

Technology-Supported Orchestration Matters: Outperforming Paper-Based Scripting in a Jigsaw Classroom

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Abstract—Under the umbrella of ubiquitous technologies, many computational artifacts have been designed to enhance the learning experience in physical settings such as classrooms or playgrounds, but few of them focus on aiding orchestration. This paper presents a systematic evaluation of the signal orchestration system (SOS) used by students for a jigsaw activity in an authentic classroom setting. The SOS comprises multiple wearable personal signal devices and an orchestration signal manager. Color and sound signals can be configured in the manager to be transmitted to the personal devices worn by the students to indicate orchestration signals for collaboration. The comparison between the SOS and a paper-based method traditionally employed for the orchestration of the jigsaw collaborative pattern showed that students in the SOS group spent significantly less time organizing the activity, obtained higher scores in the tests, experienced a stronger feeling of group formation awareness, and reported having enjoyed the experience to a greater degree.

Index Terms—Computer-supported collaborative learning, classroom orchestration, group formation, ambient awareness

1 INTRODUCTION

As a result of extensive studies conducted during the 1990s on how college affects students, Pascarella and Terenzini [1] conclude that there is consistent evidence that collaborative learning approaches can significantly enhance learning. However, the nature of social interactions is complex and there is evidence that free collaboration among individuals in groups does not necessarily lead to fruitful learning [2]. In certain scenarios, coordination and organization instructions should be provided in order to increase the likelihood of achieving a successful outcome [3]. In the face of these concerns, scripted collaborative learning methods and classroom orchestration have become key issues.

Scripts provide students with a set of instructions that guide their collaboration (specific group formation, role rotation, distribution of resources, sequence of activities) to elicit potentially effective social interactions (e.g., fostering mutual explanation and regulation) [2], [4]. The scripts that shape pedagogical methods at the macro-level (interrelated course-grained learning activities versus fine-grained computer-mediated communicative-coordinative scaffolding [5]) are typically based on collaborative learning flow patterns (CLFPs). CLFPs collect abstractions of best practices used by practitioners when structuring

the collaboration flow of scripts [6]. Examples of CLFPs include jigsaw, pyramid, brainstorming, co-op-co-op or think-pair-share [7], [8], [9].

The Jigsaw has become a well-known technique for collaborative learning. It leads to potentially effective learning by distributing knowledge and shaping a task that requires intensive cooperation. A jigsaw uses a group structure of expert groups and jigsaw groups. A big topic is broken up into smaller ones and each expert group is assigned one piece. Students in the same expert group work together to become specialists in the given topic. In the next phase, students who have gained different expertise gather in jigsaw groups. If designed appropriately, the jigsaw task can only be completed with the knowledge acquired in all expert groups, and thus with the cooperation of all team members [8]. As a result, the jigsaw fosters the interdependence of group members; promotes cognitive elaboration; and takes into account multiple perspectives and contexts and the construction of common knowledge [10], all of these associated with the effectiveness of collaborative learning.

Collaborative patterns create the need for orchestration, understood as the teacher's action of managing the flow of activities across different social stages: solo, group or class [2]. For example, in settings such as classrooms or playgrounds, orchestration of collaborative activities requires teachers to coordinate students according to their pre-planned macro-script, so that students know who belongs to each group, which working areas and resources are assigned to each group, and in which sequence they should interact with their peers [3]. Insufficient orchestration could prevent students and teachers from concentrating on the main task [11].

There is evidence of the potential of physical computing to enhance classroom orchestration [3], [13]. Computational interactive artifacts have been developed to support

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learning by augmenting the physical space and furniture with digital information that is displayed when desired by the teacher, or with digital indications managed by the students to facilitate teachers' supervision of the students' progress [11], [14], [15]. However, designs to support the orchestration of the CLFP scripting mechanisms in face-to-face settings remain largely unexplored [3], [16].

In this paper, we present a systematic evaluation from the students' perspective of the signal orchestration system (SOS), a prototype wearable technology designed to display orchestration indications (signals) in physical environments [3]. It acts as a distributed ambient orchestration awareness display [17]. We define orchestration awareness as the knowledge and perception of the flow coordination defined for a scripted face-to-face learning situation. Orchestration awareness comprises several elements, including knowledge of the group formation defined for each activity in the script, the location where each group should collaborate, the resources they should use, and activity completion/change of activity. Though there are some aspects of this definition common to the notion of group awareness (presence/participation in a specific group), orchestration awareness differs from group awareness [18] in that the latter emphasizes the perception of group work progress (product co-development). The SOS aims to aid time demanding and flexible orchestration tasks for dynamic flows of collaborative learning activities by providing pre-defined and changeable on-the-fly visual and auditory orchestration awareness signals (e.g., group formation awareness).

Orchestrating flows of collaborative learning activities in physical settings involves a set of challenges for both teachers and students. On the one hand, it demands that teachers dynamically manage students and resources. This coordination overhead represents an important workload that can divert their attention from supervising the actual learning task [19]. On the other hand, if coordination aspects are neither communicated well to students nor smoothly managed, orchestration can be time-consuming and the social climate in the classroom can quickly be disturbed by noise and a general sense of disorganization and stress.

The teachers' flow coordination challenges may be potentially resolved by a distributed system like the SOS. In a previous qualitative study reported in [3], teachers claimed that using the SOS reduced the orchestration workload as compared to their previous experience of managing similar collaborative processes. Teachers indicated that the system enabled a flexible orchestration and that students were autonomous identifying their groups and therefore they could "pay more attention to the tasks themselves and not so much to the organization". Though a systematic evaluation of the SOS from the perspective of the teacher would provide deeper insights about its impact on the teacher's role, the previous study showed that the teachers perceived the system as useful.

In this paper, we focus on the perspective of the students, where there is a need to understand how such system could improve the quality and outcomes of scripted collaborative activities. Within the scope of this study, we ask if the distributed orchestration awareness supported by the SOS can facilitate group formation as well as clearly indicate the

change of activities and reduce the time spent in orchestration tasks. Likewise, we wonder if wasting less time on the organization of the activity and profiting from distributed group formation awareness (as an element of orchestration awareness) could have an impact on the students' enjoyment and performance in the task, enabling a quieter social climate and improving their test results (a quiz related to the global collaborate learning task).

To address these questions, we developed an experimental setup consisting of a jigsaw scenario in an authentic face-to-face collaborative learning context. In this study the SOS was compared to an analogous method traditionally employed by practitioners for orchestrating the jigsaw. Our participants ($N = 52$) took part in a collaborative learning activity where they had to become experts in two human rights (out of 10) and later collaborate with experts in the remaining human rights to collaboratively solve real cases—which had been reported in the news—where human rights had been supported or violated. The scenario was planned with the teachers of the students involved in this study and their school psychologist. Jigsaw was selected as an interesting flow pattern to base the design of the collaborative learning scenario, as it includes key scripting mechanisms that need to be orchestrated in a classroom setting (formation of pre-defined heterogeneous groups, distribution of resources, sequence of several activities, change of groups) [5], [6], [8]. Moreover, the planned scenario included additional mechanisms, such as role assignment, and its enactment required flexible reconfiguration of the group composition to satisfy the jigsaw's intrinsic constraints (students leaving the classroom, for example, since groups addressing the global jigsaw task must include at least a specialist in each of the topics—specialism is developed within the expert groups) [20].

The remainder of this paper is structured as follows: first, we present the theoretical background and the signal orchestration systems along with its design process. Second, we explain the methods and describe the experiment, variables, data gathering techniques and participants. Third, we share the results, discuss the limitations of this study and propose a conclusion.

2 THEORETICAL BACKGROUND

Distributed interactive computing technologies are no longer necessarily interacted with using a traditional combination of screen, mouse and keyboard. Instead, a variety of peripherals can be used to augment the environment [21], [22]. In this context, the notion of pervasive computing is that of a digitally-enhanced habitat where physical and digital devices are seamlessly integrated [23]. In a seminal paper, Weiser [24] foresees the concept of pervasive or ubiquitous computing as invisible, context-aware, embedded technology that will serve users in seamless and unconscious interaction. In the same direction, Abowd and Sehlit define ubiquitous computing as an approach to breaking the pattern of traditional relationships between users and computational services by extending the computational interface into the user's environment [25].

Computing facilities may be blended with the environment in the form of specific *tangible bits* [26] that allow

users to manipulate and grasp information. Moreover, coupled with ambient display media such as light, sound, airflow or water in an augmented space, tangible bits enable users to gain awareness of background information in the periphery of perception. Weiser and Brown [27] claim that such forms of ubiquitous computing will lead to a new wave of calm technology characterized by the existence of various computerized services around us in an implicit and unobtrusive way.

In physical educational spaces, the introduction of technologies may be able to transform the learning experience by providing new possibilities resulting from the integration of the virtual and the tangible world [3], [22]. Embedding devices with computational power can augment spaces such as classrooms with digital information supporting face-to-face collaboration and learning [28]. Some interactive furniture can easily connect to mobile phones, tablets and a great variety of wearable devices enabling an interconnected ecosystem for technology enhanced education [22].

Technology-enhanced educational spaces use computing facilities derived from three fields: tangible user interfaces, ubiquitous computing and augmented reality [15]. Tangible user interfaces involve explicit contact with the computing artifacts such as tabletops, interactive boards [29] and building blocks [3], [26]. The growth in popularity of tangible interfaces reflects a larger emphasis on the role of the body and the environment in embodied interaction.

2.1 Technologies for Classroom Orchestration

Jermann et al. [30] reviewed a selection of systems aimed at supporting the management of collaborative learning activities and established a framework addressing the different strategies employed by these technologies to support interactions in the classroom; different systems can provide support to a variety of aspects of collaboration. They group collaborative learning support systems into three classes:

- *Mirroring systems* display indicators to users by collecting and integrating data about the interactions among students, and reflecting this information back to the users (as graphical visualizations, for example). The aim of such systems is to raise awareness among students about their actions and behaviors.
- *Metacognitive tools* provide data about what the desired interaction might look like alongside a visualization of the current state of indicators. Users of these tools are responsible for making decisions regarding diagnosis and remediation of problems.
- *Guiding or coaching systems* analyse the phases in the collaboration management process, and propose a series of remedial actions to help the learners improve their performance. The system makes decisions using collected data and tries to guide the learners.

Only a handful of systems have been designed to orchestrate collaborative activities (“guide or script the collaboration”) in face-to-face settings that do not require that learners rely on a desktop computer to use them and, at the same time, provide a global picture that can support on-the-fly decision making within large classes [11]. Following

a similar approach to the SOS, relevant examples are Shelf [11], Lantern [28], [11] and Reflect [28]. However, while these are kinds of mirroring tools, the SOS aims to support guiding.

Shelf and Lantern are awareness tools, designed to retrieve information on the changing status of participants in a collaborative activity, by providing only color signals, changing brightness and occasionally blinking. They have been created to support interaction in recitation sections and provide group awareness to the users [28], [11]. While using Lantern, each group of collaborating students has a device on their table. The color shows the exercise that the corresponding team is working on, and there is a special color indicating that the team is receiving help from the teaching assistant. The brightness indicates the time that has been spent on the current exercise. The frequency of blinking corresponds to the time that the team has been waiting for help.

Findings indicate that using Lantern considerably improved the quality of interaction not only between students and teaching assistants, but also among collaborators. Also, students put significantly less effort into catching the attention of the assistant, which led to more productivity while waiting. In addition, stronger collaboration between teams has been observed which can be explained in terms of group awareness: knowing about another team’s progress could encourage others to seek their help [11].

Reflect [28] is an interactive tabletop that measures the level of collaboration among participants sitting around it. By tracking the voice of each user, it displays the amount of talking through a visual representation that all the participants can see. The device is aimed at preventing unbalanced participation, which is known as a deterrent for effective learning. Results showed that users are more aware of their participation levels when using the table in speaker mode (where they see their amount of talk); in the same condition underparticipants also increased their participation but the effect was not as strong as was observed for overparticipants who gradually balanced their level of talk [28].

Reflect is an example of a mirroring system similar to second messenger [31], a tool that encouraged overparticipants to reduce their levels of participation by displaying information in real time, but where the effect was not as strong for underparticipants; or conversation clock and conversation votes [32]. In both cases, users can see a visualization of their conversation levels on a shared surface. Studies of these devices suggest that there are a variety of reactions to the visualizations, especially in terms of reactions to long-term and short-term history, as well as changes in behavior among above and below average speakers.

Recent studies have shown that ambient awareness displays can support classroom orchestration and that calm technologies may allow learners to focus on solving the task rather than getting distracted by coordination requirements [11]. We suggest that wearable devices have promise for classroom orchestration by enhancing the orchestration awareness perceived by the students; as Billingham and Starner [33] posit, if successfully designed, they can help users to perceive and filter information without having to allocate significant attentional resources.

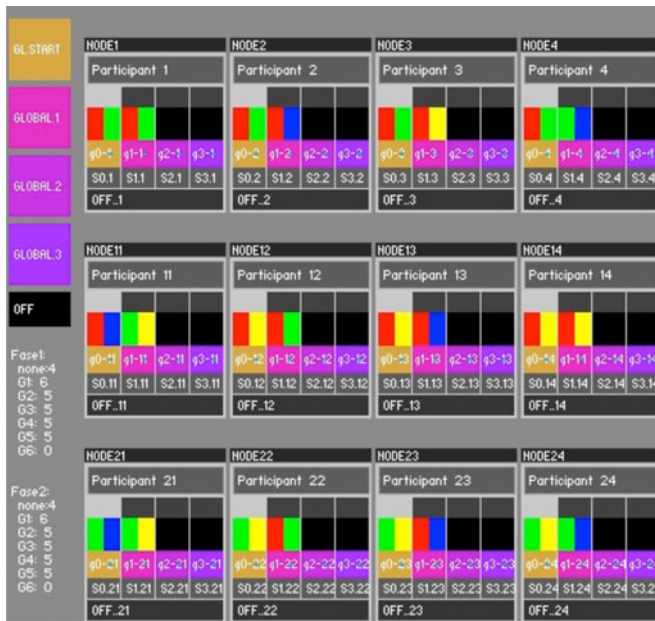


Fig. 1. Image of the canvas in the OS-manager.

2.2 The Signal Orchestration System

The signal orchestration system has been designed to support orchestration of complex collaborative inquiry macro-scripts in the classroom [3]. Prototypes of the SOS are composed of a set of wearable personal signal devices (PS-device), which have a visualization module and a communication module, and the orchestration signal manager (OS-manager), a graphical user interface that facilitates remote control of the devices and monitoring of the overall experience.

The visualization module in each PS-device can display different color combinations associated with signals that teachers send to the students to orchestrate aspects of the collaborative learning flow. The wearable devices contain five LEDs (red, green, blue, white and yellow) that can be turned on and off individually or in pairs, as well as blink. The device, which can also emit a tone, receives commands from a communication module. This module includes a transceiver that allows the PS-device to be remotely controlled by a central computer from up to 100 meters away. A central computer runs the OS-manager where the orchestration signals can be configured and transmitted to the PS-devices [3].

A key feature of the wearable devices is that all signals become visible to the user as well as to the whole group, hence providing group awareness. This is the main reason why our approach excludes the use of mobile phones. Any orchestration signal sent to a mobile phone would remain individual and personal, thus not providing visual or auditory hints for group awareness. We have discussed these issues in previous research [3], [17]. In addition, mobile phones vary in affordances and characteristics, and it may be difficult to ensure that every student will own one that is compatible with the system requirements. Likewise, with a plethora of mobile applications running on each device students could easily be distracted from the learning task.

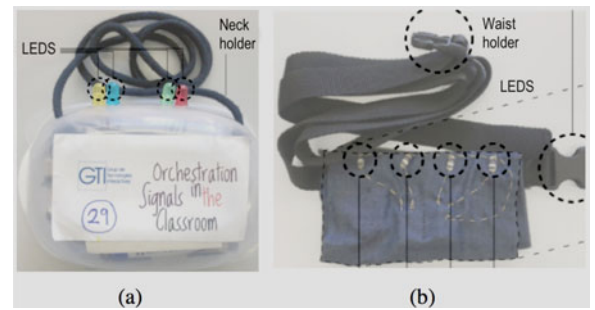


Fig. 2. SOS PS-devices. Necklace (a) and belt (b) prototypes.

The wearable devices are controlled from a central computer that runs the OS-manager (see Fig. 1). The OS-manager interface shows a canvas (2) with a visual representation of each PS-device. Through this visual interface teachers can configure different types of signals (a single color, combinations of pairs of colors, blinking, tone, etc.) to be sent to each device.

A unique number that matches the internal configuration and external labeling of each device identifies each PS-device in the OS-manager. The graphical box representing each device in the OS-manager contains an input text-field to type the name of the student for quicker identification. Below each box, there is a button for individual signal transfer to enable testing, individual correction, and group-membership readjustment. Though the current prototype of the OS-manager has been successfully used in the experiments, it is not intended for typical teachers. As part of our continuing research into the SOS impact from the teachers' perspective, we are presently working on the development of several alternative OS-Manager user interfaces aiming for flexibility and sufficiently intuitive use for the teachers to plan and manage real-time orchestrational decisions.

2.3 Redesign of the Wearable Devices

So far three different low-cost designs of the SOS devices for the students have been implemented and tested through several jigsaw collaborative learning scenarios. The use of the first two designs (a, b) in Fig. 2, was evaluated in two experiments on real scenarios [3]. The first design (a) consisted of a plastic rectangular container to be hung from the neck. Devices were sitting on the chest and LEDs remained clearly visible to the user and the other members of the group. In prototype (b) the device's components were contained in a belt made of fabric that users could wear around their waists.

Our previous findings indicated that the necklace prototype was more visible, but its size and weight made it uncomfortable. Moreover, observations during the activities revealed that female participants felt uneasy about hanging the devices around their necks in their chest area, as this part of the body became a focus of attention. The fabric belt was lighter, thinner and provided a better aesthetic experience, but it was less visible [3].

In order to run the experiments described in this paper, we re-designed the PS-devices and optimized them for a third time. A new design—developed as an intermediate

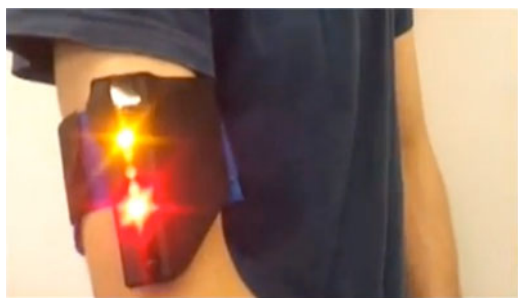


Fig. 3. New design of the SOS PS-Devices. Arm bracelet.

approach between the previous designs—was created (see Fig. 3) to improve their robustness and make them more comfortable.

Since it is important for the system to provide group awareness, the place on the body where the device should be worn is critical. As neither the chest nor the waist were optimal solutions, the new design can be placed on the arm allowing the user to see it as well as other members in the group. In addition, if participants sit down, the arm remains visible and therefore the signals sent to the device are still publicly displayed. The new design also includes one white LED that allows for more and different color combinations and signals.

3 METHODS

A qualitative study where a group of master students used the devices to manage the coordination of a jigsaw task showed that the signal orchestration system can be used to support collaborative flows in a classroom environment [3]. However, we have not yet studied whether this technological mediation outstrips the paper-based method conventionally employed by teachers.

The formal comparison of both systems is appropriate to evaluate whether the incorporation of this new technology in the classroom might bring fruitful outcomes or significantly increase the potential of the collaborative dynamics. The aim of this study is to evaluate the effects of the signal orchestration system in the orchestration of a jigsaw classroom with the focus on the experience of the students rather than the teachers, through testing the following four hypotheses:

- *H1—Students in the SOS group will spend less time during group formation in both expert and jigsaw phases.* During the orchestration of collaborative activities, a relatively large amount of time is wasted because students have to find out which team they belong to, who their collaborators are and to move around the room to group in the space that has been assigned for that purpose. This procedure is usually repeated for each phase of the collaborative pattern. It is true that other methods for addressing this problem exist; labeling the places where groups have to gather could be a solution. However, we suggest that our approach allows for more flexibility that makes it suitable for other collaboration scripts (with similar flow coordination mechanisms) and contexts where students are

asked to move around in an outdoor space, change groups or tasks frequently, or where group rearrangements need to be done without altering the physical setup.

- *H2—Students in the SOS group will report a better sense of group formation awareness.*

A key feature of the PS-device is its capacity to display signals that everybody in the classroom can see. All the students receive their signal at the same time and can simply look around to see the signals that others have received. We hypothesize that if this occurs, the process of group formation might be more agile and less time demanding and that students will have a better sense of what needs to be done, with whom and when.

- *H3—Students in the SOS group will perform better in an individual post-test.*

Loss of instructional time due to off-task behavior is a well-documented issue in learning settings, and a negative relationship between off-task behavior and learning outcomes has been studied in many contexts following Carroll's time-on-task hypothesis [34]. We predict that wasting less time in group formation and relying on the device to indicate signal orchestration aspects, will reduce stress in the classroom and help students assign more time and attentional resources to the learning task. This could potentially lead to the achievement of higher scores.

- *H4—Students in the SOS group will enjoy the activity more.*

Our previous studies with SOS suggest that students are usually motivated to use the system during collaborative activities. However, besides the motivation encouraged by the device, we suggest that as a group students might create a better social climate in the classroom (where students feel like they know what they have to do because they will receive the information in real time via the devices, and a potential feeling of chaos is minimized) and better enjoy the activity. We build on the work of Pekrun et al. [35], who have found positive correlations between enjoyment and positive emotions, and positive emotions with positive learning outcomes.

The hypotheses described in this section have been designed to test to what extent the signal orchestration system achieves a "satisfactory orchestration" of a jigsaw scenario, by considering that important elements implying a "satisfactory orchestration" include those indicated in our hypotheses: (good) group formation awareness, (little) time spent in orchestration tasks, a sense of enjoyment (versus negative emotions), and (good) test results (quiz after the activity related to the global collaborate learning task).

3.1 Description of the Experiment

We proposed a jigsaw scenario about human rights where students had to form expert and jigsaw groups in order to solve a task. Two classes of secondary school students were combined and then divided to obtain two even groups of participants. Only 10 human rights were selected out of the 30 contained in the Universal Declaration of

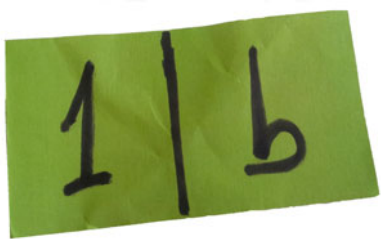


Fig. 4. Individual cards for paper-based orchestration.

Human Rights excluding those that could produce sensitive states among participants.

A jigsaw uses a redundant group structure: main groups and expert groups. The global jigsaw task can only be completed with the knowledge acquired in the expert groups, and thus with the intensive cooperation of all team members [12].

We assigned the same activity, materials and schedule to both groups and only the orchestration method was altered: group A used the SOS whereas group B used a control approach, based on paper cards.

3.2 Experimental Conditions

As explained before, this study focuses on the experience of the students while using the SOS system. Even though their teachers were in the classroom during the experiment, the group of researchers operated the OS-manager and provided indications to the students.

Participants in the experimental group used the SOS to support the orchestration of the proposed jigsaw activity. We sent signals to their PS-devices indicating group formation and change of activity. As a result, students received a tone coupled with a combination of two colors lighting up their LEDs to indicate their expert groups (they knew they had to find peers signaling the same color combination) and the color of the envelope with the resources that their group should use in that phase. Ten minutes later students changed to the jigsaw phase by following the same procedure (different color combinations were provided). During the third phase of the activity, we used the blinking LEDs mode to indicate the time slot for each group to share their findings.

As for the control system, students used a conventional paper-based method. As shown in Fig. 4, a rectangular piece of cardboard was used, on which a number and a letter are written. The former indicates the expert group whereas the latter refers to the jigsaw group.

One of these cards is assigned in an upside down position to each student at the beginning of the activity. Once the activity starts, students look at their cards and find all those peers who have been given the same number (1, 2, 3, 4 or 5). Following this, groups can gather and pick up the envelope corresponding to their group and solve the task within. After finishing the expert phase, students receive a verbal indication to switch to the jigsaw phase. Students look at the letter in their card (a, b, c, d or e) and find those who have the same letter.

It is important to mention that students in both conditions wore SOS devices. Even if we expected that the use of

a new technology to support orchestration might have an effect on the motivation of the students (hypothesis H4), we tried to reduce a potential bias associated to the novelty effect [36], [37], [38], [39], [40]. In both conditions students used the SOS to play a short game before the jigsaw dynamics, and the SOS remained in the setting as an established classroom tool.

In both cases, devices were distributed 10 minutes before the experiment started. Students wore the devices on their left arm and were given time to explore it. Before the activity started, we played a simple game to reduce the anxiety caused by the novelty of the device and learn how it works. After this playful introduction, we asked the subjects to go back to their individual seats to start the jigsaw activity.

3.3 Dependent Variables and Data Gathering Techniques

With the objective to reach valid conclusions, we implemented a mixed methods approach and triangulated data, an approach that is suitable for explaining complex phenomena in situations such as comparisons and to generate a broader understanding [41].

For the collection of quantitative data we measured four dependent variables in accordance with the hypotheses of this work. The quantitative data was complemented with qualitative observations: 1) Time spent by students in order to form groups in both expert and jigsaw phases was measured through video-based indirect observations and direct observations; 2) performance, addressed through individual test scores (comparing the difference between those obtained in the pre-test and post-test) and direct observations of classroom social climate; 3) group formation awareness (through a Likert-scale type questionnaire answered by students and direct observations); and 4) enjoyment of the activity, assessed via Likert scale questionnaires and direct observations). We have labelled these variables as time, performance, group formation awareness and enjoyment, but an extended explanation for each of them can be found in Table 1. In addition, the activity was video recorded with three different cameras located to cover the complete space of the classroom. All quantitative data was collected per student, because in both control and experimental conditions, students receive individual signals and have to find their collaborators and answer the test questions individually.

For time measurements we decided to perform video-based indirect observations that involved the collection of naturally occurring data using video cameras, a commonly used method within social interactional studies [42], [43], [44], [45], [46]. When using video recordings as data collection tool some researchers undertake a systematic coding approach, others build code from their data, while others perform analysis without the use of coding.

In our case, two researchers conducted a descriptive analysis, measuring the time at which a series of pre-established behaviours were observed: 1) seeing the signal (students turning their heads towards the arm where the device was held); 2) students sitting down with their new groups. Video-based indirect observation has been used in research to study human behavior and measure time.

TABLE 1
Dependent Variables and Data Collection Tools

DEPENDENT VARIABLE	TYPE OF DATA	DATA GATHERING TECHNIQUE	LABEL
Time spent during group formation. Number of seconds spent by each participant during group formation in expert phase and jigsaw phase. Final time measurement was calculated from the moment the participant sees the signal to the moment when s/he is sitting down with other group mates.	Quantitative + Qualitative	- Video-based indirect observations by two researchers - Direct observations by three researchers (code Obs1, 2 and 3 identify the observers)	Time
We define performance as individual scores obtained in a quiz about the topics addressed in the global collaborative task, counted in units from 0 to 17. Each correct answer equals 1 point. Blank or incorrect answers equal 0 points.	Quantitative	- Pre-test and post-test - 17 multiple choice and true or false questions about the 10 human rights selected for the study	Performance
Group formation awareness. The sense of knowing what has to be done, who with and when.	Quantitative + Qualitative	5 point Likert scale type questionnaire Direct observations by three researchers	Group formation awareness
Enjoyment of the activity. If students like the activity.	Quantitative + Qualitative	5 point Likert scale type questionnaire Direct observations by three researchers	Enjoyment

Anderson [42] used time-lapse video recordings to measure home television viewing by young children. A major home-observation study had already been conducted by Bechtel et al. [43], who installed video cameras in the homes of 20 families in the US during 1970 and had concluded that family viewing diaries overestimated actual time viewing. In order to analyze the videos and measure time, Bechtel et al. agreed that TV viewing was indicated by the state of "being visually oriented toward the screen". More recently, Kendon [44] used video to conduct spatial analysis, measuring distances and interactions among people in face-to-face settings, and Meisner et al. [45] used a similar method to analyse interactions in museums.

Scores were collected using a pre-test and a post-test described in Section 4.5. Data with regards to the variables group formation awareness and enjoyment was collected with direct observations during the enactment of the activity as well as through five point Likert-scale type questionnaires that students answered after having finished the activity. Table 1 presents a description of all dependent variables, type of data gathered and techniques used. It also presents a label to easily identify each variable.

To collect qualitative data, three researchers conducted direct observation during the studies with both control and experimental groups. Observers noted information related to group formation awareness, relationship with the device, classroom social climate, problems that may have an impact on the timing of the jigsaw flow and conversations among peers referring to the SOS device. After the experiments observers analysed and reported their observations. We used content-driven thematic analysis to identify emergent themes [47].

3.4 Participants

The experiment was conducted at a Spanish cooperative school that pays special attention to collaborative learning dynamics. Teachers and students are familiar with group work and cooperation even though the classes involved in this study did not have previous experience with the jigsaw pattern.

As the school only has one class per course, students in the second and third courses of secondary school, 13 to

15 years old, were combined and divided into two new groups. Participants were randomly allocated to each group keeping an even distribution of females and males across groups. In addition, the teachers and school psychologist assessed that the allocation of participants to one group and or another was balanced in terms of individual and group performance.

As a result, two groups of 26 participants were formed, where

1) Group A: $N = 26$ (15 male + 11 female).

2) Group B: $N = 26$ (14 male + 12 female).

Concerning the previous knowledge of participants in the subject of the activity, in Spanish education, human rights are introduced to elementary and secondary school students in a transversal manner. While each school is free to teach the subject in any activity related to civic education, officially such content is taught within the course Education for Citizenship and Human Rights. The course was designed for the last cycle of primary and all secondary education in Spain. It includes the teaching of democratic values and constitutional affairs [48].

3.5 Pre and Post Tests

One month before the experiment, both groups of students took a pre-test that consisted of 17 multiple choice and true or false type questions about the 10 human rights selected for the experiment. The pre-test allowed us to find out whether students had been equally allocated to control and experimental groups in terms of previous knowledge and performance, as well as the time required for answering the questionnaires. In addition, the test included five Likert-scale type statements asking about previous experience with collaborative activities in the classroom and the level of liking for these activities. In both cases no significant differences were found with regards to the performance of the groups, nor were differences found for the time required to solve the test. Both groups expressed equal levels of liking for group activities and collaboration.

For the post-test, the same 17 multiple choice and true or false type questions about the 10 human rights were asked again without any changes. We included six Likert-scale type statements addressing group awareness and

TABLE 2
Flow of the Jigsaw Scenario

JIGSAW PHASES	DESCRIPTION OF THE PHASE	DISTRIBUTION IN THE CLASSROOM AND SIGNAL REQUIRED
<p>Initial phase: Individual activity. Students read an introduction to the topic of human rights and the collaborative activity.</p> <p>Duration of the phase: 5 minutes</p>	<p>The text includes the first three human rights contained in the official declaration by the United Nations. These rights are the basis for contextualising the rest and comprehending the general concept underlying the ethics of human rights.</p>	<p>Each student is sitting at any table of her choice.</p> <p><i>Orchestration signal required:</i></p> <ul style="list-style-type: none"> - Experimental group: Voice command provided by the coordinator to start activity. - Control group: Same as experimental group
<p>Expert phase: Students meet in groups of five members. They pick up the assigned envelope. Each expert group receives a set of two human rights. Students have to become experts on these rights by reading and discussing about them.</p> <p>Duration of the phase: 10 minutes</p>	<p>A total of 5 Expert groups are formed. Four groups of five participants and one group of six.</p> <p>The members of each Expert group meet and become specialists on two human rights.</p> <p>All ten chosen human rights will be covered (2 human rights X 5 Expert groups).</p>	<p>Students find the other members of the group and sit at a chosen table. Five tables have been organized in the classroom.</p> <p><i>Orchestration signal required:</i></p> <ul style="list-style-type: none"> - Experimental group: Color combination sent to PS-Device indicating Expert group and distribution of resources (envelope with information). Five sets of signals are sent to students. - Control group: Voice command provided by the coordinator. Students check the letter written on the left half of their cards.
<p>Jigsaw phase: Students form Jigsaw groups. Each member contributes with his expertise in order to solve the assigned task.</p> <p>Duration of the phase: 12 minutes</p>	<p>Members of each Jigsaw group meet. Together they know ten human rights. They solve a real case (reported in the news) where some of the studied rights have been threatened or defended. They state which are the human rights pertinent to this case and why.</p> <p>Each Jigsaw group works on a different case.</p>	<p>Students find the other members of the group and sit at a table. Five tables have been organized in the classroom.</p> <p><i>Orchestration signal required:</i></p> <ul style="list-style-type: none"> - Experimental group: Color combination sent to PS-Device indicating Jigsaw group and distribution of resources. Five sets of signals are sent to students. - Control group: Voice command provided by the coordinator. Students check the number written on the right half of their card.
<p>Collective phase: This phase allows for the general sharing of knowledge.</p> <p>Duration of the phase: 2 minutes per group. Total: 10 minutes.</p>	<p>A delegate of each jigsaw group has two minutes to share with the rest of the class their findings about their specific case.</p> <p>Cases require that students reflect on at least two human rights.</p> <p>When each delegate shares the group's findings, the whole class is exposed to the ten human rights selected for the activity.</p>	<p>Students stay at their seats.</p> <p><i>Orchestration signal required:</i></p> <ul style="list-style-type: none"> - Experimental group: Blinking LEDs on the PS-Device of each Jigsaw group's leader. - Control group: Voice command provided by the coordinator. <p>End of the activity.</p>

enjoyment of the activity. Only in the case of the experimental group, we included two more questions related to the acceptance of the SOS.

3.6 Task Description

In order to carry out this experiment, the jigsaw pattern was refined into a particular design of a jigsaw classroom focused on the topic of human rights. Two envelope activities were included in the design to accommodate the needs of the particular learning setting. Table 2 presents the educational design of the scenario in all of its phases, the distribution of students in the classroom and the orchestration signal required. In the first phase, each student reads a text that contextualizes the topic of the activity and introduces the first three human rights in the official declaration. We also added a final phase where each group is given two minutes to share their findings with the rest of the class. The decision to include this final phase aims to ameliorate one of the main downsides of the jigsaw: if one of the experts fails to intensively cooperate in the global task and communicate her area of expertise, then that group might struggle with the task. As this study proposes a pre-test and post-test comparison to find differences between groups,

there is a need to reduce the impact of those students who did not perform well in the expert phase.

After finalizing the group activity students go back to their individual seats. Post-tests are distributed and solved individually. Students can leave the room after they hand in their test. The complete activity lasts approximately 50 minutes.

4 REALIZATION OF THE EXPERIMENT

The activity was presented and students were told that they could leave the room at any moment if they felt uncomfortable. In the experimental group, one student left the class and the jigsaw groups were immediately reorganized by the researchers in the OS-Manager on-the-fly. In the control group, two students did not attend class on the day of the experiment and for that reason the group had 24 participants. As in the first case, jigsaw groups were reorganized.

Experimental and control students received the same explanation about the activity and the materials. Both groups saw the SOS and played a short game using the system. In the experimental group the specific use of SOS devices to display orchestration signals was explained to the students. In the control group each student received a card-board signal.



Fig. 5. Participants in the experimental group wearing SOS devices during the activity.

In both cases the activity began with the individual phase. We gave students a paper document introducing the issue of human rights, the activity proposed and the first three human rights in the official declaration. They had five minutes to read and reflect on it.

Following this, we sent participants the first signal to gather in expert groups (Fig. 5). In the experimental group the signal arrived directly through the devices whereas, in the control group, students were asked to look at the number indicating their expert groups. After grouping with their peers, students collected the indicated material and proceeded to solve the task.

Ten minutes later, students switched to their jigsaw groups (the experimental group received new signals on the device and the control group looked at the letter indicated in the card). Again, they collected the appropriate material and completed the activity.

In the last phase, each group had two minutes to share their findings with the class. In the experimental group only those group members whose device was blinking had to share the findings. In the control group, the researcher indicated the turn for each group to share their conclusions. After the activity, students were asked to complete the post-test.

5 RESULTS

We first report the findings drawn from the quantitative analysis. In Section 5.8 we present the results of the qualitative study through the themes that emerged from the thematic analysis.

5.1 Quantitative Analysis

Aligned with our hypothesis, we have compared the time spent during organization of the jigsaw activity in two phases, expert and jigsaw, between groups. We have also compared the scores obtained in the post-test. We analysed data gathered through Likert-scale type questionnaires, which included six statements addressing different variables

- 1) When I am at class I like doing collaborative activities.
- 2) In the activity that we did today I did not like the group that I had to work with.
- 3) During today's activity we wasted time organizing the groups.

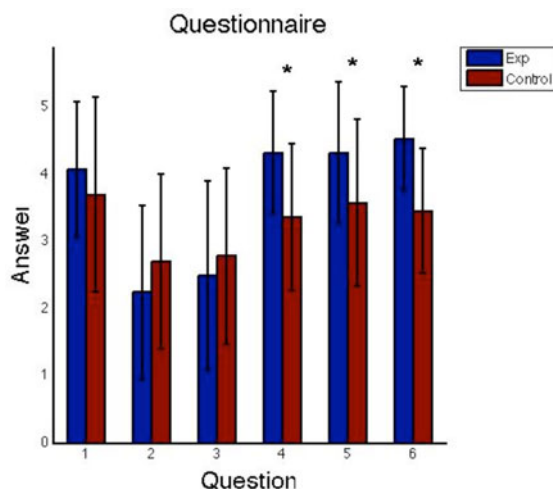


Fig. 6. Five point Likert Scale type questionnaires results.

- 4) During today's activity it was clear what we had to do in each phase.
- 5) During today's activity it was easy to see who were the other members of my group.
- 6) I liked today's activity.

Since data did not meet the assumption of normality, for each array we ran a non-parametric Mann-Whitney rank sum test. The first statement helped us establish a baseline for comparison of liking for collaborative activities between groups. We found no significant differences between groups. Fig. 6 shows statistics for all questions from one to six. Below, we report the results sorted along with the research hypotheses.

5.1.1 Time

- *H1—Students in the SOS group will spend less time during group formation in both expert and jigsaw phases.*

We used video-based indirect observations to calculate the time that each participant spent in the organization of the jigsaw activity in two phases, expert and jigsaw, excluding those phases where the activity did not require finding group members or changing position within the classroom. The resulting time is the sum of seconds between the moment when the participant sees the signal and the moment when she/he is grouped with other group members.

Data was processed using MatLab for the statistical analysis of all time comparisons between groups. In order to reach equal sample sizes we removed one participant from the experimental group whose values matched the group mean. The distribution is normal according to Lilliefors test. A Levene's test was run and its results ($p = 0.26$) fail to reject the null hypothesis of equal variances on different samples. We ran an independent-samples t-test to compare time spent during organization of the expert phase in both conditions. As seen in Fig. 7, there was a significant difference in the time variable between SOS ($M = 30.25, SD = 11.61$) and paper-based ($M = 40.54, SD = 9.06$) conditions; $t(23) = -4.14, p < 0.01$, showing that the group using the SOS spent less time in the organization of the first phase of

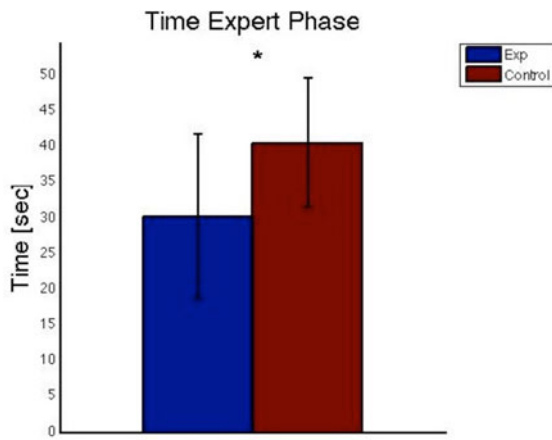


Fig. 7. Results show the experimental group was significantly faster than the control group in the expert group formation.

the activity. With regards to the jigsaw phase, no significant difference was found between groups. We will discuss this outcome in the discussion section of the paper.

5.1.2 Group Formation Awareness

- *H2—Students in the SOS group will report a better sense of group formation awareness.*

Data was gathered with a five point Likert-scale type questionnaire for the comparison of self-reported group formation awareness measures. Statements 4 and 5 addressed the dependent variable group awareness:

- 4. During today's activity it was clear what we had to do at each phase.
- 5. During today's activity it was easy to see who were the other members of my group.

After running the Mann-Whitney rank sum test, responses to question four indicate a significant difference between groups. Students using the signal orchestration system ($Mdn = 5$) reported having a better understanding of what they had to do at each phase of the activity compared to those in the control group ($Mdn = 3.5$), $U = 92$, $p < 0.01$, $r = 0.63$. Concerning statement five, "During today's activity it was easy to see who were the other members of my group" results show a significant difference between groups. Students using the SOS ($Mdn = 5$) reported significantly more group formation awareness than those in the control group ($Mdn = 4$), $U = 92$, $p = 0.02$, $r = 0.47$.

5.1.3 Performance

- *H3—Students in the SOS group will achieve a higher performance.*

The pre-tests allowed us to establish that there was no significant difference between the performances of the two groups, which served as a baseline. We calculated the scores that each participant obtained in the tests after taking part in the activity. Data was collected through paper-based questionnaires and it was processed using Matlab. As the data did not meet the normality assumption, we ran a Mann-Whitney test. The results indicated that scores

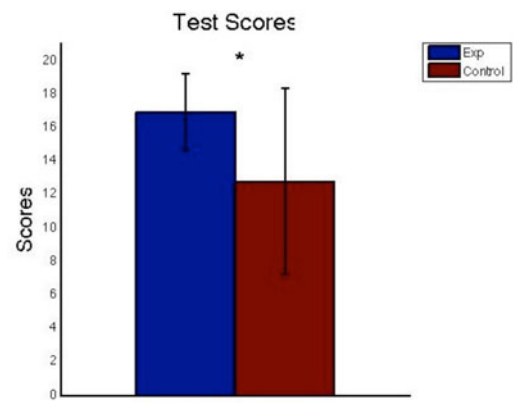


Fig. 8. Results show the experimental group scored significantly higher than the control group in the individual post-test.

were greater for those students using the SOS ($Mdn = 17$) than for those in the control group ($Mdn = 15$), $U = 411.5$, $p < 0.01$, $r = 0.51$. As shown in Fig. 8, students in the experimental group performed significantly better than those in the control group.

5.1.4 Enjoyment

- *H4—Students in the SOS group will enjoy the activity more.*

Statements two and three addressed how comfortable the students were with the groups they had to collaborate with.

- 2) In the activity that we did today I did not like the group that I had to work with.
- 3) During today's activity we wasted time organizing the groups.

In both cases, a Mann-Whitney rank sum test was run. We found no significant differences between groups and therefore fail to reject the null hypothesis. Question six addressed the overall enjoyment of the activity:

- 6) I liked today's activity.

Students in the experimental group ($Mdn = 5$) reported having enjoyed the activity significantly more than their peers in the control group ($Mdn = 4$), $U = 97$, $p < 0.01$, $r = 0.83$. The data supports that those students using the SOS rated the activity more enjoyable than those using the paper-based system.

5.2 Acceptance of the Device

Students in the experimental group had two extra questions addressing the acceptance of the device:

- 7. The device that we used for organizing the activity was useful.
- 8. I would like to use the device next time we do group activities.

The SOS had high acceptance among its users. Four fifths of the participants reported that the SOS device was useful for the orchestration of the jigsaw activity. Also, over 70 percent of the participants would like to use the SOS again if they had to do group activities in the classroom.

5.3 Qualitative Analysis

We performed thematic analysis on the data gathered by direct observations and identified three themes, which have been codified using a label. These labels are used in the discussion: 1) Distributed visualization of group formation enables a quieter social climate in the classroom [Social climate], 2) reliance on the device helps students focus on the task [Attention], and 3) novelty of the device generates engagement and fosters peer explanation [Engagement].

5.3.1 Social Climate

We observed that distributed visualization of group formation enables a quieter social climate in the classroom. Anderson et al. [49] have defined social climate as the group of factors that determine the “personality of a classroom” and can promote or impair individual performance. Observers pointed out that students in both conditions could find their group members relatively fast but with a significantly different impact on the classroom’s social climate. Observing the SOS group, one researcher pointed out: “They identify their groups very quickly. Some of them call each other by their names when they see that they have the same colors” [Obs1_EG]. During the second phase of the activity, the same observer suggested: “Students perceive the signals very quickly”. Another observer noted: “They see their groupmates very quickly, in less than a couple of minutes 95 percent of the students have formed groups. In less than 30 seconds [after receiving the signal] a sense of group awareness seems to consolidate” [Obs2_EG].

However, when it comes to the process of group formation in the control group, all three observers highlight the “noise” in the classroom and the “stress” of students: “When switching to the expert phase students are shouting the numbers that correspond to their groups. The level of noise in the classroom is significantly louder than in the experimental group” [Obs1_CG]. The same behavior is observed during the next phase of the activity: “Switching to jigsaw phase again generates a lot of noise in the classroom” [Obs1_cG]. “The levels of noise are considerably superior in this group. Students shout to each other to find their group mates and this generates a climate of chaos” [Obs3_CG].

These observations support the idea of the potential relevance of the social climate in the classroom. When a group of students begin to shout to find others who belong to the same group, the others engage in the same behavior. In a very short period of time loudness and a sense of general “chaos” take over.

5.3.2 Calm Technologies and Attention

Another theme that emerged from the observations is related to the fact that **reliance on the device helped students to focus on the task**. Participants learnt very quickly that they could rely on the SOS device to receive indications of when to change from one phase to another and who to partner up with. In contrast, participants in the control group inquired about orchestrational aspects as they worked on the task.

Observers noted that the perception of the device switched to the periphery of the students’ attention as soon as LEDs or sound were off: “Attention on the devices is

zero when they are off” [Obs2_EG]. Later, the same observer writes: “They [the students] touch the LEDs and when they see that nothing happens they immediately forget them until the task is over”. Another observer notes: “As they [the students] are working on the task they forget about the devices (they don’t touch them or look at them)” [Obs1_EG]. **However, participants in the control group seem to be anxious about finding out who they are going to team up with in the next phase.** The following statement support this observation: “While they are working on the task they are asking other classmates which letter shows on their cardboard signal” [Obs3_CG]. Students in the control group look at the instructor (a researcher who has explained the activity and is orchestrating the activity) and frequently ask, “when do we switch to the next phase” [Obs3_CG], or even state: “we have finished, can we change?” [Obs3_CG].

5.3.3 Novelty and Engagement

The results of the qualitative analysis also support that the novelty of the device generates engagement and fosters peer explanation. Students were interested in the SOS wearables as soon as they saw them. They ran to the table where the devices were displayed “casting smiles and giggling” [Obs2 and Obs3]. They looked at them as if they were toys (some students said: “They look like a christmas tree!” [Obs1, Obs2, Obs3]), and used words such as “cool” to describe them.

The game played in the beginning of both control and experimental sessions helped students learn how the SOS works and become more familiar with the device. They enjoyed being able to see the signals that other members had received and engaged in what we have labelled as “peer explanation”. “When a student doesn’t see the signal the peers in proximity indicate to him that his SOS device has turned on” [Obs1_EG]. Another observer noted: “When a student has a doubt with regards to the signals or the device, peers quickly provide an explanation. For example: ‘How do I know to which group I belong?’, ‘Because you will have the same color!’, says other student” [Obs2_EG]. In the experimental group students were focusing on each other and solving their doubts regarding orchestrational aspects between themselves. This created an interesting sense of cooperation in the classroom that was absent in the control group where students constantly addressed the instructor.

6 DISCUSSION AND LIMITATIONS

We have assessed the performance of the signal orchestration system in comparison with a paper-based system for the orchestration of the jigsaw collaborative flow pattern, in the context of a face-to-face activity. The main objective of this analysis was to evaluate if the incorporation of this technological orchestration support brings benefits to the organization of collaborative activities by reducing the time spent on each phase, providing group formation awareness, fostering the performance of students in the post-tests and increasing their enjoyment of the activity.

This study has revealed three implications that support the potential of the SOS in the proposed context. First, it reduces the time that students spend while trying to find their peers and organize their groups. Data supports that

students wearing the SOS spent significantly less time than those in the control condition forming groups during the expert phase. However, we found no significance in the jigsaw phase of the activity. We believe that limitations in the design of the control system affected the dependent variable since students in the control group had been given a card that was indicating both groups: expert and jigsaw, by providing a number and a letter respectively. As the observers pointed out [Attention], while working along with their peers in the expert phase, students in the control group were already trying to find out who were the classmates in their jigsaw groups. Even though students in the control group had this extra information (those in the experimental group did not know which group they belonged to until the reception of the signal in the PS-devices), participants in the former group did not find their collaborators faster than those using the device. The fact, that there was no significant difference between the time spent by both groups in the jigsaw phase supports that the SOS reduces the time spent in the organization of the activity. But the findings emerging from the thematic analysis present a series of factors that seem more relevant than the time variable. During group formation students in both groups behaved differently. While those in the experimental group were looking around to find their group mates according to the signals displayed on their devices and engaging in “peer explanation”, those in the control group considerably increased their voice levels creating a “chaotic” environment [Social climate]. As emerged from the observations [Attention] and [Engagement], the students wearing the SOS device established a better social climate in the classroom.

Second, participants in the experimental group obtained higher scores than their peers in the control group. Both groups had answered the same pre-test a month before the experiment and no significant difference was found in their performance.

Third, compared to the control group, students using the SOS rated the overall activity significantly higher. In the Likert-scale type questionnaires both groups reported that in general terms they enjoy collaborative activities in the classroom and no significance was found between them. After the experiment, the experimental group reported having enjoyed the experience significantly more than the control group. Even though it could still be argued that use of the technology increased the motivation, we suggest that there is a correlation with the fact that these participants reported a stronger feeling of group formation awareness, which might have led to better social climate in the classroom. As Alavi et al. [11] posits, group awareness can enhance collaboration and calm technologies may allow learners to focus on solving the task rather than getting distracted with orchestration.

In addition, as emerged in the theme [Engagement], students were motivated to use the SOS device for the orchestration of the activity and eager to cooperate with each other to explain/understand how the system worked (“peer explanation”). Within HCI, other studies have supported that the introduction of technology increases motivation [50], [51] among school students. There is evidence that students become excited about **the use of technology**,

and therefore dedicate more time to work on the subject with assistance of a given tool [52].

Last, we argue that a combination of the above factors fostered a more “satisfactory orchestration” in the experimental group: a better social climate in the classroom, a sense of group formation awareness that enabled good coordination and engagement [Engagement], and reliance on the device which allowed for further focus on the task [Attention].

7 CONCLUSIONS

In this study we have compared the signal orchestration system to the traditional paper-based method for the flow coordination of a jigsaw pattern-based script. Our results indicate that those students using the SOS spent less time on the organization of the activity, obtained better scores, reported a better sense of group formation awareness and rated the overall activity significantly higher than their peers in the control group.

The findings support that the SOS is an interesting alternative to the traditional paper-based approach for the orchestration of the jigsaw script in face-to-face settings. Even though teachers are normally worried about the orchestration time required in dynamic collaborative learning classrooms, this study also highlights the importance of issues such as group formation awareness, classroom social climate and enjoyment. Students wearing the SOS were more engaged with the activity and created a better climate in the classroom. They also found the device useful and have expressed their desire to use it again in the future.

Future work should explore the impact of the SOS system, both from the students’ and the teachers’ perspective, in the context of more dynamic collaborative scenarios where more students, changes of phase and resources are involved, or in more emergent scripts, in which data about students’ interactions is collected and analyzed in real time to enable intelligent orchestration decisions. As a first step towards this direction, we are currently working on two developments. The first focuses on the design of flexible and intuitive interfaces for the OS-Manager, which will be evaluated in user studies with teachers. The second development is a situated device, with a similar functionality to the wearable PS-devices, which could be attached to resources or specific collaboration areas in the classroom to enable the remote configuration of orchestration signals to their specific locations.

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