TIP: Tangible e-Ink Paper Manipulatives for Classroom Orchestration

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ABSTRACT

While digital tools are more and more used in classrooms, teachers' common practice remains to use photocopied paper documents to share and collect learning exercises from their students. With the Tangible e-Ink Paper (TIP) system, we aim to explore the use of tangible manipulatives interacting with paper sheets as a bridge between digital and paper traces of learning. Featuring an e-Ink display, a paper-based localisation system and a wireless connection, TIPs are envisioned to be used as a versatile tool across various curriculum activities. In this paper, we present the design principles of TIPs and a first functional prototype. We conclude by presenting future works in the evaluation of TIPs as a distributed sensor for teachers in their classroom, including learning scenario examples to illustrate our statements.

KEYWORDS

tangible manipulative, education, classroom orchestration, collaborative learning, iot

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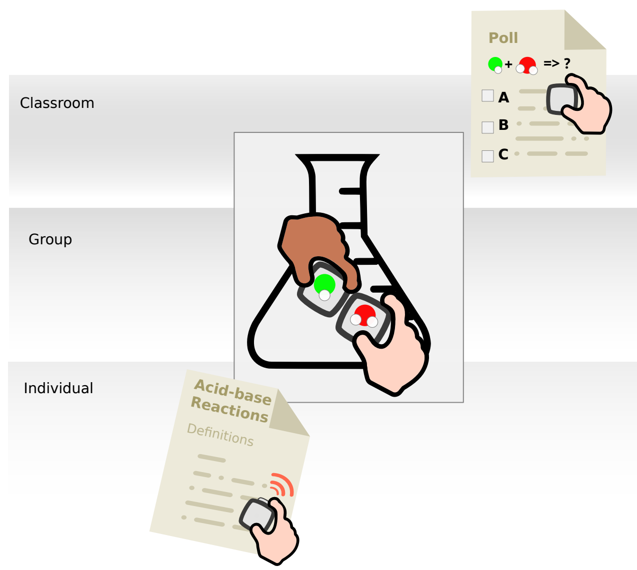

Figure 1: TIPs used in a a multi-layered learning scenario on acid-base chemical reactions, covering the entire range of Individual, Group, and Classroom levels (see Section 3).

1 INTRODUCTION

Paper is ubiquitous in classrooms; and researchers in educational technologies have for several years investigated ways to augment paper. Some research have suggested that students concentrate more easily on paper and comprehend better printed material compared to digital one. However, digital media offer ways to render things dynamically and without spatial and temporal constrains. For instance, Augmented Reality, using fiducial markers printed on paper, has been widely studied in education [5, 9, 16]. These augmented pieces of paper have been used as tangible tabletops to stimulate collaborative learning [3, 4]. While creating a lot of enthusiasm, these technologies often lead to increase in the teacher's cognitive load [19].

Classroom orchestration can be defined as the management of classroom interactions. Classroom orchestration is often described at multiple levels: individual activities, teamwork and class-wide sessions. Several works in technologies for education aim to facilitate teachers' adoption of digital medium by creating orchestration tools. Alavi et al. [1] proposed a tabletop solution for distributed classroom awareness, allowing teacher assistants to visualize the advancement status of students by simply looking at the class. Other researchers have investigated the use of wearables such as smart

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Figure 2: First functional prototype featuring individual display on shared map graphical display. This prototype was tested for an exploitative scenario, in which the user can move TIPs on a world map and retrieve information about the name of the continent, country, featured species living in the area and featured monuments.

glasses [6] to augment the vision of the teacher. However most of the research in classroom orchestration deals with building adequate dashboards for the teacher to monitor and eventually interact with the students (through tablets or laptops) [15].

In this project, we propose to investigate a new form of tangibles that function on augmented paper and feature an e-Ink display for classroom education. These Tangible e-Ink Paper (TIP) manipulatives act as distributed sensors in the classroom, allowing the teachers to perceive in real time the activity and performance of students. It also allows students to request help; or bookmark some information by using a clickable button; or dynamically explore paper content.

2 THE TANGIBLE E-INK PAPER SYSTEM (TIP)

Figure 2 shows a first functional prototype of TIP. The design of TIP has been derived from the Cellulo robot by Özgür et al. [12]. Its printed pattern-based embedded localization system allows accurate and absolute retrieval of its pose on paper [7]. With its camera, placed facing down, TIP can decode the pattern and determine its position and orientation (*x,y,theta*).

It features an e-Ink display[1,2] on its top and a push button on one of its side giving the orientation in which the device should be held (button up, to be pushed by the index finger). Just like the Cellulo robots [14], multiple TIPs can be connected via Bluetooth to a tablet or PC controller. This controller runs the logic of the activity: Receiving the position of each of the TIPs on the paper sheets, it decides what the e-Ink display should be showing. This logic is programmable and can be designed for each learning scenario.

Cellulo robots have been used for collaborative learning [2, 8, 11, 13] and classroom orchestration[17] in the past. Some first work on the analysis of Cellulo robots' localisation logs seem to be very relevant for learning analytics [10]. But with only LEDs on the top, Cellulo robots do not allow for private and detailed display of information. Besides, we estimate that the cost of building TIPs and their maintenance cost will drop by half compared to the Cellulo robots (which feature three extra motors, drivers and wheels).

3 CONCEPTUAL EXAMPLE OF A LEARNING LESSON ON ACID BASE REACTIONS

Chemistry often offers the occasion for teachers to engage students in practical activities. A typical practical activity is the measuring of acidity using pH strips while learning about acid base reactions. We propose a complementary scenario that exploits the value of TIPs by having a practical activity while preserving abstract representations (chemical molecule formula). As illustrated on Figure 1, the scenario is composed of three steps: 1) Individual work, 2) Group work and 3) Classroom activity.

1) In the **individual** activity, each student works alone on a A4 sheet that provides definitions and properties of Acids and Bases. By pressing the TIP's button, they can request for help displayed on the device (*virtually raise their hand and call the teacher*). Some words in the text are missing, and appear on the display only if the student went through the text using her TIP. The teacher can hence visualise in real time each student's level of advancement.

2) In the same scenario, the teacher can then propose a **group** activity. Each TIP displays an acid or base molecule. On large sheets of paper, each student is then required to find another student holding a TIP with a conjugate molecule to create a acido-basic chemical reaction. To make the reaction, students need to place their TIP next to each other on the same sheet of paper. The chemical reaction is shown by an animation on the TIP's e-Ink display, resulting in two new molecules.

3) Finally at the end of the session, a small quiz is ran using TIPs at the **classroom** level. Students are given a sheet of paper with the questions. When the teacher reads a question out loud, students can respond to the multiple choice question by placing their TIP on a checkbox. The teacher can share with the classroom the ratio of answers for each item and discuss the correct answer, before moving on to the next question.

4 POTENTIAL OF TIPS AS LOCALISED MANIPULATIVES IN THE CLASSROOM

Several aspects need to be considered to estimate the potential of such augmented paper manipulatives:

4.1 Learners' Interaction

TIPs e-Ink display content can be changed in real-time during the learning activity. This change can be programmed to be triggered by several events :

[1] Waveshare 1.54inch e-Paper display module, with 200x200 pixel resolution.
[2] An e-Ink display was chosen over other dot-matrix display technologies due to its typically lower energy consumption on static images.

- When the button is pressed. For instance the student asking for extra information related to the part of the exercise sheet she is on (see the Individual plane on Figure 1).
- When scanning the paper. For instance looking for some hidden information, particular zones on the paper could trigger particular content to be shown on the e-Ink display. In the group activity for the acid-base scenario, we can imagine that the molecules are shown on the TIPs' display only when inside a test tube zone.
- When combining several TIPs in a particular location. For instance, in a chemistry activity, with TIPs acting like a molecule, bringing two TIPs next to each other triggers the chemical reaction between these two molecules (see the Group layer on Figure 1).

4.2 Collaboration

In terms of collaboration, TIPs present a two level-display: 1) individual, with the e-Ink display oriented towards the person holding the device, and 2) shared, with the position of TIPs on the sheet of paper, similar to pieces placed a board game. Based on previous works on tabletop collaborative interfaces [18], we believe that this two level-display can foster collaboration by enabling both a shared workspace (paper sheet) and individual information (e-Ink display). The individual displays can be used to foster collaboration by attributing distinct perspectives to the students. The paper sheet is then used as a collaborative grounding area.

4.3 Orchestration

Teachers are a crucial part of acceptance of technologies in classrooms. We believe that the reliance of TIPs on paper sheet can be valued by teachers:

- Workflow: As illustrated by Figure 1, TIPs are envisioned to be used on multiple activity levels in the classroom: 1) for Individual work on A4 sheets, 2) for Group practical activity on larger sheets (for instance A0) or as 3) a probe for Classroom quizzes.
- Monitoring: Because each TIP can transmit in real-time its location on paper, the progress of learners on their worksheet can be accessed by teachers. It can bring awareness to the teachers by displaying on a dashboard a heatmap of the localisation of all students' devices. It can also be used by students to request help by pressing their button. Teachers can then evaluate on which parts of the exercise sheet students asked the most questions.
- Classroom management: Given the progress of the class, teachers can then decide to send messages through the e-Ink display of TIPs. Visualising in real-time on which exercises the students are can help time tracking and time management.

However, future works should propose an intuitive way for teachers to program the swarm of TIPs in order to prepare and easily create their learning scenarios.

5 CONCLUSION

In this paper, based on previous work on the Cellulo robots, we introduced our motivation and first implementation of a self-localised passive manipulative interacting with paper sheets. We envision several learning scenarios in which TIPs could be used touching various parts of the curriculum. In the future, we plan to take an iterative design approach: A first experimentation of TIPs in individual and group learning activities will inform us on the validity of our design choices (i.e. relevance of the two level-display). A new prototype could then be built, possibly featuring other sensors (such as IMU) allowing other types of interactions (for instance shaking the TIPs). We believe that these connected devices can create natural interactions between paper-based and digital work of students in the future, and look forward to explore their potential in classrooms.

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