THE LANGUAGE OF CRYSTALS: LANGUAGES AND STORYTELLING FOR INFORMATICS IN PRIMARY SCHOOL

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Abstract

This paper presents the initial study of a larger research activity focusing on understanding to which degree the learning of informatics concept in primary school students is helpful for acquiring additional competences, the so called “transfer effect”.

Grounded in constructivist pedagogy, this initial study employed a tangible, narrative-driven learning activity whose main objective was to conduct a formative assessment of the children's prerequisite competencies considered essential for the subsequent instructional sequences. This diagnostic approach served to establish a baseline proficiency level across the group, allowing for pedagogical interventions to remediate any identified skill deficits, thereby fostering a more homogeneous and solid foundation from which to launch the core learning modules.

We employed both unplugged and plugged activities, based on storytelling, hands-on manipulation, and visual representation, tailored to the concrete-operational stage of pupils’ development, to bridge the gap between play and formal logic thinking.

Pupils learned the “language of crystals” – a metaphorical system representing abstract reasoning patterns essential for becoming “light wizards”. The rules of such language were conveyed through analogies with natural language to highlight the universality of these formal structures.

The game required pupils to apply logical reasoning to forecast outcomes and to grasp concepts like state-dependent rules. A purpose-built software tool supported activity verification and assessed basic keyboard/mouse interaction skills.

Post-activity assessments revealed encouraging success rates with minimal teacher intervention. Classroom observations enabled the calibration of a replicable and documented teaching protocol adaptable to different cognitive levels.

Future activity will explore to which degree learning programming concepts can foster the development of logical reasoning capabilities.

Keywords: informatics education, primary school, educational experimentation, languages, automata, storytelling.

1 INTRODUCTION

In recent decades, informatics has been progressively institutionalized as a subject of formal school instruction across many countries. This gradual yet persistent process has occurred despite the well-documented inertia of educational systems and the resistance typically associated with curricular innovation. The most compelling rationale underlying this transition is the recognition of the pervasive role that informatics now occupies in contemporary society and the global economy. Such a development was already anticipated in Papert's seminal work [1], which not only foreshadowed the disciplinary relevance of computing but also articulated a more ambitious pedagogical vision. According to Papert, learning to program a computer could catalyse the development of more general learning abilities, thus positioning informatics not merely as an object of study but as a means to enhance cognitive growth. The broader discourse on computational thinking (see [2]) has further expanded Papert's original vision, framing programming as a technical competency and a fundamental skill with potential cross-disciplinary impact.

This idea has since stimulated extensive debate within the research community. While some scholars have provided empirical evidence supporting the claim that programming can foster transferable problem-solving and reasoning skills ([3], [4]), others have questioned the extent to which such effects can be systematically demonstrated [5]. Nevertheless, despite decades of research, whether and how programming activities enhance broader learning abilities remains unresolved and continues to represent a central challenge in informatics education.

The present article reports on the initial study of a larger research activity designed to contribute to this ongoing discussion, by investigating whether the acquisition of foundational programming concepts can influence the problem-solving performance of primary school students in tasks requiring logical reasoning. Our research is inspired by the work of Salehi et al. [6], which examined the performance of university students when solving problems outside their academic major. Their findings provide evidence that educational experiences in informatics can foster the development of problem-solving skills across domains more effectively than other disciplines. In the same spirit, we set out to investigate a related research question, but within a younger age group – primary school students – an age widely regarded as particularly promising for initiating informatics education. Since primary school learners generally lack deep knowledge of specific academic domains, to assess their problem-solving abilities we devised a puzzle requiring only simple logical reasoning skills. Our long-term goal is to conduct a large-scale experiment involving a much larger number of primary school classes and to analyze the effect of learning programming on the development of logical reasoning capabilities. To this end, we developed a web-based application that allows both pupils to engage with the puzzle with minimal guidance from their teachers and the latter to fulfil this role without needing an extensive training. This design will enable us to extend participation to a set of geographically distributed classrooms without the physical presence of researchers. Additionally, the application automatically logs gameplay data, enhancing both the quality of the evidence collected and the efficiency of data acquisition.

In the past school year, we conducted a pilot study whose results are still being analysed. We intend to use such results to refine the methodology and the tools in preparation for a broader experimental phase planned for the upcoming school year. The outcomes of this large-scale experiment will be presented in future reports.

In this article, we discuss how we addressed a key challenge, namely ensuring that all the pupils possessed two essential prerequisites:

1. A clear understanding of the puzzle rules, even among pupils as young as second grade.
2. Sufficient digital skills to confidently and accurately use the web-based application interface.

We believe the significance of this preliminary report extends beyond the scope of our specific case. The solutions we developed can inform similar contexts in which it is required that young primary school students use digital interfaces and comprehend the functioning of dynamic systems governed by purely logical rules, such as the puzzle we designed.

1.1 The logic puzzle

The game is structured around a square matrix of cells, ranging in size from 2×2 to 4×4. From any external edge of a row or column, “balls” can be launched. After traversing the grid, they exit from a different edge having possibly encountered hidden obstacles within the cells. Obstacles are inclined at ±45° thus deflecting the trajectory by ±90° relative to the direction of the launch (see Fig. 1). Each cell may contain at most one obstacle. The objective of the game is to accurately determine the configuration of the obstacles placed within the matrix. The puzzle incorporates elements of inherent difficulty, which were considered in the design and calibration of both the training and assessment sequences.

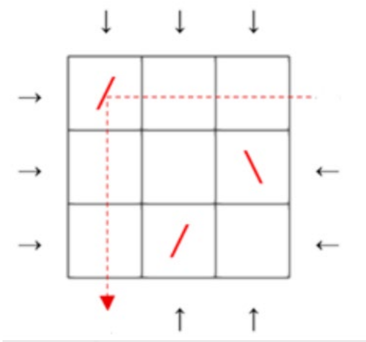

Figure 1. A 3x3 grid with 3 obstacles with the trajectory of a launch modified by one of them.

1.2 Prerequisites

The analysis conducted in the pilot classes highlighted the necessity of assessing two competencies considered essential prerequisites for engaging with the puzzle:*Theoretical*: an understanding of the physical principle whereby the trajectory of a ball, upon encountering an obstacle with an inclination of ±45° (relative to the ordinate axis), is deflected at a right angle relative to its initial direction.*Technological*: proficiency in using the mouse, specifically the ability to interact with the graphical interface (placing and removing obstacles).

2 METHODOLOGY

In this section we describe the teaching strategies adopted and tools used to ensure that all pupils participating in the pilot experience possessed the theoretical and technological prerequisites. These strategies were initially developed through preliminary work with a small group of second grade (K2) pupils, based on the hypothesis – later confirmed – that they would prove equally or more effective for upper-grade classes.

2.1 Theoretical prerequisite

Given the young age of the learners, which are in the Piaget's concrete-operational stage of their development, we developed an unplugged tool to support their understanding of how the trajectory of a launch is deflected upon encountering obstacles. Geometric optics, with the laws of reflection, was identified as a suitable means of emulating the trajectory deflection mechanism. We therefore framed the puzzle as ray of lights whose trajectory is deflected by hidden mirrors. It should be noted that since this activity is not oriented towards the teaching of physics, the interest was focused on grasping the mechanisms of deviation of ray light trajectories upon encountering a mirror rather than on internalizing the underlying physical principles. The situation also proved to be particularly suitable for introducing certain symbolisms and some principles of formal languages and their construction, with the degree of formalism adapted to the grade level (second/third vs. fourth grade). Finally, as suggested in [7], to maximise the emotional involvement of pupils, a detailed fantasy scenario, described below, was developed in collaboration with the teachers, to be used both during the introductory phases and as a permanent narrative framework throughout all subsequent stages of the activity.

2.1.1 The Backstory

Driven by the need to justify the use of an unplugged instrument based on optical mechanisms, the activity (titled "The Magic Crystal and the Labyrinth of Lights") was set in a fantasy world, vaguely inspired by the Harry Potter saga, in which aspiring "light wizards" must learn the principles for navigating a labyrinth containing crystals (mirrors, also "obstacles", in the following), which possess their own language – the knowledge of which is essential to finding a way out. Further details are described, in Italian, in [8]. This story serves as a foundation for the teaching activity.

2.1.2 The Labyrinth of Lights

Guided by the principles of geometric optics, we created a demonstrative prototype featuring a grid maze (see fig. 2). This design incorporated diagonal guides that allowed mirrors to be positioned at precise angles, transforming the grid into a configurable puzzle. To navigate this environment, educators employed a laser pointer — dubbed a "magic wand" — leading pupils through a curated learning sequence to discover the mechanics of reflection.

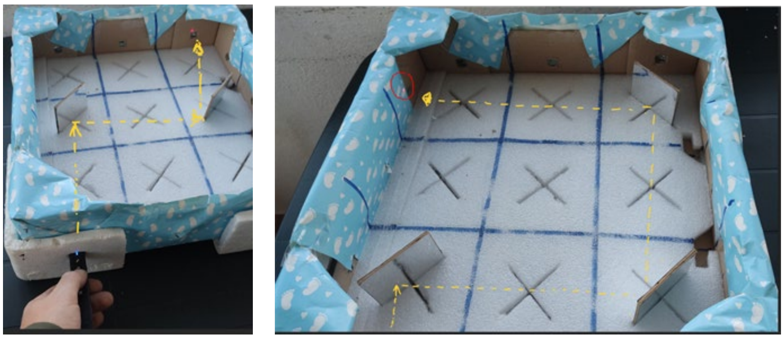

Figure 2. A physical prototype of the labyrinth of lights.

Along with the maze, a plywood structure (the “path grid”) with hooks placed in the centre of each cell was built (see Fig. 3). It was used to physically show the trajectory of a ray light by means of a piece of yarn attached to the hooks, in cases where children had difficulty mentally visualizing the trajectories of light for a given mirror configuration

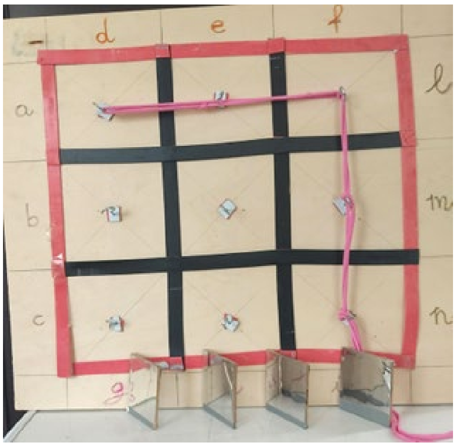

Figure 3. The insertable mirrors and the grid of paths (physical).

2.1.3 The Language of Crystals

As anticipated, the launch of the activity was also an opportunity to experiment with introducing children to some informatics concepts related to languages (natural and formal), a topic that also connects with other disciplines (see [9]); the goal was certainly not to teach formal theory, but rather to encourage the intuition of rules, structures, and dependencies, with constant practical references based on their personal experience with natural languages.

Teaching rationale. To become light wizards, the apprentices must acquire the fundamentals of the language of crystals (the mirrors that can be placed on the grid) that allow them to understand the rules of reflection.

Students were therefore encouraged to learn the four fundamental words ("Up"; "Down"; "Right"; "Left") necessary to describe directions of ray lights. These words have been elaborated considering the directional confusion observed in children (see [10]), which could lead to making right/left inversion errors when observing external figures.

To formalise the rules for calculating the trajectories of light in the maze, we added two words in the language of the crystals to describe the mirrors that can be positioned on the grid: Zin (or “ / ”, for a mirror with a +45 inclination) and Zum (or “ \ ” for mirrors with –45 degrees inclination). Depending on the direction of origin of the ray light , expressed using one of the four basic words of the language of the crystal, and one the two kinds of mirror which are encountered, expressed as one of the additional two words, the new direction taken by the ray light can still be expressed using one of the four “directional” words.

This was explained attaching it to the concept of "synonym" in natural language (students are familiar with), by showing, for example, that a direction “Up” can derive both from direction “Left” plus mirror “Zin” and from direction “Right” plus mirror “Zum”, that is both “Left+Zin” and “Right+Zum” are synonyms (see fig.4).

Left + Zin = Up Right + Zum = Up

Figure 4. The language of crystals: defining the word “Up”.

We also provided a paper version of the path grid, shown in Fig. 5 with the representation of the three paths followed by three distinct ray lights for a given configuration of mirrors.

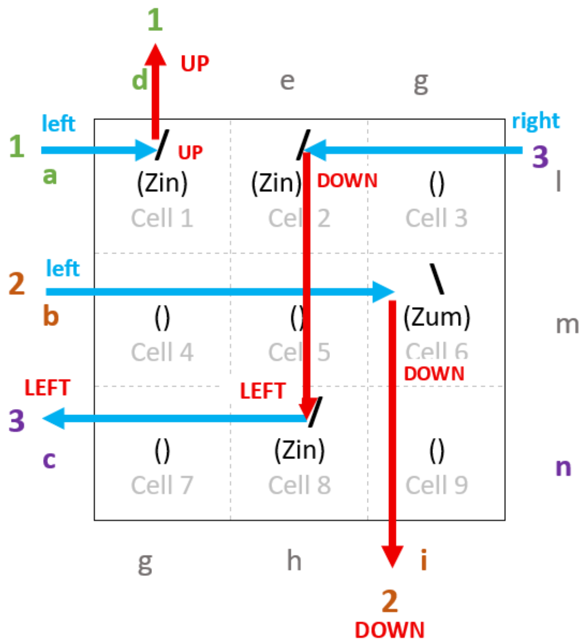

Figure 5. Example of path representations using the grid of paths.

3 RESULTS

The methodologies described in Sect. 2 enabled us to provide the prerequisites outlined in Sect. 1.2 to the pupils of 12 classes at the primary school "C. Goldoni" in Latina (part of the *Istituto Comprensivo* "G. Giuliano"). In collaboration with 10 teachers from that school, we conducted a detailed analysis of the compatibility between the exercises proposed through the tool and the cognitive developmental stages of the pupils. This process led to the progressive refinement of the web application interface and the careful calibration of instructional timing.

3.1 Teaching Sequence and Classroom Activities

The teaching activity was first carried out with a second-grade class and was conducted in a highly detailed and carefully structured manner (Fig. 6). The entire session lasted approximately 5 hours, including transitions and breaks. Of this time, about 2 hours and 30 minutes were devoted to the physical version of the puzzle using the grid, while 1 hour and 40 minutes were dedicated to the digital version of the game.

We compiled a detailed report documenting the implementation of the activity, which subsequently served as the basis for a joint post hoc analysis with the teachers involved in the project. This analysis enabled us to refine the instructional design of certain phases and achieve a more precise timing calibration. The report, annotated with the observations that emerged from the post hoc analysis, was then used as a guide for conducting the activity in the other classes participating in our pilot study. As experience with other classes progressed, the activity duration was reduced to 3 hours for the second-grade classes. We found that children in third grade classes were more responsive; hence, the time required in such classes was shorter than that required for second graders. For the fourth (and fifth) graders, a total of 2 hours was sufficient to plan for achieving the objectives.

Figure 6. Class activities.

3.2 Observation and Assessment Strategies Adopted

As previously stated, the activity aimed to assess pupil gaps in the identified prerequisites and address them within the allotted timeframe. The observations were conducted based on the teachers' consolidated knowledge of the pupils, complemented by their responses to the various situations presented to them using unplugged and plugged tools. Since the goal was to maximise understanding of theoretical and technological aspects, we allocated different amounts of time to the children based on their individual needs; this approach also ensured that the games were accessible to pupils with special educational needs.

With this clarification, it is evident that the empirical and inclusive approach did not necessitate overly formal assessment tools. With the teachers' help, we could identify the distribution of pupil skills and behaviours reported in Table 1. With minimal tolerances, it can be considered valid for all classes (with an average class size of approximately 20 students).

Table 1. Average distribution of class results.

Pupils' category	Percentage of pupils	Category description
Lightning	5-10%	Immediately grasps the concepts taught and develops strategies to solve even more complex problems than those presented
Centred	60-80%	Comprehends the concepts taught through play within the expected timeframe and manner
Misguided	10-15%	Exhibits some misconceptions related to the functioning of mirrors, which can be corrected with the combined use of unplugged and plugged tools
Mentorable	0-5%	Does not fully achieve the objectives with the proposed activities and exhibits some weaknesses that will need to be addressed in subsequent phases of the work (outside the scope of this paper)

Before being adjusted to the various age groups, the activity was planned in two 2-hour modules to avoid fatigue and potential loss of attention among the classes. However, the classes proved interested and responsive to the changes planned throughout the various phases of the activity. One at a time, one step at a time, and barring any unusual circumstances, everyone completed the proposed program to the full extent. They took varying amounts of time and, in some cases, required understandable patience, but the outcome was generally satisfactory and positively surprising, even in the teachers' opinion.

4 CONCLUSIONS

The activity's success confirmed the power of storytelling as a pedagogical lever: immersed in the role of "light wizards", the pupils faced challenges with enthusiasm and curiosity, which, despite their apparent simplicity, conveyed the first rudiments of formal information technology. The metaphor of the labyrinth of lights has proven to be a powerful tool for activating imagination, logical thinking, and abstraction skills, transforming light obstacles and deviated trajectories into concrete opportunities to reason about rules, states, and transitions.

The language of crystals, built step by step through symbols and paths, allowed pupils to meet deep structures of computational thinking, without ever losing the sense of play and discovery. This experience suggests that, if appropriately guided, even the little ones can begin to speak the language of informatics – not as an abstract technique, but as a story that becomes known. The way is open: the evidence gathered will form the basis for the consolidation and extension of experimentation in the later stages of the project, bringing the lights of the labyrinth to other children and teachers.

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