Paper Interface Design for Classroom Orchestration

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Abstract
Designing computer systems for educational purpose is a difficult task. While many of them have been developed in the past, their use in classrooms is still scarce. We make the hypothesis that this is because those systems take into account the needs of individuals and groups, but ignore the requirements inherent in their use in a classroom. In this work, we present a computer system based on a paper and tangible interface that can be used at all three levels of interaction: individual, group, and classroom. We describe the current state of the interface design and why it is appropriate for classroom orchestration, both theoretically and through two examples for teaching geometry.

Keywords
Augmented reality, paper, tangibles, geometry, education, scattered interface

ACM Classification Keywords
H.5.2 Information Interfaces and Presentation: User interfaces – User-centered design

General Terms
Design, Human Factors

Introduction
Designing computer systems for educational purposes is a difficult task. While the advantages of using computers for learning, such as automation, time gain, realism, and

storage capacity, are numerous and simple to understand, leveraging them in a real-world environment is challenging. During the last decades, research and development on educational computer systems in the HCI community has focused on the usability at the level of the *individual*, which is commonly referred to as the first circle of usability [3]. Communities such as CSCL and CSCW have focused on the second circle, which is the interaction at the level of the *group*. The third circle, which describes the interactions at the *classroom* level, has mostly been neglected by the past work in this field by either communities, as can be seen in the overview of the related work below. After analyzing the approaches used in previous systems, we came to the conclusion that not taking into account the third circle in the design of computer systems for education is one of the main reasons why those systems are so scarce in classrooms nowadays.
In this paper, we present the design of a computer system used to study geometry in a classroom. The system is specifically designed to be used at all three levels of interaction. To optimize its integration in the classroom, the system is based on the medium that is the most used in classrooms nowadays: paper.

Related work

Many computer systems have been developed to teach geometry. For descriptive geometry, interactive multimedia animations were developed with Macromedia Flash [5]. The animations were compared with traditional teaching methods and were found to be appreciated by students for the step-by-step approach that they allow as well as the ability to repeat them whenever.
Another kind of approaches, using augmented reality, is particularly popular to learn 3D geometry and develop spatial skills. They rely on head mounted [7] or on vertical [11] displays to show mathematical objects that can be controlled by tangibles.Most of these works report a clear gain in engagement from the students [4].
Several dynamical geometry softwares such as Cabri Geometry[1] or Archimedes Geo3D[2] have been developed to address the lack of *manipulability* of the concepts. However, the use of a WIMP interface is truly different from the original geometry tools (ruler and compass), and as Kortenkamp and Dohrmann mention [8], the risk is to spend more time learning the software than learning geometry.
A pen and paper [10] approach can address this issue. Oviatt and colleagues [12] have shown that the closer from traditional pen and paper, the better the performance of students. In other words, digital stylus yielded better results than pen tablets, which in turn outperformed graphical tablets.

Technical setup and tools

The TinkerLamp is a tabletop environment developed at CRAFT [15]. It is composed of a camera and a projector facing the table at approximatively one meter height. The projection area, i.e. the playground for applications, is of dimension 50 by 35 centimeters. The lamp is able to detect tagged objects placed under it thanks to a tag tracking library and can provide visual feedback through the projector. The TinkerLamp has already been successfully applied to study logistics [6].

Elements of the interface

The system is based on the TinkerLamp and the interface formed of four types of objects: sheets, cards, tools, and artifacts. Activities are printed on paper *sheets*, just like regular exercise sheets, except that a tag is printed on them

[1] www.cabri.com
[2] www.raumgeometrie.de

so that the computer can recognize them. Commands are issued to the program using *cards* that have the same format as the ones used in standard card games. Each card has a title, a tag, a logo, and a short description of what it does. Regular *tools*, such as pencils, rulers, erasers and protractors, can be used to perform the activities, possibly with a tag if an interaction with the TinkerLamp is needed. Finally, *artifacts*, such as wooden blocks and geometrical shapes are tagged and used when needed in any activity.

Paper interface in the classroom

As explained in the introduction, the main problem with current learning environments is their failure to address the classroom interaction level. This section points out three design choices that make paper interface especially suitable for the 3rd level of interaction.

Use of paper The most important aspect of integration in the classroom is the use of paper. At school, exercises are most often given out on paper, completed on paper, and carried home on paper to do the homeworks. They are stored in a classifier in order to keep a trace of what has been done and can be used to refresh the knowledge if necessary. Far from replacing paper, augmentations improve it by reunifying the familiar attributes of paper with the power of computers. Exercise sheets are still prepared and completed on paper. The difference with the usual workflow is that the paper can be augmented when needed, and that some content can be dynamically added by printing sheets in addition to the regular pedagogical material.

Use of tools Learning how to use tools such as a compass, a ruler, various kinds of pencils, or an eraser, is part and parcel of learning geometry. With paper as interface, tools can be easily integrated in activities by referring to them or asking the student to use a tool to perform a specific action. More importantly, they can be used in the exact same way as they would be used without augmentation, training the student's primary skills instead of how to use a specific environment as is the case with other systems (Cabri Geometry, CAD softwares). There is therefore no need to transfer the skills learned on the computer back to the classroom environment.

Tangible *External representations* play a key role in problem solving and learning([1, 9]), by helping the learner to make inferences or freeing up cognitive load to allow the learner to focus on the core of their task. Another important dimension for learning is the coupling between cognition and physical experience [2]. Tangibles are both external representations as well as physical objects on which *actions* can be exerted. Numerous examples of tangible and learning can be found in [13]. With the TinkerLamp any object from the real world can be included in an activity provided that it can be tagged. There are two main advantages of using tangibles as far as the classroom interaction is concerned. First, it allows to fragment the interface, easing orchestration. Second, it brings peripheral awareness, which is key in a classroom.

Two examples

In order to demonstrate how paper augmented with the TinkerLamp meets the requirements inherent in the three levels of interaction, we developed two prototypes to teach geometry at two different levels.

Geometry at primary school

In the context of primary school geometry education, the TinkerLamp is used to ease the transition from concrete geometry activities to an internalization of abstract concepts. Activities that require too much attention from the teacher or a resource that is not available for the whole class at once are often organized by groups: one or more groups do this activity, while the rest of the class works on a more autonomous activity, such as exercise sheets. Being a table top environment, the TinkerLamp fits well in this organization; it is more adapted to group learning activities, as opposed to interactive white boards, whose verticality fits teaching better. We developed several pedagogical activities and present two of them hereafter: one to learn the classification of quadrilaterals, another to introduce the concept of angles.

Classification of quadrilaterals The activity on the classification of quadrilaterals consists in a booklet. Each page of the booklet contains two boxes, in which the pupils have to place given shapes according to their class (e.g. rectangles in the top box, other parallelograms in the bottom box). The booklet, as well as the shapes, can be produced with a regular printer, and the activity can be done without any augmentation. However, if four additional paper cards are printed, the booklet can be augmented with the TinkerLamp: one card gives feedback on the pupils' work, and others display features of the shapes, such as side lengths or angle measures.

The classification of quadrilaterals activity exemplifies how the TinkerLamp is integrated in the regular workflow of the classroom. The activity can indeed be designed so that it can be performed without the TinkerLamp. The booklet finishes with a synthesis exercise that does not need the TinkerLamp, thus making it possible for a group to leave the TinkerLamp with a tangible and persistent result. In this case, the presence of paper is an asset for the teacher orchestrating a classroom: the various paper elements are remotely distinguishable, which allows the teacher to gather information globally. For example, if a pupil is using the feedback card a lot or is stuck on the first pages of the activity, he may need a face to face explanation.

Far from being a fully automatic system trying to replace teachers, the TinkerLamp aims at supplying them with information to orchestrate the classroom. The TinkerLamp further supports teachers, by relieving them from the menial tasks where they are not required.

Discovering angles One introductory activity about angles aims at giving an intuition about angles to the pupils by playing with reflections: some cards generate a ray attached to them and reflected by other cards. A paper protractor, on which the base line is projected, can be used as a first contact with angle measurement tools: another card controls a guide line projected from the center of the protractor to this card, and shows the value of the angle. The added value of paper as interface truly appears when a real protractor, which pupils have to master, can be used. The pupils are then asked to move the guide line to a given angle, and measure its complement. They report the values in a table on the activity sheet and add them to discover that the sum is always equal to 180°.

Descriptive geometry

Descriptive geometry studies the representation of 3D objects on a plane. It is based on the concept of projecting a point on a plane to go from the original three dimensions of the point to the two dimensions of the plane. It has been shown that technical drawing is linked to the spatial intelligence and that developing spatial perception is, for example, essential for the training of engineers [5, 14]. In her work, Sorby also showed that students who work on sketches with paper and pencils learn better than people who learn on only a multimedia software. However, she additionally found out that students prefer to learn on the multimedia software rather than by sketching. With the TinkerLamp, the students get the best of both world. Paper and pencil do not disappear, but the computer is also used to augment the paper. We now give examples of two typical activities performed in descriptive geometry and how performing them with the TinkerLamp suits all three levels of interaction.

Completing the primary views One of the typical activities in the introductory chapters of descriptive geometry is to be able to draw the three primary views of a 3D object. A student is typically given partial drawings of each of the three primary views and must complete them. The three primary views can be linked together by construction lines. While drawing those construction lines is a simple and mechanical task, it needs to be done with high care and precision. It therefore takes a lot of time while not bringing much learning value. With the TinkerLamp, students can ask the system to project the construction lines for them. They can then focus on the cognitive more relevant task of completing the primary views using the construction lines.
Students still use their regular tools (ruler, set square, pencils, etc.). They interact with the system with a card to tell it to show the construction lines. The exercise sheet remains the same as without the TinkerLamp, only the final drawing lacks the construction lines.
Such a task demonstrates the integration of the TinkerLamp at the individual level. Note that the activity could be easily changed to integrated at the second level by having a group of three students completing the activity collaboratively (for example, each student could be responsible for one of the primary views).

Model matching Two teams participate in this activity. Team A uses tangible blocks to build a 3D model. Once satisfied with the model built, the team saves the layout of its model and hands the blocks to team B. The system has saved the layout, but only shows to team B two of the three primary views of of the model saved. The role of team B is to construct the same model as the one built by the first team, by using only the two primary views displayed by the system.
In this activity, cards are used by the teams and by the teacher. Team A uses a card to save the model. Team B can use a card to display the construction lines, which help relate the 3 primary views together. Since this is a difficult task, another card can be used to show the current model on the two primary views where the target model is shown. However, this card, as well as the card to display the solution, is given only to the teacher. Distributing cards to different types of actors is one example of how the interface can be *scattered* for a better orchestration. The tangible blocks are also an added value for the orchestration, since the teacher, but other students as well, can clearly see who is doing what, increasing their peripheral awareness. The blocks are also relevant from a learning point of view since they allow each student to have a different view of the same object; they also force students to perform a frequent back-and-forth between the internal representation of the 3D model and the external representation offered by the tangible blocks.
Note that tools and paper are not used in this activity, which underlies the fact that not all four types of objects forming the interface need to be used in an activity for it to have an added-value.

Conclusion and future work

We have presented a new paper-based environment designed to be usable at the three levels of interaction in which learning in a classroom appears: individual, group, and classroom. The interface of the system is composed of four types of objects (sheet, cards, tools, artifacts). We have described both theoretically and with two examples how such an interface can be used for learning activities at all three levels of interaction. Although the examples both involved studying geometry, the concepts presented are generalizable to other subjects.

Future work The two examples described are only at an early stage of development. More development is needed in order to create additional activities and to test the usability and integration of the system in a classroom environment. To keep them in phase with the real classroom environment, the activities will remain co-designed with teachers. Finally, user studies in classrooms are planned to assess the impact of the technology both on the classroom orchestration and the students' learning.

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