A Study on How Users Perceive Distributed Interactions on Web Applications

FELIX ALBERTOS-MARCO[1], JOSE A. GALLUD[2], AND VICTOR M. R. PENICHET[2]

[1]DIEI, Campus Universitari Igualada-UdL, 08700 Igualada, Spain
[2]ESII, University of Castilla-La Mancha, 02071 Albacete, Spain

Corresponding author: Jose A. Gallud (jose.gallud@uclm.es)

ABSTRACT Currently, users are able to interact with several devices, from smart watches to desktop computers, to perform different tasks. Such diversity of heterogeneous devices form a multi-device and multi-display ecosystem. Although this device ecosystem is usually connected by cloud services, a new interconnected environment is possible due to the emergence of a new paradigm based on distributed interactions. New techniques such as the proposed responsive Web interaction provides users with an environment that supports distributed interactions using the Web platform. This paper presents a study on how users perceive distributed interactions in educational environments using multi-device setups. The educational environment enriched with the Web interaction hub tool allows users to interact in a heterogeneous device ecosystem as if it were a single device. This paper was performed with more than 150 students using a satisfaction metric. The results show the impact that distributed interactions made on students, who preferred using distributed interactions in multi-device environments over traditional interactions.

INDEX TERMS Web applications, distributed interactions, responsive web interaction, user study, education environments.

I. INTRODUCTION

The Internet has made interactions with Web applications possible from almost anywhere and using any device. As a result, we can use the Web platform to perform tasks using multiple devices in a coordinated manner, therein using the interactive resources distributed among these devices.

In recent years, many theoretical and practical proposals have focused on managing these complex interactive scenarios. Combining distributed interaction and Web applications is challenging because there is not enough knowledge and even less consensus on how to distribute interaction in Web applications. Most of the developments are ad-hoc solutions based on particular case studies and/or developers intuition.

The Web is a platform that offers many of the necessary principles for successfully managing distributed interactions in multi-device environments. These principles offer guidance for the design of Web applications in the areas of compatibility, utility, interoperability and universal design [1].

This paper presents a study on how users perceive distributed interactions in educational environments using multi-device setups. The article presents a new technology that allows users to use distributed interactions in a heterogeneous device ecosystem. Different distributed scenarios have been developed to show how this new concept works. Finally, the article describes a study of those scenarios. A total of five groups of high school students (more than 150 students) participated in this study.

To support the creation of multi-device Web applications, the Responsive Web Interaction approach (see section III) is used. This tool facilitates the dynamic management of interaction by Web applications. It focuses on the presentation and navigation levels for the description of the interaction in currently interactive scenarios. There are also support tools [2] for the execution of the environments designed with these principles in mind.

The article is organized into the following sections. Section II describes the tool used to support distributed interactions. Section III presents the Responsive Web Interaction concept and the supporting tool. Section IV presents several applied scenarios whereby distributed interactions offer several advantages to users. Section V contains the core tasks of this research, which is the user testing. Section VI discusses the results obtained in the previous section. The final section contains the conclusions and future work.

II. DISTRIBUTING INTERACTIONS ON THE WEB

Distributed interactions can be defined as a new paradigm whereby a user can perform different interactions on a set of heterogeneous devices as if it were a single device [3]. With this approach, users can utilize the different capabilities present in all the devices in their ecosystem in performing their tasks. The distributed interactions paradigm can be viewed as an alternative communication paradigm, instead of using cloud services.

Previous related works use a different definition of Distributed Interactions. There are many applications that use the paradigm of distributed interactions on several devices. Examples include document viewers [4], [5], a snake-like game [4], exploring distributed maps [5], [6], video streaming applications [4]–[6] and even more complex scenarios such as learning applications [7], [8].

Bunde-Pedersen [9] proposed a generic definition of Distributed Interaction, suggesting that distributed interaction is the action that entities, individuals or computational resources perform through interfaces on distributed data.

Some authors work on how data are distributed. As an example, Rekimoto [10] presented a technique that can be used for data transfer between different computers as well as within the same computer. Fitzmaurice [11] proposed the use of context, location, and user information to address the increasing complexity of data access in forthcoming environments. There are many ways to transfer information among a set of devices; however, they do not provide a direct mechanism to exchange information in the same way as proposed in this article.

Villanueva *et al.* [12] presented a direct manipulation technique to exchange information among different devices. Santosa and Wigdor [13] identified gaps in data management and cross-device interactions as the main obstacles and opportunities for improvements in multi-device interaction. Wäljas *et al.* [14] defined Distributed Interaction as a key concept for cross-platform service user experience and the continuity of content and data for ensuring smooth transitions between platforms. All these approaches are focused on how data and information are used by multiple devices and/or users, but they do not focus on how the interaction itself is distributed.

For Houben *et al.* [15] Distributed Interaction is a computing paradigm in which the interaction with a computer system is distributed across multiple devices, users and locations. Recently, Houben [16] slightly changed this definition, thereby describing Distributed Interaction as interaction with a computer system that is dynamically distributed across multiple individuals, devices and environments. According to this approach, the interaction itself plays a prominent role in the distribution.

In previous works, we have analyzed how interactions with Web applications are performed in several scenarios. These scenarios consist of multi-device environments [17] where the interactive elements can be used to improve or support user tasks [2], facilitating, for example, universal access [3], or in situations with connectivity issues [18] supporting virtual rehabilitation on the Web [19] or within e-Learning environments [20].

III. SUPPORTING DISTRIBUTED INTERACTIONS: THE RESPONSIVE WEB INTERACTION AND THE WEB INTERACTION HUB

The basis of the research is a method for the distribution of interactions with Web applications called Responsive Web Interaction. This approach enables the design of interactions using primitives that control what is occurring in the interaction through the user interface. For example, some elements of the user interface can be configured to communicate to other elements, what are the interactions they are receiving. This control permits the utilization of the interactive capabilities of the device(s) when they execute one or several Web applications.

The distributed interactions paradigm is a emerging mechanism that allows the user to perform interactions on a set of heterogeneous devices as if it were one device. With this approach, users can take advantage of the different capabilities present in all the devices in their ecosystem in performing their tasks. This section introduces a model to support distributed interactions called Responsive Web Interaction. The underlying concept under the ''Responsive Web'' expression is to provide users with a responsive experience at the interaction level.

The model presented in the Figure 1 shows the foundations for the specification of the Responsive Web Interaction. These foundations allow not only the management and the design of user interaction over each interactive element of the Web application, but also allow modelling the available elements within the interactive cycle.

This model can be divided in two parts. The first part, highlighted in the model with a grey background, describes how the elements of the Web application are organized. The second one, is focussed on describing the mechanisms to support distributed interactions within the Web application. It is worthy to note that the first part is partially represented in the model. It is fully described as the Offline Model in a previous work [18]. There, it is used to support the analysis of interrupted tasks based on user navigation with Web applications. It provides mechanisms to describe states and operations that users can perform when the interruption begins and ends. It also provides adequate mechanisms so that users can keep performing their tasks in the presence of interruptions. Hereafter, this work is focussed on the second part of the model.

A. OVERVIEW OF THE MODEL

In this section we describe the components of the model in charge of distributing the interaction in Web applications, which is depicted in the Figure 1.
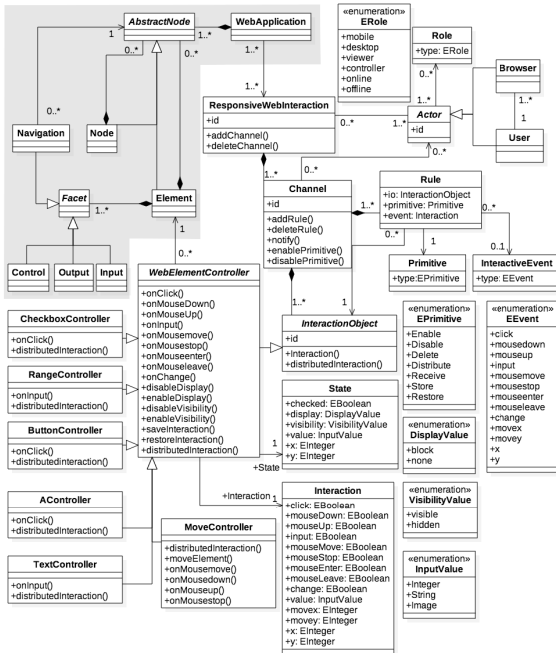
FIGURE 1. Main entities of the model for the specification of responsive web interaction.

1) CHANNEL

A channel constitutes a set of interactive objects and rules. It facilitates the design of the Responsive Web Interaction, allowing the distribution of the interaction through it. Also, it also has references to the actors participating on the system, being able to use their contextual information.

2) RULE

Rules describe how the interaction objects manage interaction over channels. A Rule is defined with the combination of an interaction object, a primitive and an interaction.

3) PRIMITIVE

A primitive defines the behaviour of an interaction object when it receives an interaction. It allows the custom behaviour of the Web application according to the design of the interaction process. Available primitives are:

- Enable: Enables interaction over the interactive element.
- Disable: Disables the interaction over the interactive element. The interaction element will be on the user interface, but user interaction will not be possible.
- Delete: Removes the interactive element from the user interface. It will not be included within the user interface.
- Distribute: The interaction over the interactive element will be sent through the channel.
- Receive: The interaction object receives the interaction broadcasted through the channel.
- Store: The interaction object locally saves the state of the interactive element.

- Restore: The interaction object restores the state of the interactive element.

4) InteractiveEvent

The interactive events are the actions the user performs over the Web application's user interface. They are defined as follows:

- mousedown: the user clicks the left button of the mouse over the interactive element.
- mouseup: the user releases the left button mouse over the interactive element after executing the action described by the mousedown interactive event.
- click: the user clicks with the mouse on the interaction element. This action is produced because of performing the mousedown followed by the mouseup action.
- input: the user introduces a value in the interactive element.
- mousemove: the mouse is moving over the interactive element.
- mousestop: the mouse stops over the interactive element after the mousemove event has been fired.
- mouseenter: the mouse enters over the interactive element.
- mouseleave: the mouse leaves the interactive element.
- change: the interactive element changes the state. Each interaction object (defined as follows) manage its own state. In the model, it is extended through the WebElementController entity.
- movex: the mouse moves (in pixels) within the x axis over the interaction element.
- movey: the mouse moves (in pixels) within the y axis over the interaction element.
- x: the mouse is located at the position x over the interaction element.
- y: the mouse is located at the position y over the interaction element.

5) InteractionObject

The interaction objects are in charge of managing the interaction performed over the interactive elements of the Web application through the channels. They are an abstraction for the definition of interactive elements.

6) WebElementController

The specialization of the InteractionObject, called WebElementController, allows the definition of interactive objects related with the interactive elements of the Web. This component manages the interactive elements over the Web, also allowing the mechanisms to support the primitives of the model.

Each one of the elements is directly related with an element of the Web application. It is worthy to note that many instances of the WebElementController can be associated with the same element of the Web application.

The specializations of the WebElementController define a custom behaviour according to existent or new elements

of Web applications. Each one manages the interaction according the interactive properties of the corresponding element on the Web interface. For example, the model shows the specializations CheckboxControler, RangeController or ButtonController, among others. Their names correspond with existent Web elements (checkbox, range and button respectively). Their function is to be mapped with the corresponding Web elements to manage user interaction over them.

Moreover, it is also possible to use specializations that are not associated with an existent element on Web applications. These specializations manage interaction mechanisms that can be performed using the user interface on Web applications but do not have a specific constructor within the elements defined by the HTML. As an example, the model shows the specialization MoveController. It provides with mechanisms to manage the movement of interactive objects in the user interface of Web applications.

7) INTERACTION
The Interaction represents the interactive events that characterise an interaction with an HTML element in a specific moment. Using this component is possible to describe what is going on with the element regarding the interaction. Its values correspond with the interactive events previously described as well as the following one:

- value: it is the value of the element. The type of the value is one of the described in the enumeration InputValue: Integer, String or Image.

8) STATE
The State indicates the values of an interactive element within the Web application. Its attributes are:

- checked: shows if the interactive element is checked to true or false (only if the interactive element supports this interaction).
- display: shows the value of the property 'display' of the interactive element. Allowed values are 'block' or 'none'.
- visibility: shows the value of the property 'visibility' of the interactive element. Allowed values are 'visible' and 'hidden'.
- value: shows the value of the element. Allowed values are 'Integer', 'String' and 'Image'.
- x: shows the x coordinate of the current position of the element in the user interface.
- y: shows the y coordinate of the current position of the element in the user interface.

9) ACTOR
This entity represents two types of actors within the model: the user/s interacting with the Web application through the user interface and the browser/s executing an instance of the Web application.

10) ROLE
Each actor within the system has an assigned role. This characterization is used to enrich the rules, allowing the

management of the interaction according the actors within the ecosystem and their roles. Defined roles are:

- Mobile: the device is a mobile device.
- Desktop: the device is a desktop computer.
- Viewer: the device has the role viewer in the view/controller pattern.
- Controller: the device has the role of controller in the view/controller pattern.

B. THE WEB INTERACTION HUB
One proposal for the distribution of an interaction is the Web Interaction Hub (WIH) [2]. It uses the Responsive Web Interaction paradigm to allow the "connection" of devices' and users' interactive capabilities to the Web application. The WIH utilizes how the web is designed to distribute interactions among the available users' and devices' capabilities. It is aimed at mapping devices and user capabilities with the interactive elements of the Web. It works as an application layer, providing something similar to a "USB hub" [2]. It allows the "connection" of multiple device capabilities to the Web application.

The WIH is in charge of addressing all the issues related to device synchronization, device discovery, and user interface adaptations, among others. The ultimate aim of the WIH is to allow any existent Web application to use the Responsive Web Interaction paradigm.

The WIH is a piece of software composed of two elements: the WIH Engine and the WIH Server. Both elements coordinate the distribution of the in- teraction. The WIH Engine is a Javascript library running locally on the browser. The WIH engine is included in the Web application, just like any other Javascript library. It is in charge of managing the interaction between the interaction elements of the Web application and the interactive capabilities available on the WIH. Also, it is in charge of performing the adaptations on the Web application to support new interaction mechanisms.

The WIH Server is a Websockets[1] server running on the server side. It is in charge of managing the communication between the devices connected to the Web application.

IV. APPLYING THE RESPONSIVE WEB INTERACTION IN THE CLASSROOM
Using the tools described in the previous section, this section presents three scenarios that have been designed to be used in the classroom. These scenarios are designed to engage students in the classroom, for instance, to navigate through the options available on a Web page that is shown to all the students.

The first scenario is the distribution of the mouse interactions on a mobile device and the use of the speech-to-text capability of current smartphones (Distributed Point&Click Interaction, subsection IV-A). The second scenario is a distributed menu that is based on the creation of distributed user interfaces (Distributed Menu Interaction, subsection IV-B).

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[1]https://www.w3.org/TR/websockets/

The third scenario is a slideshow, which allows the management of a presentation with slides using a mobile device that is detected when connected to the Web application, thereby distributing the interactive components (SlideShow Distributed Interaction, subsection IV-C).

A. DISTRIBUTED POINT&CLICK INTERACTION

In this section, the process of using the Point&Click interaction, as well as the Speech-to-Text capability of a mobile device to edit text within an educational platform, Moodle, is described.

Figure 2 shows the Moodle application in the background. The user, whose mobile phone has the Point&Click interaction method distributed, is creating a new topic in the Web application's forum. He/she wants to enter text in the body of the message. To do so, the user moves the cursor (Figure 2-A) inside the text field using the touchpad on his mobile phone to control the mouse pointer in the Web application. Then, the user clicks in the text field using the screen of the mobile device (Figure 2-B). As a result, the text field is shown on the mobile device. The user is now able to write text on the mobile device. However, using the Speech-to-Text capability of the mobile device, he/she talks (Figure 2-C) to the mobile device. The mobile device uses the Speech-to-Text capability to transform the voice into text. The text is inserted in the text field. Note that the text is shown on the mobile device and in the Moodle Web application in real time. Once the user finishes entering the text, he/she closes the keyboard on the mobile device, and the education task is completed (Figure 2-D). At that point, the WIH (Web Interaction Hub) removes the text field from the mobile device. The user can continue using the Point&Click interaction method with the mobile device.

FIGURE 2. Distributing interactions between a mobile phone and a desktop computer.

B. DISTRIBUTED MENU INTERACTION

Among the most used resources in the classroom are Web applications. Web applications usually have navigational elements for navigating through the webpages of Web applications. Figure 3 shows the webpage of the Computer Science Department of the University of Castilla-La Mancha. On this page, students can navigate through the information about the department such as teaching activities, research activities, student information and the staff of the department. These areas are arranged in a menu located at the top of the webpages.

FIGURE 3. Webpage of the computer science department of the University of Castilla-La Mancha.

When using a webpage in the classroom, the teacher can use the mobile device to interact with the options in the menu, allowing anyone with a mobile device to perform the same interaction. Figure 4 shows the user interface in the mobile device with the menu. By selecting an element of the menu and using the distribution of the interaction, the Web application will navigate to the selected webpage.

FIGURE 4. Distribution of the Interaction: a menu on the mobile device.

C. SLIDESHOW DISTRIBUTED INTERACTION

Another frequent task within the classroom involves the presentation of multimedia contents or work done by the students in the form of slides. There are Web applications that support the creation of sliders for the presentation of this type of content. This scenario shows how multiple devices can be used to interact with this type of Web application. Figure 5 depicts a Web application for browsing slides running on a desktop computer. At the bottom of the user interface, two buttons are shown that are intended to allow the user to move
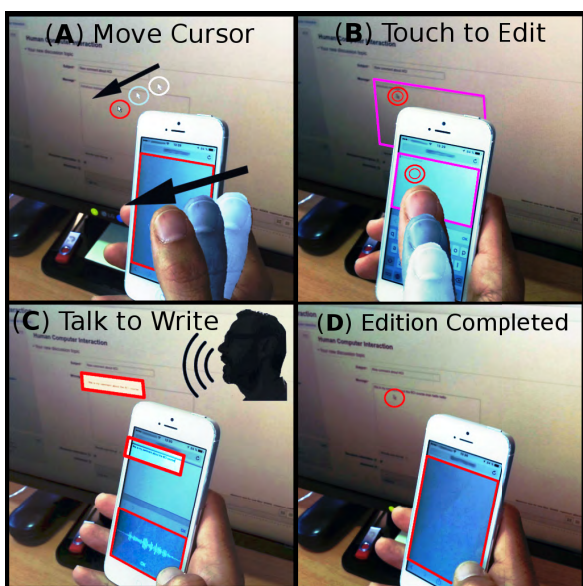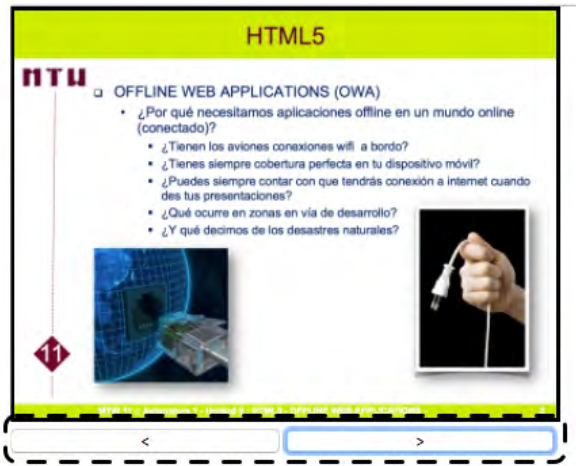
FIGURE 5. SlideShow: execution of the Web application on one device.

to the next slide or to the previous slide. This control has been highlighted in Figure 5 with a dotted box.

In this context, if a mobile device is connected to the Web application, the controls for navigating through the presentation will be removed from the user interface of the desktop computer and shown on the user interface of the mobile device. Figure 6 shows this scenario, where the removed/added elements are highlighted with a dotted box. To facilitate the dynamic management of the interaction on this scenario, an extension of the tool that implements the viewer/controller pattern has been used.
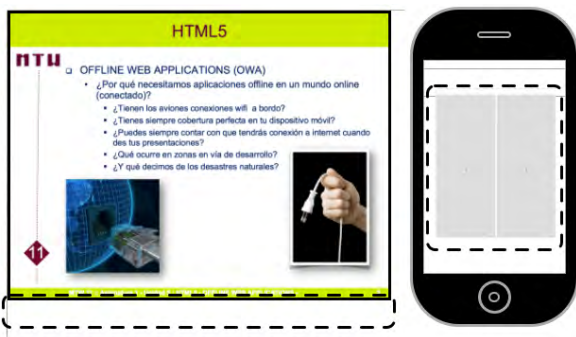

FIGURE 6. Slideshow: execution of the Web application on two devices.

V. ANALYZING THE USERS' PERCEPTION ON DISTRIBUTED INTERACTIONS

This sections analyzes the users' perception when using distributed interactions. The main goal of the evaluation is to determine how the students feel using distributed interactions in Web applications when performing their tasks and if this distribution changes the perception of the task. To that end, users use a set of interactive devices distributed in the environment.

Next, the test is presented, therein describing the design participants, apparatus, procedure and the results obtained through the execution of the test.

A. DESIGN

The tasks consist of the interaction with Web applications that use the paradigm of distributed interactions.

Participants should perfom each task using both methods, the traditional interaction (TI, without distributed interactions), and the proposed (the one that implements distributed interactions by using the Responsive Web Interaction mechanism or RWI).

The tasks are defined in the following list:
1) Navigate the proposed website.
2) SlideShow: Users have to show at least three different slides
3) Point&Click: Users have to post a message on the forum available in Moodle explaining what they have observed during their visit to the computer science research institute.

To conduct the tasks in the evaluation, the participants are given 5 minutes. Once the users have finished the tasks, they evaluate their experience using the cards in Figure 7.

FIGURE 7. Faces representing the 5-point scale of the Smileyometer.

For the evaluation, the "Smileyometer" [21] technique has been used. This technique is based on the use of a scale of five points represented by five faces. This method is used to extract a user's opinion about the activities under study and to determine how fun or pleasant it is for them. Figure 7 shows the cards used to conduct the evaluation. To evaluate the current activity, students can use any of the cards to give a value within the "Smileyometer" scale, from 1 to 5, where 1 corresponds to "Awful" while the maximum rating, 5, corresponds to "Brilliant".

To evaluate each of the interactions (traditional and RWI), the users have to select one card for each type of interaction, answering the question "how much fun was it to do that activity?". One card for each interactive mechanism is placed on each of the corresponding areas for the evaluation, as observed in Figure 8. The left side includes an area for the "traditional" interaction, represented with a mouse and
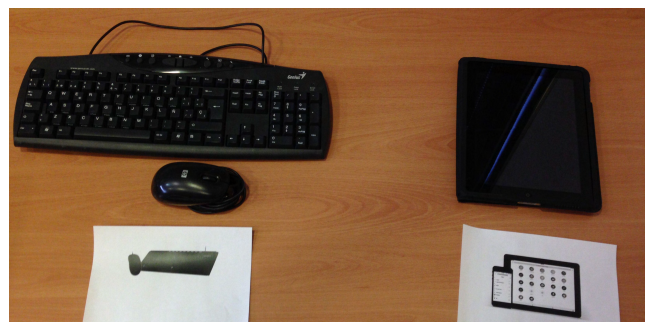

FIGURE 8. Setup for the evaluation of the interaction: Traditional Interaction (left) and Responsive Web Interaction (right).

keyboard. On the right side, there is an area for the "Responsive Web Interaction", represented with a tablet. Once each member of the group has placed the corresponding card on each area, the score is calculated according to the number of points that each area has received. Note that during this process, the students are not supervised to avoid conditioning the results.

B. PARTICIPANTS

The 153 participants in total were organized into 5 groups labeled G1, G2, G3, G4 and G5. An analysis of the distribution of the groups according to their age and academic courses (according to the Spanish education law) is shown in Table 1. All the participants were students from primary and secondary schools from Albacete (Spain). The courses represented in the sample are 5° and 6° of primary school, 1°, 3° and 4° of Secondary Obligatory Education (ESO) and one group from a medium-level technical and vocational school. The age range is from 11 to 23 years old. The most representative age range is from 10 to 12 years old, with 62.09% of students in that age range.

TABLE 1. Distribution of the students within the groups.

Group	N° Students	%	Ages	Course
G1	17	11%	11	6° Primary
G2	22	14%	12	1° ESO
G3	32	21%	17-23	Technical School
G4	56	37%	10-11	5° Primary
G5	26	17%	14-16	3° and 4° ESO
	153	100%		

All the participants have basic knowledge about how to use desktop and laptop computers. They also have basic knowledge about the use of smart phones and tablets. All the participants have used Web applications on smartphones, tablets or other computers such as desktop and laptop computers. All the participants use at least one of these devices daily, and they use them regularly to browse Web applications many times during a week. Concerning the use of electronic learning platforms, such as Moodle, none of the participants have used these types of Web platforms, and very few of them know of their existence.

All participants were conveniently informed and agreed to participate. The group responsible was also conveniently informed. None of the participants in the evaluation were paid.

C. APPARATUS

The hardware used to perform the evaluation consisted of a laptop computer, i.e., an ASUS R510J with an Intel Core i7-4720HQ CPU, 8GB of RAM, 128 GB SSD and an NVidia GeForce 930M graphics card with 1 GB of memory; a 27'' widescreen connected to the laptop; two tablets (iPad 2); a smart phone (iPhone 5); and a mouse and keyboard. The Web applications used in the evaluation were running on an Apache 2.4.7 web server running on a Dell

Vostro 220 server running Ubuntu 14.04 LTS with an Intel Core 2 Duo e7400 processor, 4 GB of RAM, 310 GB hard disk and an ATI RV515 graphics card.

The laptop, tablets and smartphones were connected to the network using the Eduroam WiFi connection available at the research institute where the evaluation was performed.

D. PROCEDURE

The evaluations were performed in 5 sessions planned on the following dates: 15/12/2016 (G1), 26/01/2017 (G2), 16/02/16 (G3), 25/04/2017 (G4) and 04/05/2017 (G5). Each session corresponds to a visit by a primary or secondary school to the Computer Science Research Institute (I3A). The main goal of the visits was to show the students the environment where the researchers performed their work and to introduce them to the research topics that each research group is working on, as well as the installations at the research institute.

In each visit, the number of students varies from 17 to 56 people in each group. In addition, each visit has a time limit associated with it. As a result, each group is divided into sub-groups of 4 to 9 students to allow every student to be able to interact with the Web applications.

The interactive devices available in the environment are described in section IV.

The step-by-step procedure was as follows:

1) Each sub-group, at the beginning of the session, is asked about their experience with Web applications, how frequently they use them, what type of Web applications they use to determine their preferences and introduce the activities to perform during the evaluation. The idea behind this introduction is to not make them feel "evaluated".

2) The next step is to initiate a small debate to determine the opinion of the participants on the use of Web applications on multiple devices and their view of the distribution of the interactions among them.

3) The person in charge of conducting the tests shows an example of distributed interactions using the webpage at the Computer Science Department of the University of Castilla-La Mancha. This example consists of distributing part of the menu to a mobile device, as observed in Figure 4.

4) Each participant perform each task ("traditional" first, then the "multi-device" version). Participants employed one device with the "traditional" version, and two devices with the "multi-device".

5) At the end of the session are the participants asked to evaluate their experience with the "traditional" and "multi-device" scenario with the cards presented in Figure 7.

E. RESULTS

The evaluation is conducted based on the number of votes for each of the available values of the "Smileyometer" test for

each interaction mechanism. This information is represented in radar charts. Radar charts enable the representation of multivariate data in the form of a two-dimensional chart. For this evaluation, we are using the five quantitative variables of the "Smileyometer" test, representing the percentage of votes. The value range is from 0% at the center of the chart to 100% at the edge of each variable. The Traditional Interaction (TI) is represented with a dotted line, while the Responsive Web Interaction (RWI) is represented with a solid line.[2]

For group G1 (Figure 9), opinions on the TI were quite heterogeneous. The most predominant opinions were "Good" (29.41%) and "Really good" (35.29%). The RWI was unanimously evaluated as "Brilliant" (100%).
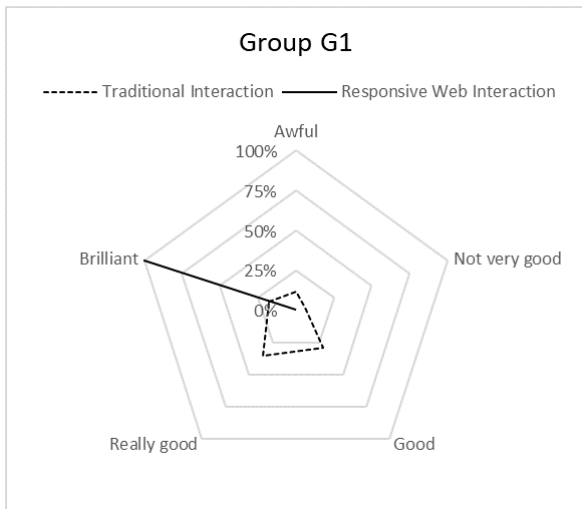

FIGURE 9. Results for the G1 group.

The results for the TI in the second group (G2) (Figure 10) are very similar to those for G1, although the valuation "Not very good" is chosen 27.27% of the time, which is the same result as "Good" and slightly lower that the value for "Really good", with a value of 31.82%. For the RWI, the most popular option remains "Brilliant" but with a value of 63.64%.

The results for the third group (G3) (Figure 11) show that for the TI, the most popular option is "Good" (43,75%), with a decreasing tendency through "Really good" and "Brilliant". This group did not choose the "Not very good" or "Awful" options. Concerning the RWI, there is a change for the most popular option, with "Really good" obtaining 46.88% of the votes and "Brilliant" achieving 40.63%.

The results for the fourth group (G4) (Figure 12) show that "Good" is the most voted option (33.93%), with "Brilliant" having a similar value (30.36%). For this group, "Brilliant" is also the predominant vote, with 57.14%, following the tendency of the groups G1 and G2.

The results for the fifth and last group (G5) (Figure 13) show that for the TI, "Good" (57.69%) and "Really good"
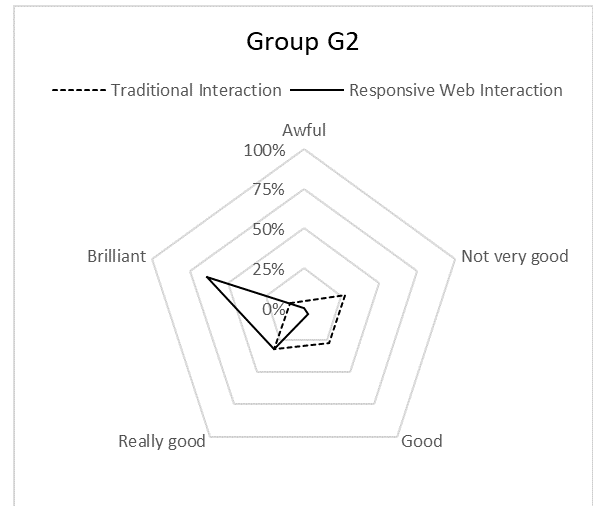
FIGURE 10. Results for the G2 group.
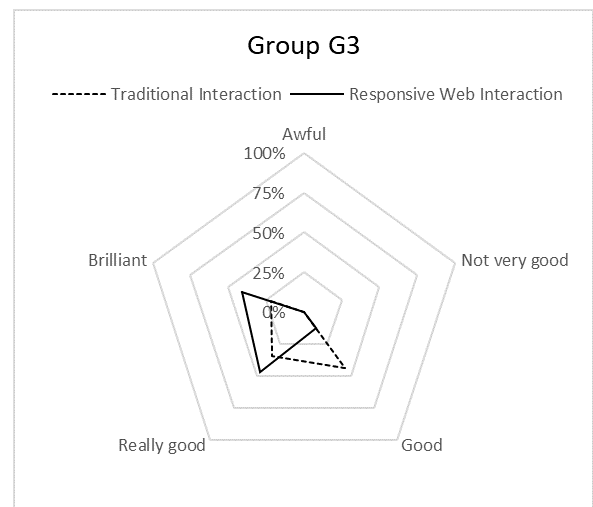
FIGURE 11. Results for the G3 group.

TABLE 2. How much fun was it to do that activity?

How fun was it?	TI	%	RWI	%
Awful	7	4,58	2	1,31
Not very good	8	5,23	2	1,31
Good	59	38,56	15	9,80
Really good	50	32,68	52	33,99
Brilliant	29	18,95	82	53,59
	153	100,00	153	100,00

(38.46%) are the most popular options. For the RWI, almost half of the users have a score of "Really good" (46.15%).

Finally, the Table 2 summarizes the results of all the groups with the TI and RWI. The results show that for the TI, the most voted option was "Good", with a total of 59 votes (38.56%), followed by "Really good" with almost the same number of votes (50). The "Brilliant" option received less than half of the votes, 29, that the most popular option received. The results for the evaluation of the RWI show that the most
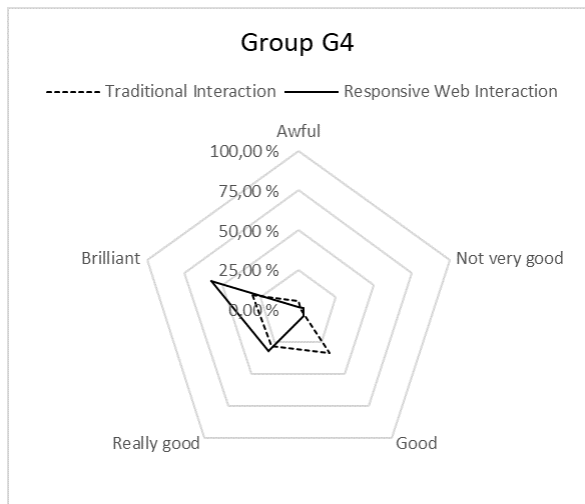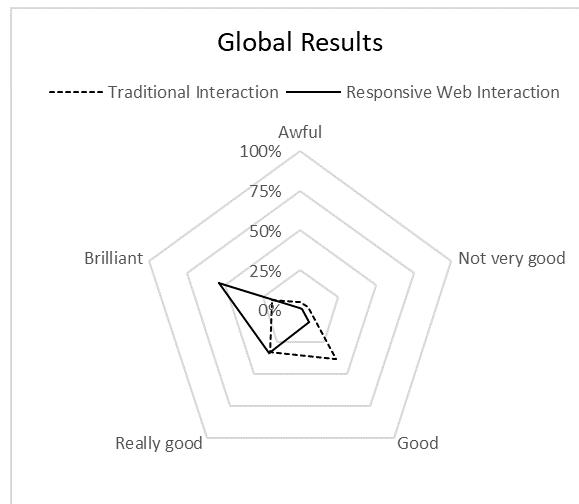
FIGURE 12. Results for the G4 group.

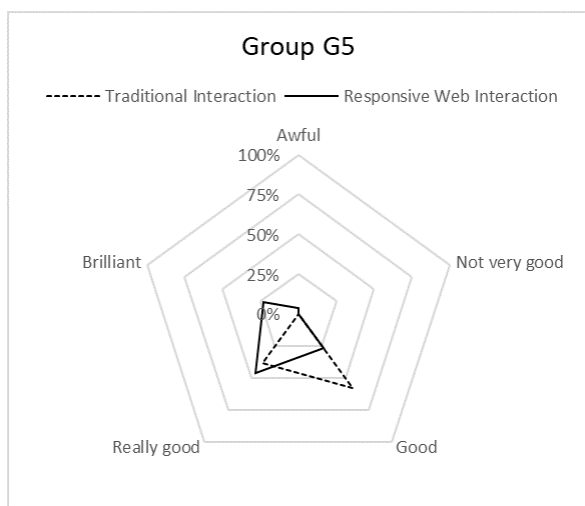**FIGURE 14.** Global results of the evaluation.

FIGURE 13. Results for the G5 group.

popular option was ''Brilliant'', with a total of 82 votes, representing more than half of all participants, with 53.59%. The option ''Really good'' (33.99%) is in the same range as the TI for the options ''Really good'' and ''Good'' (32,68%-38,56%). These results are depicted in Figure 14.

VI. DISCUSSION

The results show that when performing tasks in multi-device environments with Web applications, the groups of students with ages between 10 and 12 years, corresponding to the groups G1, G2 and G4, clearly have a lot of fun using RWI and distributing the interactions among the available devices. Analyzing the results, it can be observed that, for these groups, the most popular option is ''Brilliant''. On the other hand, for the TI, the results show that ''Good'' is the most popular option, closely followed by ''Really good''.

However, for the groups with ages between 14 and 23 years, corresponding to the groups G3 and G5, although

the results show that they also have a lot of fun using RWI, the most popular option for the RWI is ''Really good'', while for the TI, the result is the same as the other groups: ''Good''.

Note that when interpreting the results of the evaluation, according to Read and MacFarlane [21], the ''Smileyometer'' is not useful for kids under 10 years of age. At this age, kids tend to evaluate with the highest option on the scale, therein presenting minimal variability. For the results of this evaluation, excluding participants under 10 years, it can be observed that the behavior of the G1 group (Figure 9) with the RWI evaluation seems to follow that pattern. However, the same group, when evaluating the TI (Figure 9), produces heterogeneous results, having votes for each of the available options within the test.

During the evaluation with the ''Smileyometer'' test, during the tasks, the users made many comments about their experience using distributed interactions. We can summarize these comments as lessons learned. In the G2 group, the participants liked how the distributed interaction was performed. They sometimes anticipated how some of the interactive devices could be used for distributing the interaction. For example, when they were interacting with the distributed menu, they anticipated the distribution of the mouse interaction asking questions such as ''Why not controlling the mouse …?''. They anticipated the interactions to be distributed in the subsequent tasks in the evaluation. Similarly, when using the distributed mouse, they anticipated that the elements of the Web application selected with the distributed mouse, such as drop-down lists and input fields, would be shown in the user interface of the mobile phone controlling the distributed mouse. They also noted that some of the interactions were not necessarily better when distributed, specifically, the distributed mouse. They stated that this interaction is more accurate with the traditional mouse. They also wondered what would occur if there are many users interacting simultaneously when distributing the interaction. This is the

case when using the distributed mouse and multiple pointers can be controlled simultaneously using RWI.

The G3 group coincided with the previous group. They stated that distributed interactions are better, but depending on the context, they could be less convenient. The users on this group, as the older group in the evaluation, clearly understood the context of use for distributed interactions. They showed how some tasks could be more suitable for distributing interactions.

For the G4 group, all the opinions coincided with respect to the preference for distributed interactions. According to their comments, the reason behind their preferences is that they prefer working with mobile devices instead of desktop computers. However, there were also users that demonstrated their preference for using TI. This group of users identified some tasks as being more suitable for being performed using distributed interactions according to the context of use. It can be shown that these users are not used to interacting with applications using distributed interactions.

Finally, the users in the G5 group were less motivated in using the Web applications presented in the test. For example, the distribution of the interactions in the case of the distributed menu was something that they were not really interested in – only the use of multiple mouse cursors with the point&click stimulated their curiosity. However, in general, they compare the distribution of the interaction with the use of remote desktop applications. This seems to be why they do not feel very excited about the presented Web applications.

VII. CONCLUSIONS

This paper presents a study on how users perceive distributed interactions in educational environments using multi-device setups.

Distributed interactions are supported by the new Web-based application called Responsive Web Interaction. The Responsive Web Interactions is deployed as a library that allows users to interact in a heterogeneous-device ecosystem as if it were a single device.

This study was performed with more than 150 students using the smileyometer. The results show the impact that distributed interactions made on students, who preferred (satisfaction) using distributed interactions in multi-device environments over traditional interactions. The experiment confirms that the development of applications that make use of distributed interactions is a promising and emerging field.

The research presented in this article introduces a new perspective in the interactive relationship between the user and her multi-device ecosystem. The distributed interactions paradigm might change the way interaction designers plan, define and develop user interfaces, moving the focus from the device to the multi-device ecosystem.

The Web platform is a changing and dynamic field, where innovation is always present. So, the future work will take into account new advances in Web technologies. Among other challenges, we will have to face how to deal with concurrency

and conflicting interactions, or the notion of privacy in applications that support distributed interactions are important issues worthy to be addressed. Similarly, the management of distributed interactions in scenarios with connectivity issues is still a problem worth solving. The W3C is still developing specifications for dealing with the problems related to offline navigation, among others, in offline Web applications. One of the last and more promising efforts is the definition of the Service Workers [22]. This specification describes a method that could be used to manage Web applications while offline.

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JOSE A. GALLUD was born in Valencia, Spain, in 1966. He received the degree in computer science from the Universidad Politecnica de Valencia in 1991 and the Ph.D. degree from the University of Murcia in 2001. He has been a Full Professor of computer sciences at the University of Castilla-La Mancha (UCLM), Spain, since 1993. His initial research focused on parallel computing and the development of distributed applications. Since 2002, he has belonged to the Laboratory of Interactive Systems Everywhere Research Group, UCLM. He has been responsible for different research projects concerning the development of mobile applications and context-awareness systems

FELIX ALBERTOS-MARCO received the Ph.D. degree from the University of Castilla-La Mancha (UCLM) in 2017. He is a member of the Interactive Systems Everywhere Research Group. He is currently at the Universitat de Lleida, where he belongs to the Grup de Recerca en Interacció Persona Ordinador i Integració de Dades (Griho). He is involved in the field of human-computer interaction. His current research interests include the Web, distributed interactions, multi-device environments and how users perform their tasks in today's scenarios. His other research fields are collaborative environments and E-learning. During his career, he has been involved in various research projects. From 2014 to 2018, he was funded by a fellowship at UCLM. He is a member of the Asociacion Interaccion Persona-Ordenador.

VICTOR M. R. PENICHET received the Ph.D. degree from the University of Castilla-La Mancha (UCLM) in 2007. His current research is focused on human-computer interaction, especially on movement-based interaction, including gestures and full-body interaction. Distributed user interfaces, tangible user interfaces, and computer-supported cooperative work are also areas of interest. He belongs to the ISE Research Group (ISE), Albacete Research Institute of Informatics, UCLM. Many publications in several national and international conferences and journals are based on his research. He is involved in various research projects in collaboration with other universities and companies. He has been working on university educational issues since 2003, currently being an Associate Professor at UCLM.

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