to be able to delete all the questions and their responses associated with a session, to enforce their students' privacy if necessary [92].

General: Below, there are some general design guidelines that aim to improve the teacher's experience with an ARS.

Allows the creation of unlimited sessions: It is important that teachers are not restricted to the number of sessions/presentation that they can create [61].

Allows an unlimited number of questions per session: Similar to the above, it is important that teachers can ask as many questions as they want in a session to match their teaching style [72].

Can be used in large classrooms (with more than 100 students): Since this project discusses ARS used in higher education where large classes are very common, it is desired that an ARS can be used in these settings [61].

Existence of online help [81]: One of the problems of older versions of ARSs was the need of technical support to become able to use such systems because of the frequent technical errors [51]. Hopefully, web-based ARSs do not suffer from those types of technical errors, but even if some problems appear at some point, teachers need to be able to solve them quickly without the need to contact a specialised support team. The existence of online help can also help teachers become familiar with an ARS quicker.

Existence of free mobile applications [75]: In an ideal case, an ARS should have a mobile application in addition to its web-interface, where teachers can create questions on the go. A mobile application should be available for the most frequently used stores [88]: App Store [2], Google Play Store [10], Windows Store [36] and Chrome Web Store [5].

C.2 Students' Interface

Despite students only interacting with the ARS for a very short amount of time, as they only have to respond to questions, it is still important to be provided with good user experience. The following design guidelines aim to do exactly that.

Anonymity: As mentioned in the previous section, anonymity is a very important benefit of ARSs for students. [67, 64, 59, 58, 89] However, some teachers mentioned that they like ARSs because it allows them to monitor students' attendance [53]. This, by default, is controversial to anonymity. The way that some tools manage to have both is by asking students to sign in before answering any questions and then it is up to the teacher to decide if they want students to respond anonymously or not (either to their classmates only or to everyone). However, requiring students to sign in for attendance purposes made some students feel that that they were being monitored all the time [67], therefore, creating a bad impression of ARSs. Other students were also reported to cheat just to be marked present as [53]. Both of these are not desirable, and

for this reason, only the full anonymous mode will be considered beneficial from this moment. Full anonymity can be made possible by the following:

Participating without logging in [65]: Even if an ARS asks for students to log in, this should not be enforced and each student can skip this step and still be able to participate in a session.

Participating without providing a name [65]: Some ARSs ask students for a name/nickname so that it can be used during their interaction and to accompany their responses. Students should not be forced to provide one, and an automatic username should be used instead if necessary.

Participating without providing an email [65]: Similarly to the above, students should not be forced to provide an email to participate, and they should be able to easily skip this step if they are prompted to enter an email.

Connect to a classroom environment: There are different ways to connect to a classroom environment/session and students should have the option to decide which way they prefer based on which device they are using at that moment [69].

Connecting using a URL [69]: The simplest way to connect to a classroom environment is for students to type a URL into their browser.

Connecting using a QR code [69]: If students are using their mobile phones to connect to a session, then they may prefer to scan a QR code to get to the desired web page.

Connecting using a URL and an access code [69]: Another way to connect to a session is by typing a simple URL to a browser and then entering a usually short access code to get to the classroom session.

Presentation of questions: This is the most important part of the students' interface, as it is the part where students see the question and its possible options (if any) before responding.

Showing one question at a time: By showing one question at a time, it is ensured that all students are at the same question [64, 51].

Use of a secure connection (https) to transfer students' responses [69]: An https connection is necessary to avoid privacy concerns.

Informing students that their responses have been recorded: One of the complaints of students when using early versions of clicker-based ARSs was that they had no feedback on whether their response was submitted or not [49]. By giving students this kind of feedback, the problem is avoided, and good design practices are also followed.

Presentation of results: Presenting the results on students' device is quite important, especially if students do not have good visibility of the projector screen.

Displaying the overall results on students' devices: In this way, students can get an overview of what they responded compared to their classmates [67, 64, 91, 55, 59].

Displaying personal results on students' devices: By getting personal results, e.g. how many questions they responded correctly in a session, students can rate their knowledge of the topic and work to improve their performance [59, 66].

General: Below, some general design guidelines are provided to improve students' experience with an ARS.

Existence of online help [81]: As simple as the students' interface is, it should have some form of online help in case students get stuck at some point. This will also help avoid students from bothering teachers with technical questions and also to improve their satisfaction when using an ARS. It is worth noting that the help feature should be available directly from the students' interface.

Existence of free mobile applications [75]: Similarly to the teachers' interface, the existence of a mobile application enhances the experience of students who may prefer to use an app to respond to questions instead of visiting a web-page. A mobile app should be available for the most frequently used stores [88]: App Store [2], Google Play Store [10], Windows Store [36] and Chrome Web Store [5].

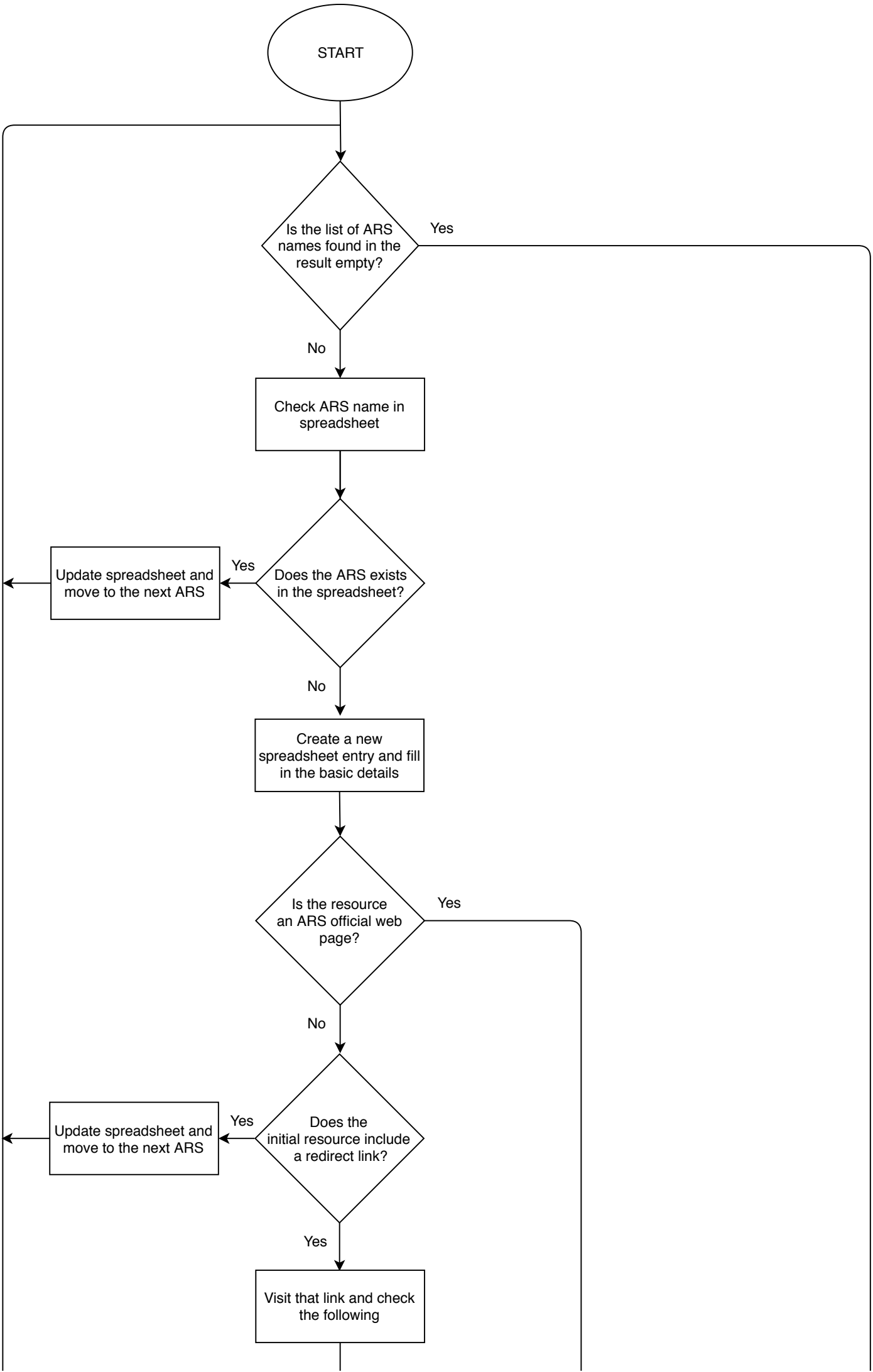
Appendix D

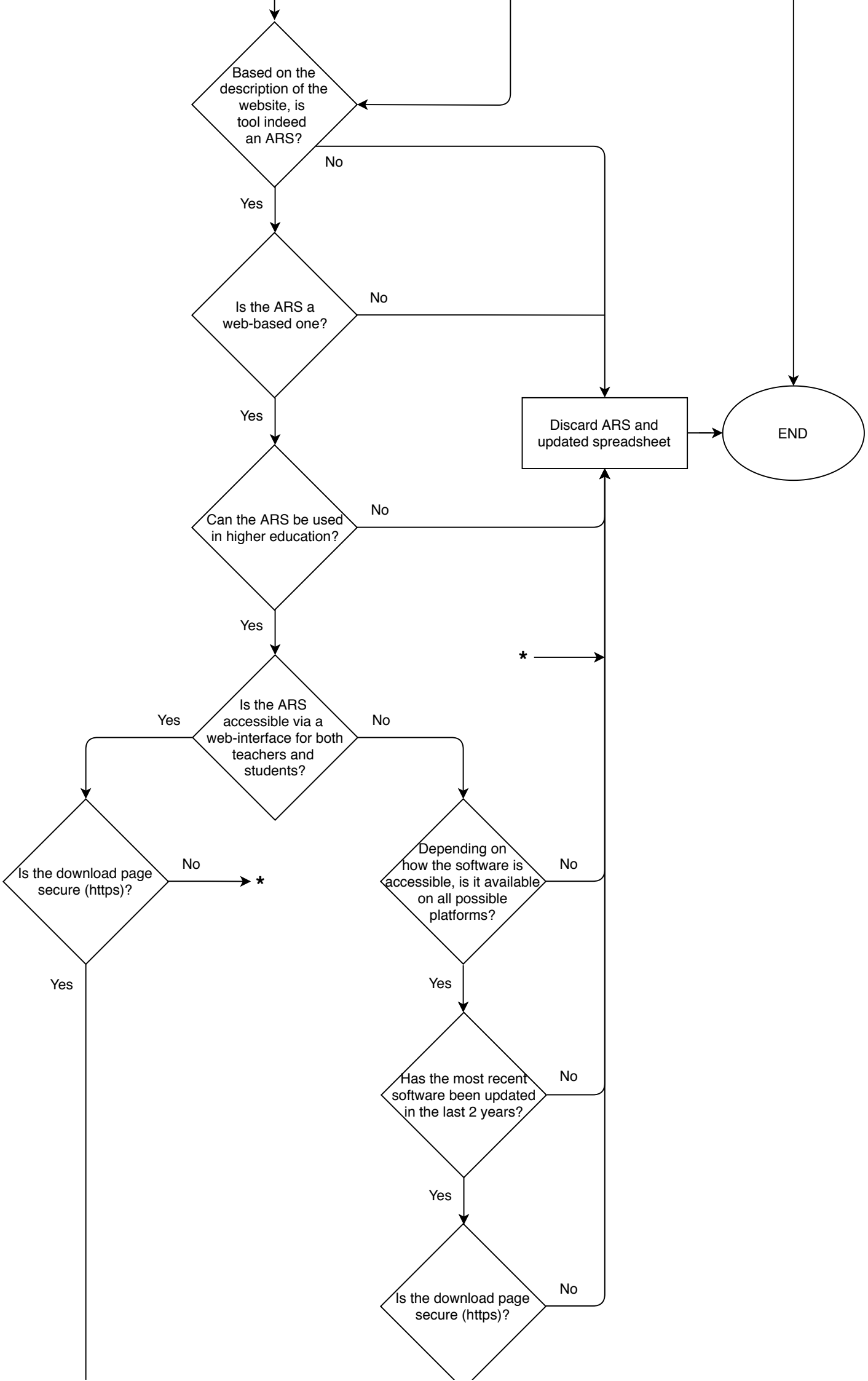
Systematic Review Preparation

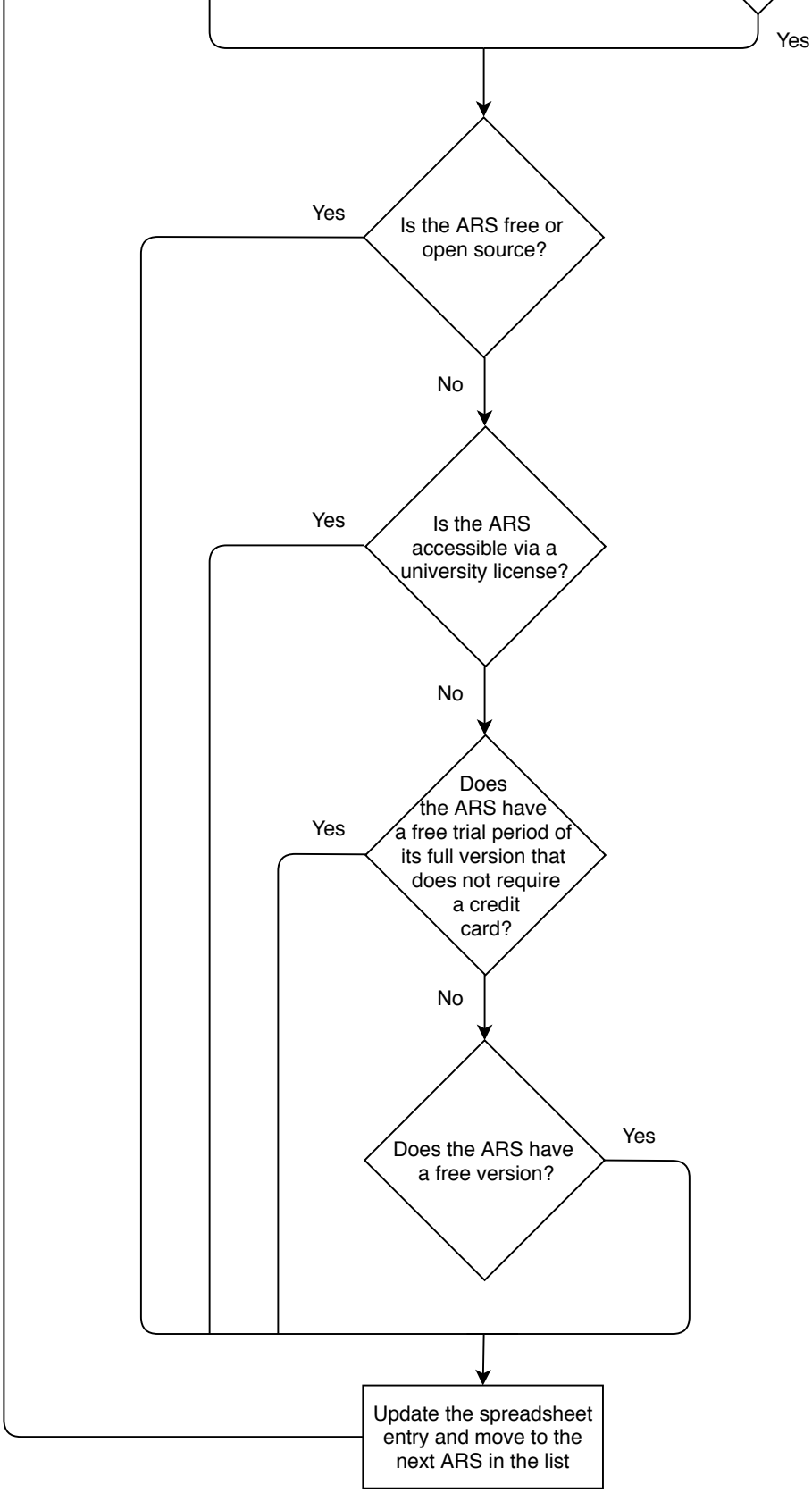
This appendix includes all the supportive materials of the systematic review preparation according to the PRISMA statement [71]. All the details regarding the systematic review can be found in Chapter 5.

D.1 Search Procedure Flow Diagram

This diagram in the following pages describes the selection criteria regarding ARSs. It describes what steps were followed if the search result included at a least one ARS name.


START
Is the list of ARS names found in the result empty?
Yes
No
Check ARS name in spreadsheet
Does the ARS exists in the spreadsheet?
Yes
Update spreadsheet and move to the next ARS
No
Create a new spreadsheet entry and fill in the basic details
Is the resource an ARS official web page?
Yes
No
Does the initial resource include a redirect link?
Yes
Update spreadsheet and move to the next ARS
Yes
Visit that link and check the following


Based on the description of the website, is tool indeed an ARS?
No
Yes
Is the ARS a web-based one?
No
Yes
Discard ARS and updated spreadsheet
END
Can the ARS be used in higher education?
No
Yes
*
Is the ARS accessible via a web-interface for both teachers and students?
Yes
No
Is the download page secure (https)?
No
*
Depending on how the software is accessible, is it available on all possible platforms?
No
Yes
Yes
Has the most recent software been updated in the last 2 years?
No
Yes
Is the download page secure (https)?
No


Yes
Is the ARS free or open source?
Yes
No
Is the ARS accessible via a university license?
Yes
No
Does the ARS have a free trial period of its full version that does not require a credit card?
Yes
No
Does the ARS have a free version?
Yes
Update the spreadsheet entry and move to the next ARS in the list

Appendix E

Systematic Review Comparison

This appendix includes the comparison tables that were created to evaluate the ARSs found in the systematic review. The tables are separated based on the ARS version accessible (i.e. partial version or full version) and the interface under consideration (i.e. teachers' or students' interface). The criteria and the evaluation procedure are described in Chapter 5. The ARSs considered in the comparison along with their scores can be found in Tables E.1 and E.2 (TI: Teachers' Interface, SI: Students' Interface).

E.1 Teachers' Interface Comparison

Tables E.3, E.4, E.5, E.6 and E.7 compare the ARSs that only have a partial version available free of charge, while tables E.8, E.9, E.10 and E.11 compare the ARS that have all their functionality available for free of charge either by design, for a limited amount of time or because of they are accessible using an educational license in terms of the teachers' interface.

E.2 Students' Interface Comparison

Tables E.12, E.13 and E.14 compare the ARSs that only had a partial version available free of charge. Table E.15 compares the ARS that have all their functionality available for free of charge either by design, for a limited amount of time or because they are accessible using an educational license in terms of the students' interface.

ARS brand name	Overall Score	TI score	SI score
Poll Everywhere [24]	**64%**	**65%**	63%
Wooclap [37]	**64%**	**67%**	56%
Mentimeter [19]	**63%**	**59%**	**75%**
UMU [34]	55%	57%	50%
Socrative [30]	54%	49%	**69%**
Slido [29]	51%	49%	56%
Crowdpurr [6]	48%	41%	**69%**
Quiz-maker [28]	46%	45%	50%
Meeting Pulse [18]	46%	45%	50%
VoxVote [35]	46%	45%	50%
Kahoot! [16]	43%	39%	56%
Glisser [7]	39%	35%	50%
GoSoapBox [13]	39%	35%	50%
Imakiku [14]	37%	31%	56%
TapToSpeak [31]	30%	27%	38%
OnlineTED.com [21]	30%	24%	50%
IQPolls [15]	28%	20%	56%

Table E.1: Comparison results of the partial version ARSs. All ARSs above have a free version and a premium version

ARS brand name	Overall Score	TI score	SI score
TopHat [33] (Free full version with University of Edinburgh license)	**57%**	**59%**	**50%**
ARSnova [3] (Open source)	52%	47%	69%
Pingo [22] (Free full version)	49%	45%	63%
Zeetings [38] (Free full version for educational account)	45%	45%	50%
Q-ARS [27] (Free trial of full version)	41%	41%	44%
Teachably [32] (Free full version)	44%	37%	39%
AuResS [4] (Free full version)	34%	31%	44%
Answer Garden [1] (Free full version)	33%	25%	56%

Table E.2: Comparison results of the full version ARSs.

			Poll Everywhere [24]	**Wooclap** [37]	**Mentimeter** [19]	**UMU** [34]	**Socrative** [30]	**Slido** [29]	**Crowdpurr** [6]	**Quiz-maker** [28]	**Meeting Pulse** [18]	**VoxVote** [35]	**Kahoot!** [16]	**Glisser** [7]	**GoSoapBox** [13]	**Imakiku** [14]	**TapToSpeak** [31]	**OnlineTED.com** [21]	**IQPolls** [15]
Before class	Question Types	Single-choice polls	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		Multiple-choice polls	1	1	1	1	1	1	0	1	1	1	0	0	0	0	0	0	1
		Single-choice questions	1	1	1	1	1	1	0	1	0	1	1	0	1	0	0	1	0
		Multiple-choice questions	1	1	1	1	1	1	0	1	0	1	0	0	0	0	0	0	0
		Single-choice image polls	1	1	1	1	0	0	0	1	0	0	0	1	0	0	0	0	0
		Multiple-choice image polls	1	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
		Single-choice image questions	1	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
		Multiple-choice image questions	1	1	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0
		Open-ended queries	1	1	1	1	1	1	1	1	1	1	0	1	1	1	0	0	0
		Sorting problems	0	1	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0
		Matching problems	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Image queries	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Questions from the audience	1	1	1	1	0	1	0	0	1	0	0	1	1	0	1	0	0
		Integration with content slides	0	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0
		Total	*11/14 79%*	*14/14 100%*	*11/14 79%*	*8/14 57%*	*5/14 36%*	*6/14 43%*	*2/14 14%*	*9/14 64%*	*5/14 36%*	*6/14 43%*	*3/14 21%*	*5/14 36%*	*4/14 29%*	*2/14 14%*	*2/14 14%*	*2/14 14%*	*2/14 14%*

Table E.3: Comparison of the question type features for the teachers' interface of the partial version ARSs.

			Poll Everywhere [24]	**Wooclap** [37]	**Mentimeter** [19]	**UMU** [34]	**Socrative** [30]	**Slido** [29]	**Crowdpurr** [6]	**Quiz-maker** [28]	**Meeting Pulse** [18]	**VoxVote** [35]	**Kahoot!** [16]	**Glisser** [7]	**GoSoapBox** [13]	**Imakiku** [14]	**TapToSpeak** [31]	**OnlineTED.com** [21]	**IQPolls** [15]
Before class	Question settings	Create using web-interface	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		Set a timer	1	1	1	0	0	0	1	1	0	1	1	0	0	0	0	1	0
		Save questions	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1
		Option to update or not a response	1	0	1	0	1	0	1	0	0	0	0	1	0	0	0	0	0
		Option for mandatory question	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	0	0
		Option to score questions	0	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0
		Total	*4/6 67%*	*4/6 67%*	*4/6 67%*	*4/6 67%*	*3/6 50%*	*2/6 33%*	*4/6 67%*	*3/6 50%*	*2/6 33%*	*3/6 50%*	*4/6 67%*	*4/6 67%*	*2/6 33%*	*2/6 33%*	*2/6 33%*	*3/6 50%*	*2/6 33%*
	Pr. software plugins	PowerPoint [25]	1	1	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0
		Google Slides [9]	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
		Keynote [17]	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
		Prezi [26]	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
		Total	*3/4 75%*	*1/4 25%*	*0/4 0%*	*0/4 0%*	*0/4 0%*	*3/4 75%*	*1/2 50%*	*0/4 0%*	*1/4 25%*	*0/4 0%*	*0/4 0%*	*0/4 0%*	*0/4 0%*	*0/4 0%*	*0/4 0%*	*0/4 0%*	*0/4 0%*

Table E.4: Comparison of the question settings and presentation software plugins for the teachers' interface of the partial version ARSs.

			Poll Everywhere [24]	**Wooclap** [37]	**Mentimeter** [19]	**UMU** [34]	**Socrative** [30]	**Slido** [29]	**Crowdpurr** [6]	**Quiz-maker** [28]	**Meeting Pulse** [18]	**VoxVote** [35]	**Kahoot!** [16]	**Glisser** [7]	**GoSoapBox** [13]	**Imakiku** [14]	**TapToSpeak** [31]	**OnlineTED.com** [21]	**IQPolls** [15]
During class	Presentation of questions	Presenter's screen	0	0	0	0	0	1	1	0	1	0	0	0	0	0	1	0	1
		Option to hide/show results	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	0	0
		Total number of students who have voted	0	1	1	1	1	1	1	0	1	1	1	0	0	1	0	1	0
		Total percentage of students who have voted	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Manually stop accepting responses (w or w/o timer)	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1
		Total	*2/5* *40%*	*3/5* *60%*	*3/5* *60%*	*3/5* *60%*	*3/5* *60%*	*4/5* *80%*	*4/5* *80%*	*2/5* *40%*	*4/5* *80%*	*3/5* *60%*	*1/5* *20%*	*1/5* *20%*	*2/5* *40%*	*3/5* *60%*	*3/5* *60%*	*2/5* *40%*	*2/5* *40%*
	Presentation of results	Multiple/Single-choice queries results in bar chart	1	1	1	1	1	1	1	1	1	1	1	0	1	1	0	1	1
		Open-ended queries results in word cloud	1	1	1	0	0	1	0	0	1	1	0	0	0	0	0	0	0
		Option to change the visualisation type	1	1	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0
		Option to change the visualisation colours	1	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0
		Automatic moderation of open-ended responses	0	0	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0
		Hide students names	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	0
		Total	*5/6* *83%*	*2/3* *67%*	*5/6* *83%*	*1/2* *50%*	*1/3* *33%*	*2/3* *67%*	*2/3* *67%*	*1/2* *50%*	*1/2* *50%*	*2/3* *67%*	*1/6* *17%*	*1/6* *17%*	*1/2* *50%*	*1/2* *50%*	*1/6* *17%*	*1/3* *33%*	*1/6* *17%*

Table E.5: Comparison of the features for presenting the questions and results for the teacher's interface of the partial version ARSs.

			Poll Everywhere [24]	**Wooclap** [37]	**Mentimeter** [19]	**UMU** [34]	**Socrative** [30]	**Slido** [29]	**Crowdpurr** [6]	**Quiz-maker** [28]	**Meeting Pulse** [18]	**VoxVote** [35]	**Kahoot!** [16]	**Glisser** [7]	**GoSoapBox** [13]	**Imakiku** [14]	**TapToSpeak** [31]	**OnlineTED.com** [21]	**IQPolls** [15]
After class	Statistics	Stores students responses	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1
		Total number of students who voted	1	1	1	1	0	0	1	1	1	1	1	0	0	1	0	1	0
		Total percentage of students who voted	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
		Time to answer each question	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
		Access results from previous sessions	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1
		Downloading of responses	1	1	0	1	1	0	0	1	1	1	1	1	1	0	0	0	0
		Emailing of responses	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
		Option to delete all queries and responses	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	0	0
		Total	*5/8 63%*	*5/8 63%*	*4/8 50%*	*6/8 75%*	*6/8 75%*	*3/8 38%*	*4/8 50%*	*4/8 50%*	*5/8 63%*	*5/8 63%*	*5/8 63%*	*4/8 50%*	*4/8 50%*	*4/8 50%*	*4/8 50%*	*3/8 38%*	*2/8 25%*

Table E.6: Comparison of the after class features of the teachers' interface for the partial version ARSs.

			Poll Everywhere [24]	**Wooclap** [37]	**Mentimeter** [19]	**UMU** [34]	**Socrative** [30]	**Slido** [29]	**Crowdpurr** [6]	**Quiz-maker** [28]	**Meeting Pulse** [18]	**VoxVote** [35]	**Kahoot!** [16]	**Glisser** [7]	**GoSoapBox** [13]	**Imakiku** [14]	**TapToSpeak** [31]	**OnlineTED.com** [21]	**IQPolls** [15]
General	Help & Support	Unlimited sessions	1	1	1	1	1	1	0	0	1	0	1	0	1	1	0	0	1
		Unlimited queries per session	1	1	0	1	1	0	0	1	0	0	1	1	1	0	1	0	0
		Used in large class-rooms	0	0	1	0	0	1	0	0	1	1	1	1	0	0	0	0	0
		Online help	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0
		Total	*3/4 75%*	*3/4 75%*	*3/4 75%*	*3/4 75%*	*3/4 75%*	*3/4 75%*	*1/4 25%*	*2/4 50%*	*3/4 75%*	*2/4 50%*	*4/4 100%*	*3/4 75%*	*3/4 75%*	*1/2 50%*	*1/2 50%*	*0/4 0%*	*1/4 25%*
	Mobile Application	App Store [2]	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0	0	0
		Google Play Store [10]	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0	0	0
		Windows Store [36]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Chrome Web Store [5]	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
		Total	*0/4 0%*	*0/4 0%*	*0/4 0%*	*2/4 50%*	*3/4 75%*	*0/4 0%*	*0/4 0%*	*0/4 0%*	*0/4 0%*	*0/4 0%*	*2/4 50%*	*0/4 0%*	*0/4 0%*	*0/4 0%*	*0/4 0%*	*0/4 0%*	*0/4 0%*
		Overall	**33/51**	**34/51**	**30/51**	**29/51**	**25/51**	**25/51**	**21/51**	**23/51**	**23/51**	**23/51**	**20/51**	**18/51**	**18/51**	**16/51**	**14/51**	**12/51**	**10/51**
		Total	**65%**	**67%**	**59%**	**57%**	**49%**	**49%**	**41%**	**45%**	**45%**	**45%**	**39%**	**35%**	**35%**	**31%**	**27%**	**24%**	**20%**

Table E.7: Comparison of the general features of the teachers' interface of the partial version ARSs. The last row has the overall total of all the features of the teachers' interface.

			Q-ARS [27]	**TopHat** [33]	**Pingo** [22]	**Zeetings** [38]	**Teachably** [32]	**AuResS** [4]	**Answer Garden** [1]	**ARSnova** [3]
Before class	Question Types	Single-choice polls	1	1	1	1	1	1	0	1
		Multiple-choice polls	1	0	1	1	1	1	0	1
		Single-choice questions	1	1	1	0	0	0	0	1
		Multiple-choice questions	1	0	1	0	0	0	0	1
		Single-choice image polls	0	0	0	0	0	0	0	1
		Multiple-choice image polls	0	0	0	0	0	0	0	0
		Single-choice image questions	0	0	0	0	0	0	0	0
		Multiple-choice image questions	0	0	0	0	0	0	0	0
		Open-ended queries	1	1	1	1	1	1	1	1
		Sorting problems	1	1	0	0	0	0	0	0
		Matching problems	0	1	0	0	0	0	0	0
		Image queries	0	1	0	0	0	0	0	1
		Questions from the audience	1	1	0	1	1	0	0	1
		Integration with content slides	0	1	0	1	0	0	0	0
		Total	*7/14 50%*	*8/14 57%*	*5/14 36%*	*5/14 36%*	*4/14 29%*	*3/14 21%*	*1/14 7%*	*8/14 57%*

Table E.8: Comparison of the question type features of the teacher's interface of the full version ARSs.

			Q-ARS [27]	**TopHat** [33]	**Pingo** [22]	**Zeetings** [38]	**Teachably** [32]	**AuResS** [4]	**Answer Garden** [1]	**ARSnova** [3]
Before class	Question Settings	Create using web-interface	1	1	1	1	1	1	1	1
		Set a timer	1	1	1	0	1	0	0	1
		Save questions	1	1	1	1	1	0	1	0
		Option to update or not a response	1	0	0	0	0	1	0	0
		Option for mandatory questions	0	0	0	0	0	0	0	1
		Option to score questions	0	1	0	0	0	0	0	0
		Total	*4/6 67%*	*4/6 67%*	*3/6 50%*	*2/6 33%*	*3/6 50%*	*2/6 33%*	*2/6 33%*	*3/6 50%*
	Pr. software plugins	PowerPoint [25]	0	1	1	0	0	0	0	0
		Google Slides [12]	0	0	0	0	0	0	0	0
		Keynote [17]	0	1	0	0	0	0	0	0
		Prezi [26]	0	1	0	0	0	0	0	0
		Total	*0/4 0%*	*3/4 75%*	*1/4 25%*	*0/4 0%*	*0/4 0%*	*0/4 0%*	*0/4 0%*	*0/4 0%*
During class	Presentation of questions	Presenter's and teachers' screen	0	0	0	1	0	0	0	0
		Option to hide/show results	0	0	0	1	0	1	0	1
		Total number of students who voted	0	1	0	1	1	0	0	1
		Total percentage of students who voted	0	0	0	0	0	0	0	0
		Manually stop accepting responses (w or w/o timer)	1	1	1	1	1	1	0	1
		Total	*1/5 20%*	*2/5 40%*	*1/5 20%*	*4/5 80%*	*2/5 40%*	*2/5 40%*	*0/5 0%*	*3/5 60%*

Table E.9: Comparison of the question setting and presentation of questions features and presentation software plugins of the teacher's interface of the full version ARSs.

			Q-ARS [27]	**TopHat** [33]	**Pingo** [22]	**Zeetings** [38]	**Teachably** [32]	**AuResS** [4]	**Answer Garden** [1]	**ARSnova** [3]
During class	Presentation of results	Multiple/Single-choice queries results in bar chart	1	1	1	1	1	1	0	1
		Open-ended queries results in word cloud	1	1	1	0	0	0	1	0
		Option to change the visualisation	0	0	1	0	0	1	0	0
		Option to change the visualisation colours	0	0	0	1	0	0	0	0
		Automatic moderation of open-ended responses	0	0	0	0	0	0	1	0
		Hide students names during presentation	1	1	1	1	1	1	1	1
		Total	*3/6 50%*	*3/6 50%*	*2/6 67%*	*3/6 50%*	*3/6 33%*	*3/6 50%*	*3/6 50%*	*2/6 33%*
General	Help & Support	Unlimited sessions	1	1	1	1	1	1	1	1
		Unlimited queries per session	1	1	1	1	1	1	1	1
		Used in large classrooms	1	1	1	1	1	1	1	1
		Online help	0	1	1	1	1	1	1	1
		Total	*3/4 75%*	*4/4 100%*	*4/4 100%*	*4/4 100%*	*4/4 100%*	*4/4 100%*	*4/4 100%*	*4/4 100%*
	Mobile Application	App Store [2]	0	0	0	0	0	0	0	0
		Google Play Store [10]	0	0	0	0	0	0	0	0
		Windows Store [36]	0	0	0	0	0	0	0	0
		Chrome Web Store [5]	0	0	0	0	0	0	0	0
		Total	*0/4 0%*	*0/4 0%*	*0/4 0%*	*0/4 0%*	*0/4 0%*	*0/4 0%*	*0/4 0%*	*0/4 0%*

Table E.10: Comparison of the presentation of results features of the teacher's interface of the full version ARSs.

			Q-ARS [27]	**TopHat** [33]	**Pingo** [22]	**Zeetings** [38]	**Teachably** [32]	**AuResS** [4]	**Answer Garden** [1]	**ARSnova** [3]
After class	Statistics	Stores students responses	1	1	1	1	1	0	1	1
		Total number of students who voted	0	1	1	1	0	0	0	1
		Total percentage of students who voted	0	1	0	0	0	0	0	0
		Time to answer each question	0	0	0	0	0	0	0	0
		Access results from previous sessions	1	1	1	1	1	0	1	0
		Downloading of responses	0	1	1	0	1	1	1	1
		Emailing of responses	0	0	0	1	0	1	0	0
		Option to delete all queries and responses	1	1	1	1	1	0	0	1
		Total	*3/8 38%*	*6/8 75%*	*5/8 63%*	*5/8 63%*	*4/8 50%*	*2/8 25%*	*3/8 38%*	*4/8 50%*
		Overall Total	**21/51 41%**	**30/51 59%**	**23/51 45%**	**23/51 45%**	**19/51 37%**	**16/51 31%**	**13/51 25%**	**24/51 47%**

Table E.11: Comparison of the after class features of the teacher's interface of the full version ARSs. The last row has the overall total of all the features of the teachers' interface.

			Poll Everywhere [24]	**Wooclap** [37]	**Mentimeter** [19]	**UMU** [34]	**Socrative** [30]	**Slido** [29]	**Crowdpurr** [6]	**Quiz-maker** [28]	**Meeting Pulse** [18]	**VoxVote** [35]	**Kahoot!** [16]	**Glisser** [7]	**GoSoapBox** [13]	**Imakiku** [14]	**TapToSpeak** [31]	**OnlineTED.com** [21]	**IQPolls** [15]
Before voting	Anonymity	Participate w/o log in	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		Participate without a name	1	1	1	1	1	1	1	1	1	1	0	1	1	1	0	1	1
		Participate without an email	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1
		Total	*3/3 100%*	*3/3 100%*	*3/3 100%*	*3/3 100%*	*3/3 100%*	*3/3 100%*	*3/3 100%*	*3/3 100%*	*3/3 100%*	*3/3 100%*	*2/3 67%*	*2/3 67%*	*3/3 100%*	*3/3 100%*	*2/3 67%*	*3/3 100%*	*3/3 100%*
	Connect to a session	Using a URL	1	1	1	0	0	1	1	1	1	0	0	1	0	0	1	0	0
		Using a QR code	0	1	1	1	0	0	0	0	0	1	0	0	0	1	0	1	1
		Using a URL and an access code	0	1	1	1	1	1	1	0	0	1	1	0	1	1	0	1	1
		Total	*1/3 33%*	*3/3 100%*	*3/3 100%*	*2/3 67%*	*1/3 33%*	*2/3 67%*	*2/3 67%*	*1/3 33%*	*1/3 33%*	*2/3 67%*	*1/3 33%*	*1/3 33%*	*1/3 33%*	*2/3 67%*	*1/3 33%*	*2/3 67%*	*2/3 67%*

Table E.12: Comparison of the before voting features of the students' interface of the partial version ARSs.

			Poll Everywhere [24]	**Wooclap** [37]	**Mentimeter** [19]	**UMU** [34]	**Socrative** [30]	**Slido** [29]	**Crowdpurr** [6]	**Quiz-maker** [28]	**Meeting Pulse** [18]	**VoxVote** [35]	**Kahoot!** [16]	**Glisser** [7]	**GoSoapBox** [13]	**Imakiku** [14]	**TapToSpeak** [31]	**OnlineTED.com** [21]	**IQPolls** [15]
During voting	Presentation of questions	One question at a time	1	1	1	0	1	1	1	1	1	1	1	1	0	1	1	1	1
		Secure (https) connection	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		Submission message	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1
		Total	*3/3 100%*	*3/3 100%*	*3/3 100%*	*2/3 67%*	*3/3 100%*	*3/3 100%*	*3/3 100%*	*2/3 67%*	*3/3 100%*	*3/3 100%*	*3/3 100%*	*3/3 100%*	*2/3 67%*	*3/3 100%*	*3/3 100%*	*3/3 100%*	*3/3 100%*
After voting	Presentation of results	Overall results	0	0	0	0	0	1	1	1	1	0	0	1	1	0	0	0	1
		Personal results	0	0	0	1	1	0	1	1	0	0	1	0	1	0	0	0	0
		Total	*0/2 0%*	*0/2 0%*	*0/2 0%*	*1/2 50%*	*1/2 50%*	*1/2 50%*	*2/2 100%*	*2/2 100%*	*1/2 50%*	*0/2 0%*	*1/2 50%*	*1/2 50%*	*2/2 100%*	*0/2 0%*	*0/2 0%*	*0/2 0%*	*1/2 50%*

Table E.13: Comparison of the during and after voting features of the students' interface of the partial version ARSs.

			Poll Everywhere [24]	Wooclap [37]	Mentimeter [19]	UMU [34]	Socrative [30]	Slido [29]	Crowdpurr [6]	Quiz-maker [28]	Meeting Pulse [18]	VoxVote [35]	Kahoot! [16]	Glisser [7]	GoSoapBox [13]	Imakiku [14]	TapToSpeak [31]	OnlineTED.com [21]	IQPolls [15]
General	Help & Support	Online help	1	0	1	0	0	0	1	0	0	0	0	1	0	1	0	0	0
		Total	*1/1 100%*	*0/1 0%*	*1/1 100%*	*0/1 0%*	*0/1 0%*	*0/1 0%*	*1/1 100%*	*0/1 0%*	*0/1 0%*	*0/1 0%*	*0/1 0%*	*1/1 100%*	*0/1 0%*	*1/1 100%*	*0/1 0%*	*0/1 0%*	*0/1 0%*
	Mobile Application	App Store [2]	1	0	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0
		Google Play Store [10]	1	0	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0
		Window Store [36]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		Chrome Web Store [5]	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
		Total	*2/4 50%*	*0/4 0%*	*2/4 50%*	*0/4 0%*	*3/4 75%*	*0/4 0%*	*0/4 0%*	*0/4 0%*	*0/4 0%*	*0/4 0%*	*2/4 50%*	*0/4 0%*	*0/4 0%*	*0/4 0%*	*0/4 0%*	*0/4 0%*	*0/4 0%*
		Overall Total	**10/16 63%**	**9/16 56%**	**12/16 75%**	**8/16 50%**	**11/16 69%**	**9/16 56%**	**11/16 69%**	**8/16 50%**	**8/16 50%**	**8/16 50%**	**9/16 56%**	**8/16 50%**	**8/16 50%**	**9/16 56%**	**6/16 38%**	**8/16 50%**	**9/16 56%**

Table E.14: Comparison of the general features of the students' interface of the partial version ARSs. The last row has the overall total of all the features of the students' interface.

			Q-ARS [27]	**TopHat** [33]	**Pingo** [22]	**Zeetings** [38]	**Teachably** [32]	**AuResS** [4]	**Answer Garden** [1]	**ARSnova** [3]
Before voting	Anonymity	Participate without log in	1	0	1	1	1	1	1	1
		Participate without a name	1	0	1	1	0	1	1	1
		Participate without an email	1	0	1	1	1	1	1	1
		Total	*3/3 100%*	*0/3 0%*	*3/3 100%*	*3/3 100%*	*2/3 67%*	*3/3 100%*	*3/3 100%*	*3/3 100%*
	Connect to a session	Using a URL	1	0	0	1	0	0	1	1
		Using a QR code	0	0	1	0	0	0	1	0
		Using a URL and an access code	0	1	1	0	1	1	0	1
		Total	*1/3 33%*	*1/3 33%*	*2/3 67%*	*1/3 33%*	*1/3 33%*	*1/3 33%*	*2/3 67%*	*2/3 67%*
During voting	Pr. of questions	One question at a time	1	1	1	1	1	1	1	1
		Secure (https) connection	1	1	1	1	1	1	1	1
		Submission message	1	1	1	1	1	1	0	1
		Total	*3/3 100%*	*3/3 0%*	*3/3 100%*	*3/3 100%*	*3/3 100%*	*3/3 100%*	*2/3 67%*	*3/3 100%*
After voting	Pr. of results	Overall results	0	0	1	1	1	0	1	1
		Personal results	0	1	1	0	0	0	0	1
		Total	*0/2 0%*	*1/2 50%*	*2/2 100%*	*1/2 50%*	*1/2 50%*	*0/2 0%*	*1/2 50%*	*2/2 100%*
General	Help	Online help	0	1	0	0	0	0	1	1
		Total	*0/1 0%*	*1/1 100%*	*0/1 0%*	*0/1 0%*	*0/1 0%*	*0/1 0%*	*1/1 100%*	*1/1 100%*
	Mobile Application	App Store [2]	0	1	0	0	0	0	0	0
		Google Play Store [10].	0	1	0	0	0	0	0	0
		Windows Store [36]	0	0	0	0	0	0	0	0
		Chrome Store [5]	0	0	0	0	0	0	0	0
		Total	*0/4 0%*	*2/4 50%*	*0/4 0%*	*0/4 0%*	*0/4 0%*	*0/4 0%*	*0/4 0%*	*0/4 0%*
		Overall Total	**7/16 44%**	**8/16 50%**	**10/16 63%**	**8/16 50%**	**7/16 44%**	**7/16 44%**	**9/16 56%**	**11/16 69%**

Table E.15: Comparison of the students' interface of the full version ARSs.

Appendix F

Materials of Usability Studies

This appendix includes all the materials that were used to perform the two usability studies. The materials are separated per type and a clear indication of when they were used is given. A detailed description of the usability evaluation performed can be found in Chapter 6.

F.1 Participant Information Sheets and Consent Forms

The next four pages include copies of the Participant Information Sheets and Consent Forms given to academics and students before starting the study. The Participant Information Sheet was given first and contains the following details:

- Information about the researchers
- The purpose of the study
- Details about the study procedure
- Risks and benefits of participating in the study
- How the participant's data will be stored and used
- Data protection rights

The Consent Form was given after the participant has the read the Participant Information sheet and asked for consent to collect the participant's data in different manners, store and use their data and finally agree to take part in the study.

Participant Information Sheet – Teachers

Project title:	Review of web-based Audience Response Systems used in Higher Education
Principal investigator:	Dr Cristina Andriana Alexandru
Researcher collecting data:	Elina Michaelidou
Funder (if applicable):	–

This study was certified according to the Informatics Research Ethics Process, RT number 2019/80319. Please take time to read the following information carefully. You should keep this page for your records.

Who are the researchers?

The research team consist of Dr Cristina Andriana Alexandru, Dr Aurora Constantin and Elina Michaelidou.

What is the purpose of the study?

The purpose of the study is to examine the usability of an Audience Response System (ARS) when used by teachers to perform some basic functionality of the tool.

Do I have to take part?

No – participation in this study is entirely up to you. You can withdraw from the study at any time, without giving a reason. Your rights will not be affected. If you wish to withdraw, contact the PI. We will stop using your data in any publications or presentations submitted after you have withdrawn consent. However, we will keep copies of your original consent, and of your withdrawal request.

What will happen if I decide to take part?

During the study we will collect data regarding your interaction with three ARSs. There will be three parts to this study for each ARS. In the first part we will observe you perform a number of specified tasks on one of the three ARSs and make note of any difficulties, how long it takes you to accomplished each of the tasks and the path that you followed to complete it. In the second part you will be asked to complete a short questionnaire to give us your general opinion on the tool's usability, and in the

last part you will be asked to answer a few questions regarding your experience with using the system. This process will be repeated for each of the three ARSs. The data will be collected using pen and paper (notes and questionnaire), a timer, a screen-recorder (observation), and an audio recorder (interview).

Compensation. [only required if applicable]

There is not compensation for completing this study.

Are there any risks associated with taking part?

There are no significant risks associated with participation

Are there any benefits associated with taking part?

The provided data will be used to provide suggestions on usability and design guidelines of future ARSs and can be used in the creation of a prototype of an improved version of the ARSs under examination. All these will aim to improve your future interaction with ARSs to better suit your classroom needs.

What will happen to the results of this study?

The results of this study may be summarised in published articles, reports and presentations. Quotes or key findings will always be anonymous. We may include your comments in our publications or disclose them to other researchers, but they will be shared without your name, and we will not disclose any opinions or comments that could allow you to be identified. With your consent, information can also be used for future research. Your data may be archived for a minimum of two years.

Data protection and confidentiality.

Your data will be processed in accordance with Data Protection Law. All information collected about you will be kept strictly confidential. Your data will be referred to by a unique participant number rather than by name. Your data will only be viewed by the research team (Dr Cristina Andriana Alexandru, Dr Aurora Constantin and Elina Michaelidou).

All electronic data will be stored on a password-protected encrypted computer, on the School of Informatics' secure afs file servers, and all paper records will be stored

in a locked filing cabinet in the PI's office. Your consent information will be kept separately from your responses in order to minimise risk.

What are my data protection rights?

The University of Edinburgh is a Data Controller for the information you provide. You have the right to access information held about you. Your right of access can be exercised in accordance Data Protection Law. You also have other rights including rights of correction, erasure and objection. For more details, including the right to lodge a complaint with the Information Commissioner's Office, please visit www.ico.org.uk. Questions, comments and requests about your personal data can also be sent to the University Data Protection Officer at dpo@ed.ac.uk.

Who can I contact?

If you have any further questions about the study, please contact the Principal Investigator researcher Dr Cristina Andriana Alexandru (Cristina.Alexandru@ed.ac.uk).

If you wish to make a complaint about the study, please contact inf-ethics@inf.ed.ac.uk. When you contact us, please provide the study title and detail the nature of your complaint.

Updated information.

If the research project changes in any way, an updated Participant Information Sheet will be sent to you by email by Elina Michaelidou (E.Michaelidou@sms.ed.ac.uk)

Alternative formats.

To request this document in an alternative format, such as large print or on coloured paper, please contact Elina Michaelidou (E.Michaelidou@sms.ed.ac.uk).

General information.

For general information about how we use your data, go to: edin.ac/privacy-research

Participant Information Sheet – Students

Project title:	Review of web-based Audience Response Systems used in Higher Education
Principal investigator:	Dr Cristina Andriana Alexandru
Researcher collecting data:	Elina Michaelidou
Funder (if applicable):	–

This study was certified according to the Informatics Research Ethics Process, RT number 2019/80319**.** Please take time to read the following information carefully. You should keep this page for your records.

Who are the researchers?

The research team consist of Dr Cristina Andriana Alexandru, Dr Aurora Constantin and Elina Michaelidou.

What is the purpose of the study?

The purpose of the study is to examine the usability of an Audience Response System (ARS) when used by students to perform some basic functionality of the tool.

Do I have to take part?

No – participation in this study is entirely up to you. You can withdraw from the study at any time, without giving a reason. Your rights will not be affected. If you wish to withdraw, contact the PI. We will stop using your data in any publications or presentations submitted after you have withdrawn consent. However, we will keep copies of your original consent, and of your withdrawal request.

What will happen if I decide to take part?

During the study we will collect data regarding your interaction with a three ARSs. There will be three parts to this study for each ARS. In the first part we will ask you to perform a number of specified tasks on one of the three ARSs and make note of any difficulties. You will be in the same room with two more students so that we can simulate the use of the ARSs in a classroom environment. No interaction with the other participants will be needed and you will work on your own interface. In the

second part you will be asked to complete a short questionnaire to give us your general opinion on the tool's usability, which will be followed by some questions regarding your experience with using the system. This process will be repeated for each of the three ARSs. The data will be collected using pen and paper and SurveyMoney (questionnaire).

Compensation. [only required if applicable]

There is not compensation for completing this study.

Are there any risks associated with taking part?

There are no significant risks associated with participation

Are there any benefits associated with taking part?

The provided data will be used to provide suggestions on usability and design guidelines of future ARSs and can be used in the creation of a prototype of an improved version of the ARSs under examination. All these will aim to improve your future interaction with the ARSs during in class usage.

What will happen to the results of this study?

The results of this study may be summarised in published articles, reports and presentations. Quotes or key findings will always be anonymous. We may include your comments in our publications or disclose them to other researchers, but they will be shared without your name, and we will not disclose any opinions or comments that could allow you to be identified. With your consent, information can also be used for future research. Your data may be archived for a minimum of two years.

Data protection and confidentiality.

Your data will be processed in accordance with Data Protection Law. All information collected about you will be kept strictly confidential. Your data will be referred to by a unique participant number rather than by name. Your data will only be viewed by the research team (Dr Cristina Andriana Alexandru, Dr Aurora Constantin and Elina Michaelidou).

All electronic data will be stored on a password-protected encrypted computer, on the School of Informatics' secure afs file servers, and all paper records will be stored in a locked filing cabinet in the PI's office. Your consent information will be kept separately from your responses in order to minimise risk.

What are my data protection rights?

The University of Edinburgh is a Data Controller for the information you provide. You have the right to access information held about you. Your right of access can be exercised in accordance Data Protection Law. You also have other rights including rights of correction, erasure and objection. For more details, including the right to lodge a complaint with the Information Commissioner's Office, please visit www.ico.org.uk. Questions, comments and requests about your personal data can also be sent to the University Data Protection Officer at dpo@ed.ac.uk.

Who can I contact?

If you have any further questions about the study, please contact the Principal Investigator researcher Dr Cristina Andriana Alexandru (Cristina.Alexandru@ed.ac.uk).

If you wish to make a complaint about the study, please contact inf-ethics@inf.ed.ac.uk. When you contact us, please provide the study title and detail the nature of your complaint.

Updated information.

If the research project changes in any way, an updated Participant Information Sheets will be sent to you by email by Elina Michaelidou (E.Michaelidou@sms.ed.ac.uk)

Alternative formats.

To request this document in an alternative format, such as large print or on coloured paper, please contact Elina Michaelidou (E.Michaelidou@sms.ed.ac.uk).

General information.

For general information about how we use your data, go to: edin.ac/privacy-research

Participant number:_____

Participant Consent Form – Teachers

Project title:	Review of web-based Audience Response Systems used in Higher Education
Principal investigator (PI):	Dr Cristina Andriana Alexandru
Researcher:	Elina Michaelidou
PI contact details:	Cristina.Alexandru@ed.ac.uk

Please tick yes or no for each of these statements.

		Yes	No
1.	I confirm that I have read and understood the Participant Information Sheet for the above study, that I have had the opportunity to ask questions, and that any questions I had were answered to my satisfaction.		
2.	I understand that my participation is voluntary, and that I can withdraw at any time without giving a reason. Withdrawing will not affect any of my rights.		
3.	I agree to being audio recorded.		
3.	I agree to my interactions with the tool being screen recorded.		
4.	I consent to my anonymised data being used in academic publications and presentations.		
5.	I understand that my anonymised data can be stored for a minimum of two years		
6.	I allow my data to be used in future ethically approved research.		
7.	I agree to take part in this study.		

Name of person giving consent	Date dd/mm/yy	Signature

Name of person taking consent	Date dd/mm/yy	Signature

THE UNIVERSITY of EDINBURGH informatics

Participant number:_____

Participant Consent Form – Students

Project title:	Review of web-based Audience Response Systems used in Higher Education
Principal investigator (PI):	Dr Cristina Andriana Alexandru
Researcher:	Elina Michaelidou
PI contact details:	Cristina.Alexandru@ed.ac.uk

Please tick yes or no for each of these statements.

		Yes	No
1.	I confirm that I have read and understood the Participant Information Sheet for the above study, that I have had the opportunity to ask questions, and that any questions I had were answered to my satisfaction.		
2.	I understand that my participation is voluntary, and that I can withdraw at any time without giving a reason. Withdrawing will not affect any of my rights.		
3.	I consent to my anonymised data being used in academic publications and presentations.		
4.	I understand that my anonymised data can be stored for a minimum of two years		
5.	I allow my data to be used in future ethically approved research.		
6.	I agree to take part in this study.		

Name of person giving consent	Date dd/mm/yy	Signature

Name of person taking consent	Date dd/mm/yy	Signature

THE UNIVERSITY of EDINBURGH informatics

F.2 Researcher's Scripts

During each study, a script was used to give the participant more information about ARSs and to provide them with details about each step of the study. A different script was used for the teachers' and student's study.

F.2.1 Researcher's Script - Teachers

INTRODUCTION [5 mins]

Hello! Thank you for agreeing to take part in this study. Please read this Participant Information Sheet and sign this Consent Form if you are happy to proceed [hand them PIS + CF and wait until they give it back]. The aim of this study is to examine the usability of three web-based Audience Response Systems, ARSs for short. To make sure we have the same understanding, I will give you a short definition of ARSs. A web-based ARS is a tool which allows teachers to ask questions to students during a class, and students can then respond using any of their web-enabled personal devices such as laptops, tablets, phones. The responses are sent back to the teacher via a Wi-Fi connection and can be displayed to the class. Older versions of ARSs required students to purchase a handheld device to respond to question. These devices are known as clickers, and hence the name clickers can still be used to describe an ARS today. We will only focus on web-enabled ARSs.

The ARSs that we will use today are Poll Everywhere [24], Wooclap [37] and Mentimeter [19]. The study is separated in three parts for each ARS. For the first part I will ask you to do a set of tasks while taking notes and screen recording your interactions. The second part will be a short questionnaire and the last part will be an interview.

Please remember that in this study we are testing the system not you. If you have any questions, please let me know now as I will not be able to provide any explanations during the study.

For each tool in tools:

The first/second/last tool that we will examine is [enter ARS name].

PART A [at least 10 mins per ARS]

[Only the first time: Initial Interview]

For the first part I will ask you to complete a few tasks using my laptop. I have already logged you in the tool and what you see is a fresh interface. The session will be screen recorded. The recording will be stored locally, and it will not record any

microphone sounds. These are the tasks that I want you to do [hand them the tasks]. When you finish the first task, please let me know so that I can help you with the next task. The second task will be done in conjunction with myself to represent students. Please read the tasks before we begin. [Wait for them to read the tasks.] Is everything clear? Do you have any questions? [Answer any questions they may have.] I start the screen recording now, you may begin. [Once they finish]. Thank you. I will now stop the screen-recording.

PART B [2-3 mins per ARS]

The second part is a short questionnaire to give us some general feedback about the ARS. [Hand them questionnaire].

PART C [5 mins per ARS]

Thank you for completing the questionnaire. The third part is a short interview, where I will ask you some specific questions about your interaction with the ARS. This part will be audio-recorded.

[Press play. Interview questions. Press stop]

Next ARS

CONCLUSION [5 mins]

Thank you for completing the study. Before leaving, I have a few more questions to ask you regarding your overall experience. This part will be audio-recorded.

[Press play. Interview questions. Press stop]

Thank you for your participation. Do you have any final questions?

F.2.2 Researcher's Script - Students

INTRODUCTION [5 mins]

Hello! Thank you for agreeing to take part in this study. Please read this Participant Information Sheet and sign this Consent Form if you are happy to proceed [hand them PIS + CF and wait until they give it back]. The aim of this study is to examine the usability of three web-based Audience Response Systems, ARSs for short. To bring everyone to the same level I will give you a short definition of ARSs. A web-based ARS is a tool which allows teachers to ask questions to students during a class, and students can then respond using any of their web-enabled personal devices such as laptops, tablets, phones. The responses are sent back to the teacher via a Wi-Fi connection and can be displayed to the class. Older versions of ARSs required students to purchase a handheld device to respond to question. These devices are known as

clickers, and hence the name clickers can still be used to describe an ARS today. We will only look at web-based ARSs.

The ARSs that we will use today are Poll Everywhere [24], Wooclap [37] and Mentimeter [19]. The study is separated in three parts for each ARS. For the first part I will ask you to do a set of tasks while taking notes. The second part will be a short questionnaire and the last part will be another short questionnaire for students.

Please remember that in this study we are testing the system not you. If you have any questions, please let me know now as I will not be able to provide any explanations during the study.

For each tool in tools:

The first/second/last tool that we will examine is [enter ARS name].

PART A [5 mins per ARS]

For the first part, we will try to simulate a lecture interaction. Some questions will be presented on the screen and you should answer them by following the instructions that I will give you.

[Connect laptop to a screen or ask students to read from laptop screen].

Please connect to the classroom environment by following the instructions on the screen. Please dont choose the text-message option. If there are any issues, please let me know.

[Once everyone is connected move to the first question.]

Please respond to this question.

[Once everyone has replied move to the next question.]

Please respond to this question. You can submit more than one answer.

[Once everyone has replied move to the next part.]

Thank you. This part is now over, please wait quietly for a few minutes.

PART B [5 mins per ARS]

The second and third parts are short questionnaires to give us some general feedback about the ARS. You can use your personal devices to complete the questionnaire. Please visit this URL, or you can scan this QR code [show them paper with URL + QR code]. Once you finish please wait quietly until I give you further instructions.

PART C [5 mins per ARS]

Thank you for completing the questionnaire. The third part is another short questionnaire to give us some specific feedback about the ARS. Please be as precise as possible. You can use your personal devices to complete the questionnaire. Please visit this URL, or you can scan this QR code [show them paper with URL + QR code].

Once you finish please wait quietly until I give you further instructions.

Next ARS

CONCLUSION [5 mins]

Thank you for completing the study. Before leaving, I have a few more questions to ask you regarding your overall experience. Please complete a questionnaire to give us you overall thoughts and some demographics information. You can use your devices to complete the questionnaire. Please visit this URL, or you can scan this QR code [show them paper with URL + QR code]. Once you finish you are allowed to leave.

F.3 Teachers' Initial Interview

Before starting interacting with any ARSs teachers were asked some questions to determine their experience with ARS. The questions can be found below:

1. Before starting I would like to ask you if you have any experience with using other ARSs to prepare questions.
2. (If YES) Which ARSs have you used before?
3. (If YES) When was the last time you used an ARS to prepare questions?

F.4 Teachers' Tasks

The first part of the study was an observation, where each teacher was asked to complete a set of tasks. Their actions were recorded using a screen recorder and notes were taken to note any problems they had or comments they made. There were three main tasks, which consisted of sub-tasks. The full list of tasks that were given can be found below:

1. Before class: Question Creation
    (a) Create a new multiple-choice poll asking the question: "Which is the capital of France?" and having four possible options: "Lyon", "Marseille", "Munich", "Paris". The option Paris should be selected as the correct answer. The question should:
        i. accept anonymous responses*,

ii. not allow students to change their responses after they submitted it* and

iii. should run for 60 seconds.

(b) Create a new open-ended poll asking the question: "Which are your favourite colours?". The question should:

i. allow students to reply more than once,

ii. presented the replies as a word cloud and

iii. allow replies to appear on screen as students vote.

Note: Some of the above settings may only be controlled during presentation.

2. During class: Presentation of Questions and Voting

(a) Start presenting the questions.

(b) Start accepting responses for the first questions.

(c) Once voting for the first question is done, show the correct answer to the class.

(d) Start accepting responses for the second question.

(e) Close voting once all students have responded.

(f) Exit presentation mode.

3. After class: Analysis of Results

(a) View the results for each question

(b) Download an overall report**

* Wooclap and Mentimeter have these settings by default

** For Mentimeter this option is only available in the premium version, so only indicate where you would click to download the report.

F.5 System Usability Questionnaire

After teachers interacted with each ARS, they were asked to provide some general feedback about their interaction. The System Usability Scale (SUS) questionnaire [48] was used. The questions included are the one below. Each question had 5 possible responses ranging from strongly agree to strongly disagree.

1. I think that I would like to use this system frequently.
2. I found the system unnecessarily complex.
3. I thought the system was easy to use.
4. I think that I would need the support of a technical person to be able to use this system.
5. I found the various functions in this system were well integrated.
6. I thought there was too much inconsistency in this system.
7. I would imagine that most people would learn to use this system very quickly.
8. I found the system very cumbersome to use.
9. I felt very confident using the system.
10. I needed to learn a lot of things before I could get going with this system.

F.6 Teachers' Experience Interview Questions

Following the SUS questionnaire, teachers were asked to provide some specific information about their interaction with the ARSs. The questions were asked in the form of a semi structured interview. The questions asked to each teacher after interacting with each ARS can be found below:

1. Which task did you find the easiest to complete? (Depending on answer ask about specific observations)
2. Which task did you find the most challenging to complete? (Depending on answer ask about specific observations)
3. How straightforward was the question creation process?
4. How appropriate was the presentation screen to use in class?
5. How understandable was the presentation of the results?
6. How well did your interaction with the tool match with your expectations?

7. (If they have previous experience) Compared to your previous experience before this study how would you rate this tool?
8. What is your opinion about the interface that you interacted with?
9. Would you change anything regarding the design of the interface you interacted with?
10. Do you have any suggestions on how to improve the tool in general?
11. Any more comments or anything you would like to add?

F.7 Student's Experience Questionnaire Questions

After each group of students interacted with each ARS they were asked to describe their experience. Firstly, some general questions were asked using in a questionnaire, which was based on the System Usability Scale (SUS), and then they were asked some questions specific to their interactions with the tool again using a questionnaire. The questions of the SUS part of the questionnaire can be found in F.5. The remaining questions can be found below:

1. Which device did you use for the first part of the study?

   ◯ Laptop

   ◯ Tablet

   ◯ Smartphone

   ◯ Other (please specify) _____

2. How did you connet to the classroom environment?

   ◯ Using a URL

   ◯ Using a QR code

   ◯ Using a URL and a short code

3. How would you rate the following?

	Very Poor	Below Average	Average	Above Average	Excellent

Clarity of instructions to connect to the classroom environment.	◯	◯	◯	◯	◯
Ease of responding to the multiple-choice question.	◯	◯	◯	◯	◯
Ease of responding to the open-ended question.	◯	◯	◯	◯	◯
Ease of providing more than one response to the open-ended question.	◯	◯	◯	◯	◯
Understandability of the multiple-choice question results.	◯	◯	◯	◯	◯
Understandability of the open-ended question results.	◯	◯	◯	◯	◯

4. Would you change anything regarding the design of the interface you interacted with?

   ◯ No

   ◯ Yes (please specify) _____

5. Do you have any suggestions on how to improve the ARS in general?

   _____

6. Do you have any more comments?

   _____

F.8 Teachers' Comparison Interview Questions

After interacting with all ARSs, each teacher participant was asked to compare them in a final interview. The interview questions can be found below:

1. Which of the three ARSs do you feel provided you with the best user experience?
2. Which of the three ARSs do you feel was the most challenging to use for you?
3. Which of the three ARSs do you feel provided you with the best question creation experience?
4. Which of the three ARSs do you feel provided you with the best presentation experience?
5. Which of the three ARSs do you feel provided you with the best after-class experience?
6. Would you use any of three ARSs in your classes? (if YES, which one?)

F.9 Students' Final Questionnaire Questions

After interacting with all ARSs, each student participant was asked to complete a final questionnaire. The first part of the questionnaire was about comparing the three ARSs, and the second part included some demographic questions. The questionnaire questions can be found below:

PART A: AUDIENCE RESPONSE SYSTEMS COMPARISON

1. Which ARS provided the best user experience?
   - ◯ Wooclap [37]
   - ◯ Poll Everywhere [24]
   - ◯ Mentimeter [19]
   - ◯ No preference
2. Which ARS provided was the most challenging to use?
   - ◯ Poll Everywhere [24]

- ◯ Mentimeter [19]
- ◯ Wooclap [37]
- ◯ No ARS was challenging to use

3. Which ARS provided the best connection to a classroom experience?

   - ◯ Mentimeter [19]
   - ◯ Poll Everywhere [24]
   - ◯ Wooclap [37]
   - ◯ No preference

4. Which ARS provided the best presentation screen experience?

   - ◯ Poll Everywhere [24]
   - ◯ Mentimeter [19]
   - ◯ Wooclap [37]
   - ◯ No preference

5. Which ARS provided the best results presentation?

   - ◯ Wooclap [37]
   - ◯ Poll Everywhere [24]
   - ◯ Mentimeter [19]
   - ◯ No preference

Note: The answer options for each question (apart from the last option) appeared in random order to each participant.

PART B: DEMOGRAPHICS

6. Have you used an audience response system to answer questions before this study?

   - ◯ Yes
   - ◯ No
   - ◯ Don't remember

7. Which ARSs have you used before? (Please select all that apply)

- ◯ Glisser [7]
- ◯ Poll Eveywhere [24]
- ◯ Crowdpurr [6]
- ◯ Mentimeter [19]
- ◯ Meeting Pulse [18]
- ◯ Socrative [30]
- ◯ Kahoot! [16]
- ◯ GoSoapBox [13]
- ◯ IQPolls [15]
- ◯ Slido [29]
- ◯ VoxVote [35]
- ◯ Imakiku [14]
- ◯ Quiz-maker [28]
- ◯ TapToSpeak [31]
- ◯ Wooclap [37]
- ◯ UMU [34]
- ◯ OnlineTED.com [21]
- ◯ Q-ARS [27]
- ◯ TopHat [33]
- ◯ Pingo [22]
- ◯ AuResS [4]
- ◯ AnswerGarden [1]
- ◯ Zeetings [38]
- ◯ Teachably [32]
- ◯ ARSnova [3]
- ◯ Have not used an ARS before
- ◯ Other _____

8. When was the last time you used an ARS to answer questions?

- ◯ Last week
- ◯ Last month
- ◯ Last semester
- ◯ Earlier this academic year
- ◯ Last academic year
- ◯ More than two years ago
- ◯ Don't remember
- ◯ Have not used an ARS in the past

9. How do the ARSs you used to today compare with the ARSs you used in the past? If you have not used an ARS in the past please select N/A for all cases.

	Worse	About the same	Better	N/A
Poll Everywhere [24] is	◯	◯	◯	◯
Wooclap [37] is	◯	◯	◯	◯
Mentimeter [19] is	◯	◯	◯	◯

10. Which device would you most likely have used to respond to an ARS question if this was a real classroom?

- ◯ Laptop
- ◯ Tablet
- ◯ Smartphone
- ◯ Other (please specify) _____

Appendix G

Usability Evaluation Results

This chapter provides a full description of the results from the usability evaluation of the top three ARSs: Poll Everywhere [24], Wooclap [37] and Mentimeter [19]. For a summary of the results refer to Chapter 6.

G.1 Teachers' Usability Study

G.1.1 Interview Results

The hierarchy of the NVivo [20] nodes that represent the themes of thematic analysis that was performed on the interviews from the teachers' study can be found in Tables G.1 and G.2.

	Poll Everywhere [24]	**Wooclap** [37]	**Mentimeter** [19]
Before class	*(0)*	*(0)*	*(0)*
Question Creation	*(0)*	*(0)*	*(0)*
Positive	*(9)*	*(12)*	*(7)*
Negative	*(5)*	*(6)*	*(9)*
Poll Screen Layout	*(1)*		
Suggestions	*(3)*	*(1)*	*(3)*
Settings	*(0)*	*(0)*	*(0)*
Positive	*(0)*	*(4)*	*(0)*
Negative	*(3)*	*(2)*	*(6)*
Anonymous Responses	*(1)*		*(1)*
Timer	*(4)*		
Suggestions	*(0)*	*(1)*	*(2)*
During class	*(0)*	*(0)*	*(0)*

Presentation Screen	*(0)*	*(0)*	*(0)*
Positive	*(4)*	*(6)*	*(7)*
Negative	*(7)*	*(7)*	*(6)*
Suggestions	*(4)*	*(1)*	*(6)*
Results Presentation	*(0)*	*(0)*	*(0)*
Positive	*(4)*	*(4)*	*(6)*
Negative	*(0)*	*(2)*	*(1)*
Suggestions	*(1)*	*(4)*	*(0)*
After class	*(0)*	*(1)*	*(0)*
Results Viewing	*(0)*	*(0)*	*(0)*
Positive	*(1)*	*(0)*	*(0)*
Negative	*(2)*	*(10)*	*(2)*
Suggestions	*(1)*	*(2)*	*(0)*
Results Downloading	*(0)*	*(0)*	*(0)*
Positive	*(0)*	*(2)*	*(3)*
Negative	*(3)*	*(7)*	*(1)*
Suggestions	*(0)*	*(5)*	*(0)*
General	*(1)*	*(1)*	*(2)*
Interface	*(0)*	*(0)*	*(0)*
Positive	*(7)*	*(6)*	*(8)*
Negative	*(12)*	*(8)*	*(11)*
Labelling		*(4)*	
Visibility of Functions		*(2)*	
Suggestions	*(3)*	*(7)*	*(8)*
Labelling		*(1)*	
Visibility of Functions		*(1)*	
Expectations	*(4)*	*(5)*	*(6)*
Previous Experience	*(0)*	*(0)*	*(0)*
TopHat [33]	*(1)*	*(1)*	*(3)*
Google Forms [9]	*(1)*	*(1)*	*(1)*
Plickers [23]	*(1)*	*(0)*	*(1)*

Table G.1: NVivo [20] node hierarchy for the teachers' interview results for the ARS nodes. The numbers in parenthesis represent the number of references to that topic. When no number is present, it means that that node is not relevant for that ARS.

Comparison			
Best User Experience	*(3)*	Best Presentation Experience	*(1)*
Poll Everywhere [24]	*(1)*	*Poll Everywhere* [24]	*(0)*
Wooclap [37]	*(2)*	*Wooclap* [37]	*(2)*
Mentimeter [19]	*(1)*	*Mentimeter* [19]	*(4)*
Most challenging to use	*(2)*	Best After class Experience	*(2)*
Poll Everywhere [24]	*(3)*	*Poll Everywhere* [24]	*(3)*
Wooclap [37]	*(1)*	*Wooclap* [37]	*(0)*
Mentimeter [19]	*(2)*	*Mentimeter* [19]	*(1)*
Best Question Creation Exp.	*(1)*	Would use in Class	*(5)*
Poll Everywhere [24]	*(1)*	*Poll Everywhere* [24]	*(0)*
Wooclap [37]	*(2)*	*Wooclap* [37]	*(1)*
Mentimeter [19]	*(3)*	*Mentimeter* [19]	*(1)*
General	*(3)*		

Table G.2: NVivo [20] node hierarchy for the teachers' interview results for the Comparison node. The numbers in parenthesis represent the number of references to that topic.

The teachers' final comparison of the three ARSs can be found in Table G.3.

G.2 Students' Usability study

The results of the students' experience questionnaire can be found in the Tables G.4, G.5, G.6, G.7, G.8, G.9 and G.10.

G.2.1 Questionnaire Comments

The hierarchy of the NVivo [20] nodes that represent the themes of thematic analysis that was performed on the comments of the questionnaires from students' study can be found in Table G.11.

P. ID	Best user experience	Most challenging to use	Best question creation experience	Best presentation experience	Best after-class experience	Would use in class
TP1	Wooclap [37], Mentimeter [19]	Poll Everywhere [24]	Mentimeter [19]	Wooclap [37]	Mentimeter [19]	Wooclap [37], Mentimeter [19]
TP2	Mentimeter [19]	Poll Everywhere [24]	Mentimeter [19]	Mentimeter [19]	Poll Everywhere [24]	Mentimeter [19]
TP3	None	No preference	Mentimeter [19], Wooclap [37]	Mentimeter [19]	Mentimeter [19]	None
TP4	Wooclap [37]	Poll Everywhere [24], Mentimeter [19]	Wooclap [37]	Wooclap [37]	Poll Everywhere [24]	None
TP5	Poll Everywhere [24]	Wooclap [37], Mentimeter [19]	Poll Everywhere [24]	Mentimeter [19]	Poll Everywhere [24]	No preference
TP6	Wooclap [37]	Poll Everywhere [24]	Mentimeter [19]	Wooclap [37]	Mentimeter [19]	Wooclap [37]
Results	**Wooclap** [37]	**Poll Everywhere** [24]	**Mentimeter** [19]	**Wooclap** [37], **Mentimeter** [19]	**Poll Everywhre** [24], **Mentimeter** [19]	**Wooclap** [37], **Mentimeter** [19]

Table G.3: Teacher's final comparison of the tools. The most referred ARSs(s) can be found on the Results row. Overall, the most referred tool is *Mentimeter* [19].

		Poll Everywhere [24]	Wooclap [37]	Mentimeter [19]
Device Used	Laptop	2	2	2
	Tablet	0	0	0
	Smartphone	7	7	6
	Other	0	0	0
Connected	Using URL	8	9	4
	Using QR code	1	0	0
	Using URL + short code	0	0	4

Table G.4: Students' questionnaire results when asked to select which device they have used to respond to questions and how they connected to the classroom environment. Note: connection using QR code scored low because the QR code was not shown to students in all the sessions.

Poll Everywhere [24]	Clarity of instructions to connect to the classroom environment	Ease of responding to the multiple-choice question	Easy of responding to the open-ended question	Ease of providing more than one responses to the open-ended question	Understandability of the multiple-choice question results	Understandability of the open-ended question results
Excellent	4	4	6	4	6	4
Above Average	1	2	1	1	1	3
Average	2	1	1	4	2	2
Below Average	2	2	1	0	0	0
Poor	0	0	0	0	0	0
Score	34 (76%)	35 (78%)	39 (87%)	36 (80%)	40 (89%)	38 (84%)

Table G.5: Student's questionnaire results when asked to rate their experience with Poll Everywhere [24]. The numbers correspond to how many students selected each rating for each category. The results are scored by the following weights: Excellent: 5 points, Above Average: 4 points, Average: 3 points, Below Average: 2 points, Poor: 1 point. Total number of participants: 9. Maximum score: 45 points

Wooclap [37]	Clarity of instructions to connect to the classroom environment	Ease of responding to the multiple-choice question	Easy of responding to the open-ended question	Ease of providing more than one responses to the open-ended question	Understandability of the multiple-choice question results	Understandability of the open-ended question results
Excellent	3	5	3	3	6	1
Above Average	2	3	3	3	2	4
Average	1	1	2	2	0	4
Below Average	3	0	1	1	1	0
Poor	0	0	0	0	0	0
Score	32 (71%)	40 (89%)	35 (78%)	35 (78%)	40 (89%)	33 (73%)

Table G.6: Student's questionnaire results when asked to rate their experience with Wooclap [37]. The numbers correspond to how many students selected each rating for each category. The results are scored by the following weights: Excellent: 5 points, Above Average: 4 points, Average: 3 points, Below Average: 2 points, Poor: 1 point. Total number of participants: 9. Maximum score: 45 points

Mentimeter [19]	Clarity of instructions to connect to rhe classroom environment	Ease of responding to the multiple-choice question	Easy of responding to the open-ended question	Ease of providing more than one responses to the open-ended question	Understandability of the multiple-choice question results	Understandability of the open-ended question results
Excellent	5	5	2	1	4	3
Above Average	2	1	4	6	3	3
Average	1	2	1	0	1	2
Below Average	0	0	1	1	0	0
Poor	0	0	0	0	0	0
Score	36 (90%)	35 (88%)	31 (78%)	31 (78%)	35 (88%)	33 (83%)

Table G.7: Student's questionnaire results when asked to rate their experience with Mentimeter [19]. The numbers correspond to how many students selected each rating for each category. The results are scored by the following weights: Excellent: 5 points, Above Average: 4 points, Average: 3 points, Below Average: 2 points, Poor: 1 point. Total number of participants: 8. Maximum score: 40 points

	Clarity of instructions to connect to rhe classroom environment	Ease of responding to the multiple-choice question	Easy of responding to the open-ended question	Ease of providing more than one responses to the open-ended question	Understandability of the multiple-choice question results	Understandability of the open-ended question results	Average
Poll Everywhere [24]	34 (76%)	35 (78%)	**39 (87%)**	**36 (80%)**	**40 (89%)**	**38 (84%)**	37 (82%)
Wooclap [37]	32 (71%)	**40 (89%)**	35 (78%)	35 (78%)	**40 (89%)**	33 (73%)	35.83 (80%)
Mentimeter [19]	**36 (90%)**	35 (88%)	31 (78%)	31 (78%)	35 (88%)	33 (83%)	**33.5 (84%)**

Table G.8: Overview of student's experience questionnaire results when asked to rate their experience. The highest score per category is in bold text. Tables G.5, G.6 and G.7 in Appendix G give a detailed description for the derivation of the scores for each tool.

	Best user experience	Most challenging to use	Best connection to classroom experience	Best way to respond to questions	Best results presentation
Poll Everywhere [24]	0	**2**	1	0	2
Wooclap [37]	4	1	2	2	2
Mentimeter [19]	**5**	0	**4**	**4**	**4**
No preference	0	-	2	3	1
None	-	6	-	-	-

Table G.9: Summary of student's final comparison of the tools. The numbers correspond to how many students selected each ARSs for each category. Numbers in bold highlight the highest scoring ARS in each category.

s

		Compared to	
		Top Hat [33]	Mentimeter [19]
Poll Everywhere [24] is	Better	1	0
	About the same	**2**	1
	Worse	1	**3**
Wooclap [37] is	Better	**3**	0
	About the same	1	1
	Worse	1	**3**
Mentimeter [19] is	Better	1	-
	About the same	**4**	-
	Worse	0	-

Table G.10: Students comparison between the ARSs they have used in the study and the ARS they used in the past. The numbers represent how many students selected each option, based on the experience they had. Numbers in bold indicate the most common comparison for each ARS combination.

	Poll Everywhere [24]	**Wooclap** [37]	**Mentimeter** [19]
General	*(0)*	*(0)*	*(0)*
Connection Experience	*(0)*	*(0)*	*(0)*
Positive	*(0)*	*(0)*	*(1)*
Negative	*(1)*	*(2)*	*(0)*
Suggestions	*(4)*	*(1)*	*(1)*
Interface	*(0)*	*(0)*	*(0)*
Positive	*(3)*	*(1)*	*(1)*
Negative	*(0)*	*(0)*	*(1)*
Suggestions	*(4)*	*(2)*	*(2)*
Replying to Questions	*(0)*	*(1)*	*(0)*
Multiple-Choice	*(0)*	*(0)*	*(0)*
Positive	*(0)*	*(0)*	*(0)*
Negative	*(2)*	*(0)*	*(0)*
Suggestions	*(0)*	*(0)*	*(0)*
Open-Ended	*(0)*	*(0)*	*(0)*
Positive	*(0)*	*(0)*	*(0)*
Negative	*(0)*	*(0)*	*(3)*
Suggestions	*(1)*	*(2)*	*(4)*
Results presentation	*(1)*	*(1)*	*(2)*
Multiple-Choice	*(0)*	*(0)*	*(0)*
Positive	*(0)*	*(0)*	*(0)*
Negative	*(0)*	*(0)*	*(0)*
Suggestions	*(0)*	*(0)*	*(1)*
Open-Ended	*(0)*	*(0)*	*(0)*
Positive	*(0)*	*(0)*	*(0)*
Negative	*(0)*	*(0)*	*(0)*
Suggestions	*(1)*	*(1)*	*(2)*

Table G.11: NVivo [20] node hierarchy for the students' questionnaire comments for the ARS nodes. The numbers in parenthesis represent the number of references to that topic.

Appendix H

Extended List of Design Guidelines for Audience Response Systems

This appendix includes the final list of design guidelines for ARSs. The design guidelines were derived from a literature review on ARSs and a usability study. The literature review is described in Chapter 4 and the usability evaluation in Chapter 6.

H.1 Design Guidelines for the Teachers' Interface

Presentation Preparation:

- Support of the following question types:
  - Single-choice polls
  - Multiple-choice polls
  - Single-choice questions
  - Multiple-choice questions
  - Single-choice image polls
  - Multiple-choice image polls
  - Single-choice image questions
  - Multiple-choice image questions
  - Open-ended questions
  - Sorting problems
  - Matching problems
  - Image questions
- Support of questions from the audience
- Integration of questions with content slides via the web interface
- Existence of free presentation software plugins for the following:

  - Power Point [25]
  - Keynote [17]
  - Google Slides [12]
  - Prezi [26]

- Option to create questions following a tutorial integrated in the interface

Question Settings:

- Setting a timer to each question
- Specifying whether to allow or disallow a student to update a response after submitting
- Specifying whether to allow or disallow a student to reply more than once
- Specifying whether a response to a question is mandatory or not
- Scoring student's responses based on a correct answer
- Saving questions for future use

Results Settings:

- Multiple-choice questions should at least result in a bar chart
- Open-ended questions should at least results in a word cloud
- Ability to change the default visualisation type
- Ability to change the colours of the visualisation
- Automatic moderation of open-ended question responses
- Hiding students identity when presenting the results to the class
- Ability to specify whether to allow students' responses to be hidden to the class or not during voting

Presentation Screen:

- Existence of a different interface to present questions and results at the same time
- Showing the total number of students who have responded

- Showing the percentage of students who have responded
- Ability to manually stop accepting responses even if a timer is set

Results Manipulation:

- Ability to store students' responses for all questions asked
- Showing the total number of students who have responded
- Showing the percentage of students who have responded
- Showing how much time students required to answer each question
- Ability to access results from previous sessions
- Availability of raw results (students' responses presented in a simple table without any visualisations applied to them)
- Downloading responses for analysis with another software
- Emailing responses for analysis with another software
- Deleting all questions and responses

General:

- Allows the creation of unlimited sessions
- Allows unlimited number of questions per session
- Can be used in large classrooms (more than 100 students)
- Intuitive button names, with visible labels.
- Icons have a meaningful description when hovering over them.
- Clean layout without too many menus
- Existence of online help
- Existence of free mobile applications for the following mobile app stores:
  - App Store [2]
  - Google Play Store [10]
  - Windows Store [36]
  - Chrome Web Store [5]

H.2 Design Guidelines for the Students' Interface

Anonymity:

- Participating without logging in during the connection step
- Participating without providing a name during the connection step
- Participating without providing an email during the connection step

Connect to a classroom environment:

- Connecting using a URL
- Connecting using a QR code
- Connecting using a URL and a meaningful access code

Presentation of questions:

- Showing one question at a time
- Providing submission instructions to each question asked
- Showing a timer, if one is set
- Usage of a secure connection (https) to transfer students' responses
- Informing students that their responses have been recorded

Presentation of results:

- Displaying the overall results on student's device
- Displaying personal results on student's device

General:

- Existence of online help
- Existence of free mobile application for the following mobile app stores:
  - App Store [2]
  - Google Play Store [10]
  - Windows Store [36]
  - Chrome Store [5]