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ORIGINAL ARTICLE

Tangible versus graphical user interfaces for robot programming: exploring cross-age children's preferences

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Abstract This study explores children's opinions and preferences regarding two isomorphic user interfaces that can be used for introductory programming activities, a tangible and a graphical one. The first system (tangible) comprises 46 cube-shaped blocks that represent simple programming structures and can be interconnected to form the programming code. The second system (graphical) presents on-screen the same programming space to the user (icons similar in appearance and operation with the tangible blocks). These two operationally equivalent user interfaces were given to three children groups of different ages (5–6, 7–8 and 11–12 years) to program the behavior of a Lego NXT robot. Children in dyads were let to interact with both systems, and during the activity, data were collected regarding children's first-sight preference, enjoyment and easiness-to-use. The quantitative and qualitative analysis followed indicated that the tangible interface was more attractive especially for girls, and it was more enjoyable and finally characterized as easier to use only by younger children who were less experienced with computers. On the contrary, for older (11–12 years old) children, the tangible even though was more enjoyable, it was not considered as the easiest-to-use user interface. Taking into account the lack of empirical evidences related to the tangible user interfaces, this study discusses not only the potential usability advantages but also the disadvantages of tangible user interfaces for children.

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1 Introduction

Tangible user interfaces (TUIs) are user interfaces in which users can have interaction experience with digital information through the physical environment. These interfaces have been developed and proposed for several applications designed for different age groups [1]. Especially for children, TUIs have been proposed as tools that support playful learning in collaboration environment [2]. Several studies have investigated various characteristics of the interaction process with TUIs in order to measure the efficiency of such systems when used by young children [2, 3]. Despite the growing theoretical framework [1, 4] that supports the use of tangible user interfaces (TUIs) in children's education, there is limited research that systematically explores the advantages of TUIs compared to typical graphical user interfaces [5].

This study investigates children's preferences when using two isomorphic systems which have analogous features, such as similar shape, appearance, functionality. The first system is a tangible user interface for introductory robot programming activities, and the second is a graphical user interface (GUI) designed for the same purpose. Children of three different age groups worked in dyads and used the two systems in order to program the NXT Lego robot behavior in various programming scenarios. The objective was to measure pupils' opinions and preferences regarding the experience with the tangible and the graphical programming tools. More specifically, data regarding children's first-sight preference (FSP), enjoyment and easiness-to-use were recorded and analyzed.

2 Background

2.1 Tangible and graphical user interfaces for programming

Tools for children introductory programming have been a wide field of research since the early 1960s. Based mainly on graphical user interfaces and drawing on Papert's constructionism ideas [6], a large number of programming languages have been developed and targeted at children and novice users [7]. More recently, some of the notable languages include ToonTalk [8] and the most influential Alice [9], Scratch [10] and ROBOLAB, which feature simple syntax with graphically nested loops and conditional statements. These graphical approaches allow children to program by dragging and connecting icons on the computer screen. The programming process through graphical interface requires the ability to map the on-screen symbolic representation to the actions they produce.

Programming through a tangible interface, on the contrary, may reduce this mental gap by carrying out the programming action through the act of manipulating tangible objects [11].

The work of Fitzmaurice et al. [12] was the first that introduced in 1995 the notion of graspable interfaces, which were the everyday objects that one could use to interact with the digital world. In 1997, Ishii and Ulmer [13] defined the TUIs as the user interfaces that "augment the real physical world by coupling digital information to everyday physical objects and environments," and since then, the TUIs became an attractive research field for scientists. In the following decade, the field of TUIs has offered systems that were used in various applications [7, 14, 15]. The majority of these systems was designed for novices and was applied in fields, such as music [16], mathematics [17], learning dynamic concepts [18], three-dimensional modeling [19], storytelling [20] and quiz representation [21].

In the field of introductory programming, many tangible systems have been designed for children having as their purpose to connect the programming activity with the physical world [1, 22, 23]. Tangible systems of this type can be classified in two categories: the active [24] and the passive systems [25]. Active systems are systems with embedded electronics, whereas the operation of the passive systems is based mostly on image recognition or RFIDs. A particularly notable work in the field was presented by Suzuki and Kato [24] who developed AlgoBlocks, the first active tangible programming language dedicated to the promotion of cooperation during programming, through social interaction and discussion.

Nevertheless, despite the various research and development efforts that followed, it seems that the hypothetical advantages of using a tangible system have not yet been demonstrated with clarity and extensive evaluations [26–28]. The main reason is the high cost, and on the other hand, the complexity of tangible construction that constrains the utilization of such systems in the research laboratories [29]. In tangible programming and generally in the field of TUIs, there is limited research focusing on deeper understanding the cognitive and social advantages of using this type of tools [5, 30]. In particular, the impact of tangible environments that are designed to promote programming to people and social groups that are not typically related to it, such as children or novice, has not been studied sufficiently [7]. The hypothesis that TUIs ensure higher accessibility for children and lead to a lower age limit for participation might be worth testing. Moreover, questions regarding the conditions under which the handling of tangible objects can be more efficient in various domains, such as programming, astronomy or mathematics, remain open [26].

2.2 Comparison studies involving tangible user interfaces

A limited number of studies have attempted to clearly compare the use of a physical or tangible tool to that of a graphical equivalent. These studies and their results, which are briefly presented below, strongly emphasize the need for further research in the field.

Marshall et al. [31] studied comparatively a physical versus a graphical interface in a Piagetian balance beam task. The task involved adults and addressed the assumption that the manipulations of physical artifacts have cognitive influences on learning. The study did not find any differences between the two conditions. The researchers finally concluded that, because of the statistical limitations of the study (e.g., small samples), it is not possible to conclude whether an effect of physicality in the specific task there exists. Further research is proposed, engaging also younger participants.

Schneider et al. [32] carried out an interesting study, comparing a tangible and a multi-touch interface activity based on logistic problem tasks. The scope of the task was to investigate whether the physicality of the TUI has an impact on the performance, collaboration quality and learning benefits in the specific domain. The results provided evidence of an increase in collaboration quality and playfulness of the task. Also, the tangibility of the system helped to increase exploration and by this means to enhance performance and learning.

Xie et al. [5] presented the results of an exploratory study which compared physical, tangible and graphical jigsaw puzzle activities. The children interacted with one of the puzzles implemented using the three user interfaces (physical, tangible and graphical). The children's self-reports of enjoyment were similar for the three interface modes. Additionally, it was found that under physical and tangible condition, a significantly larger number of participants were engaged in a repeated play.

Triona and Klahr [33] made experiments with springs, manipulating physical or virtual materials. In both training conditions, the students performed equally well in the experiments. The same type of experiments were performed again by Klahr et al. [34] with virtual and physical mousetrap cars. Under all conditions, students performed equally well and no effect related with the type of interface was found.

Manches et al. [35] compared physical and virtual materials in numerical problem solving and demonstrated how the constraints of the different interfaces can influence the users' actions. The properties of each interface are crucial to the possible solutions that a user can reach when solving a numerical problem. On the contrary, Olkun [36] found no differences by comparing computer user interfaces versus concrete manipulatives at two-dimensional geometrical problems. Finkelstein et al. [37] examined the effects of using computer simulations in conjunction with the use of real equipments and parts for real circuits. The results showed that students who used computer simulations developed greater facility in manipulating real components and had a better understanding of conceptual questions related to the domain of electronic circuits. Also, Zacharia [38] performed a comparison study between real and a combination of real–virtual electronic circuits. Zacharia presented evidence that the students' conceptual understanding of electronic circuits was enhanced at the real–virtual experimentation condition, more than merely with real experimentation. Further research and data analysis showed that the replacement of real experimentation with the virtual in the experimental group had positive influence on student learning. Zacharia and Olympiou [39] conducted another study that involved experimentation in physics and especially in the domain of heat and temperature. The results indicated that the experimental conditions, physical and virtual, were equally effective in promoting students' understanding in this domain.

A particularly noteworthy work for tangible programming is the one of Horn et al. [23] who compared the use of a passive tangible against a graphical programming language in informal learning setting at the Boston Museum of science. The study revealed advantages of the tangible over the graphical programming language. In particular, the passive tangible programming language was more inviting and more supportive for active collaboration. Moreover, this active collaboration trend was stronger for girls. In parallel, Horn et al. [40] conducted a research project in kindergarten with 5–6-year-old children. Applying qualitative analysis, it was concluded that if children are given access to the appropriate technology, they can program and understand certain powerful ideas from the domain of computer programming and robots. It is clear that while tangibles appear more efficient than graphical user interfaces, more research is required to elucidate the circumstances under which the advantages are demonstrated in different domains.

2.3 Research motivation and research questions

Although there is pioneering work on the construction of tangible programming languages [15], there is a notable lack of research, with the exception of the work by Horn et al. [40], that provides empirical evidences for the advantages of the programming languages against graphical isomorphic systems. Taking into account the above lack of empirical evidences related to the TUIs [41], the present study was designed to further explore the differences between graphical and active tangible programming. It contributes to the current field by conducting a cross-age research, where children interacted with both systems and were asked to evaluate certain characteristics of them. Children were involved in predetermined tasks and in free plays as well with both systems and were let to crystallize their choices based on their experience. The study main objective is to provide further empirical evidence enlightening the potential advantages and disadvantages of TUIs utilization by children in classroom settings.

The driving hypothesis of the present study was grounded on two assumptions. First, tangible user interfaces being "natural" allow physical manipulation which is experienced as more enjoyable by children as compared to an isomorphic graphical interface. Second, tangible systems allow easier accessibility, and consequently, the user age threshold for efficient system use is reduced.

Accordingly, the research questions that this study explores focus on how the children of various ages, who have used both the tangible and the graphical user interface, evaluate the following interface qualities:

1. *Attractiveness or First-sight preference* (which interface did children first select to use?),
2. *Enjoyment* (which interface was more enjoyable?) and
3. *Easiness-to-use* (which interface was easier to use?).

The above measures were operationalized by the corresponding responses in a specially designed questionnaire and were used as dependent variables in the subsequent statistical analyses. They were explored as a function of children's age, gender and team synthesis.

3 The programming tools

3.1 The PROTEAS kit

PROTEAS kit is a general robot programming platform which consists of three subsystems. These are two active tangible programming tools T_Butterfly [42] and T_ProRob ("Tangible") and one graphical V_ProRob ("Graphical"). In the following, we present the tangible T_ProRob and the graphical V_ProRob user interfaces that have been used in this study.

3.2 Tangible interface

The T_ProRob (tangible) subsystem consists of 28 commands and 16 smaller parameters, all cubic shaped. Users can program an NXT Lego robot by connecting the cubic commands and parameters. The execution of the program starts when the user pushes the execution button on the top of the basis ("master box"). An indicative program structure, the master box and the robot are shown in Fig. 1.

In this program, the Lego's NXT robot will run the following sequence two times:

- three steps forward,
- delay,
- turn on the light
- delay
- turn off the light.

When the loop has been completed, the robot will carry out a check using the ultrasonic sensor. If there is no obstacle in front of the robot, it will take another step forward.

The user can perform very simple robot-controlling actions, such as "make a sound," "turn on the light." At the same time, the user can lead the robot to move using commands, such as "move one step forward/backward," "turn right/left." Moreover, repetition and condition programming structures are available in the system, supporting even more complicated combinations like nested loops. A special cube, where user can save the program code and reuse it later, completes the set of commands. The parameters set of T_ProRob are smaller in size cubes which can be connected to the command cubes. For example, the "turn right 90°" cube will perform the operation of "turn right 180°" if the user plugs to the command cube the parameter "2." The available parameters which concern the condition commands deal with the sound, light touch and ultrasonic robot sensors.

Fig. 1 An indicative program with the tangible subsystem T_ProRob

For the construction of this system, low-cost D9 and D25 connectors with PIC18F2620 and PIC18F4550 Microchip Technology Inc microcontrollers have been used. The program starts when the user plugs on the master box the command cubes in order to form the program structure. Then, by pushing the run button, the master box initiates the communication among the connected cubes. The communication between the programming cubes is based on the RS232 protocol. Each cube communicates with the two neighboring cubes. The master box sends data to the first cube and receives data only from the last one in the line. When the master box wants to read the programming structure, it sends the appropriate reading command to the first cube which, in turn, forward the command and its id to the next cube. Each subsequent cube adds its own id to the information packet and forward it to the following cube. Eventually, the last cube returns to the master box all the accumulated ids as a respond to the reading command. The next task which is undertaken by the master box is to send the program to a remote computer using Bluetooth or RS 232. The computer records in a database information about the commands and parameters that have been used and also statistical data concerning the program which was created by the user. Once the computer finishes the recording and compilation, the program is sent for execution to the Lego NXT robot using Bluetooth connection.

Due to the fact that all communications are bidirectional, increased system interaction with the users is supported. As the program is running, the robot can, for example, inform the condition command cube that the result of a measurement was positive. Then, the cube informs the user by turning on the corresponding LED. Moreover, the user knows, in synchronous mode, a potentially "wrong" (non-acceptable) parameter connection through an indication on the parameter cube. Finally, the systems itself sets the appropriate constraints on the users [43]. For instance, it is impossible to connect the blocks in the other way round.

For the purpose of our study, we decided to use the RS232 cable (instead of Bluetooth connection) to connect the master box to the PC.

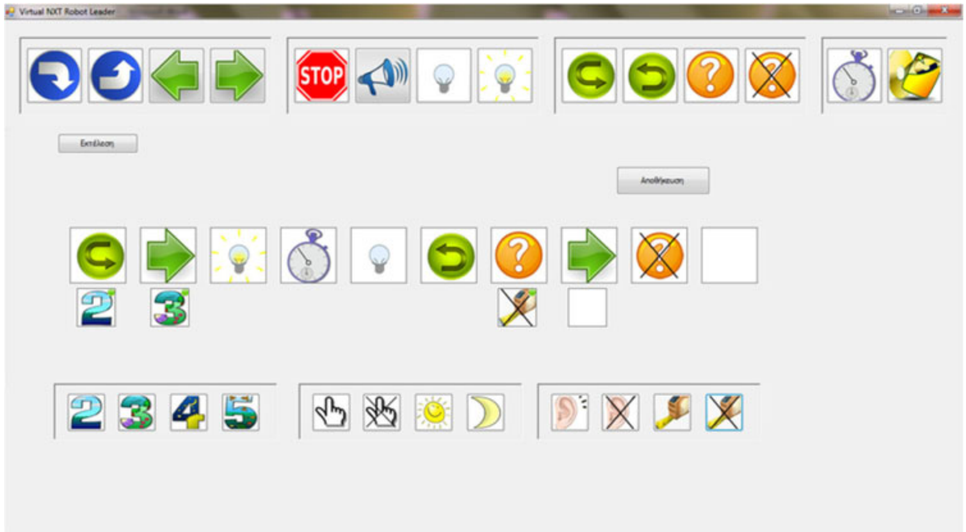

Fig. 2 An indicative program with the graphical interface V_ProRob

3.3 Graphical interface

V_ProRob (graphical) was designed as a T_ProRob reliable graphical isomorphic equivalent, that is, offering onscreen the same features and operations, as shown in Fig. 2. Users can create a program sequence by arranging the available commands and parameters (with 'drag and drop' interaction technique). The bidirectional communication, between robot and graphical environment, is achieved using Bluetooth connection and allows the subsystem to provide feedback to the users over the icons of the commands and parameters much like the tangible interface does. Finally, the graphical system is connected to a database to record details of the program that has been constructed by the user.

4 Method

4.1 Participants

The study was conducted during a 2-month period at the first experimental elementary school of the Aristotle University of Thessaloniki and the Dumbo kindergarten in Langada, Thessaloniki Greece. Sixty-one children of three age groups participated in the study (see Table 1).

Table 1 Participants

	5–6 years old		7–8 years old		11–12 years old	
	Boys	Girls	Boys	Girls	Boys	Girls
	11	7	16	11	9	7
Total	18		27		16	

Fig. 3 Two children programming the robot in Dumbo kindergarten

All children volunteered to participate as part of their everyday school activities, and they were randomly assigned to work in same age dyads. Totally there were formed 14 boy–boy dyads, 9 girl–girl dyads and 7 mixed (boy–girl) dyads. One child participated alone in the activity. All participating children spoke Greek as their native language. It is worth mentioning that in both schools, there was a course about computers and all children had some familiarity with the mouse.

4.2 Setting

Experiments were conducted in classrooms that were offered by schools for this purpose (Fig. 3). The classrooms were adequately arranged so that the two systems were equally accessible for all children. The interview and the completion of the questionnaires were conducted in the same classroom, always in visual contact with the two systems.

4.3 Design

This study explored quantitative data by means of bivariate statistical tests and a 2×3 experimental design involving gender (boys and girls) and age (three age groups: 5–6, 7–8 and 11–12 years) by implementing a two-way ANOVA.

The dependent measures of the study are students' *first-sight preference (FSP)*, *enjoyment* and *easiness-to-use*. The study had seven distinct phases: recording of the participants' profile, systems use introduction, interaction with one system (two specific tasks), interaction with the other system (two tasks with similar level of difficulty with the previous ones), free sequential interaction with both systems and completion of the questionnaires. Moreover, data from observations and interviews were analyzed.

4.4 Procedure

The activity lasted about 1 h and 15 min for each dyad. The children, guided by the researcher, first filled out the questionnaires about their age, gender, familiarity with computers and computer programming knowledge.

Then, the NXT Lego robot was presented and the researcher asked them which of the two user interfaces (tangible or graphical) they would prefer to use in order to start programming the robot. The answer to this question was recorded as the first-sight preference.

Following a simple scenario, the researcher presented to the children how they could use the programming blocks in both systems. To rule out any possible sequence effect and apply a counterbalanced presentation, we selected as presentation unit not the whole scenario, but the smaller programming steps in the scenario. This means that, instead of presenting the scenario using first one system (say, the graphical interface) and then the other (the tangible), we focused on small steps (for example, "go forward," "turn left," etc.) explaining to the children each step using successively the two systems. Even further, for each next dyad, we altered the order of using the systems for presenting the programming steps. After the end of the presentation, we asked the children to declare which system they enjoyed the most. This was the first measurement of the enjoyment variable.

We then assigned the children two missions that the NXT robot had to accomplish. The first mission was a simple sequential program up to five commands which involved cubes such as "move forward/backward," "turn on/off the light," "make a sound." The second mission was a more advanced sequential program with parameter. It was up to six commands and involved cubes such as "move forward/backward," "turn right/left" "turn on/off the light," "make a sound." Children were asked to create the respective two programs using only one interface (selected so that half of the dyads started programming using the graphical interface and the other half using the tangible). Next, we asked children to program two more, of similar difficulty level, robot missions using the other interface. So, the children had the chance to develop instruction sequences and interact with both systems. At the end of this activity, the researcher asked each child which of the two systems enjoyed the most. This was the second measurement of the enjoyment variable.

Then, the two children were free to perform robot programming two more times using each system successively. Right after, the researcher took away each child at a different table and handed the questionnaire and instructions on how to answer it. Finally, children were also asked to justify their answers, and this was recorded on a separate form.

4.5 Qualitative data collection methodology

Qualitative data were collected employing a twofold methodology approach: (1) structured observation and (2) student interviews. All data were collected by two subject–matter experts in the form of observation notes. In detail:

1. Structured observation: while interacting with the user interfaces, two researchers collected data that emerged from children's interaction. Data were obtained: (1) from the discussions between the students, (2) personal observations that focused on the difficulties that the children faced.
2. Interviewing: after completing their questionnaire, students were interviewed on their experience (semi-structured interview). Our main effort was to validate and better understand the data collected from the questionnaire and the observations. So, students were asked to give further details about their experience and comment on the points we believed needed clarification. These data being correlated with previously recorded data offered opportunity for confirmation and fine-tuning of the resulting conclusions.

4.6 Quantitative measurements

Three dependent variables operationalizing children's subjective viewpoint on the two systems were measured, namely *first-sight preference* (the most attractive system), *enjoyment* (system they liked the most) and *easiness-to-use* (the easiest system to be used). The data collection procedure employed a method based on Fun Toolkit [44]. For each question, the children had to answer a Fun Shorter and an Again and Again Table. In this method, the answers are double checked in order to enhance reliability. In the Fun Shorter, children provided a pictorial answer, placing the picture of each system in the appropriate cells of answer table. This way the children declared, for example, which system was the most enjoyable and which the least. With the Again and Again Table, children ticked their choice in a three-point Likert-type questionnaire. This way the children declared, for example, if the graphical system was very easy, easy or little easy-to-use.

5 Results

5.1 Quantitative analysis

Table 2 presents the percent frequencies of the children's preferences regarding the tangible and graphical user interfaces.

For the entire sample, the tangible interface was more likely to be selected as the children's first-sight preference (FSP) (however without statistical significance), while it was characterized as more enjoyable and easier to use (both statistically significant, $p < 0.01$ and $p < 0.05$, respectively).

5.1.1 First-sight preference/enjoyment variable

Examining gender differences, it was found that girls showed statistically significant higher *FSP* for the tangible interface ($\chi^2 = 4.24$, $p < 0.05$). No team synthesis or age effects were observed in relation with FSP.

Enjoyment was measured at three successive points in time: (a) before direct interaction (Enjoyment 1), (b) after activities upon tasks (Enjoyment 2) and (c) at the end of all activities (Enjoyment 3). The percent frequencies of children's choices are presented as a function of time for the three age categories in Fig. 4.

During the session, enjoyment is higher for the tangible and these differences are statistically significant with chi-square ($p < 0.05$) in all cases except *Enjoyment 1* for the 5–6 age group. Focusing on the frequencies of pupils' responses at the end of the session (*Enjoyment 3*), the differences in enjoyment at various group ages are statistically significant (e.g., for the total sample $\chi^2 = 21.6$, $p < 0.01$; for age 5–6 $\chi^2 = 4.76$, $p < 0.05$; for the age 7–8 $\chi^2 = 8.33$, $p < 0.01$; for the age 11–12 $\chi^2 = 9.00$, $p < 0.01$). Also, the final preference in tangible over graphical is statistically significant for the two genders (boys: $\chi^2 = 15.11$, $p < 0.01$; girls: $\chi^2 = 6.71$, $p < 0.01$).

No team synthesis, gender or age effects were observed on enjoyment.

Table 2 Percent frequencies of children's preferences between the two interfaces

	Tangible	Graphical
First-sight preference (FSP)	60.7	39.3
Most enjoyable	80.0**	20.0
Easier to use	64.4*	35.6

* $p < 0.05$; ** $p < 0.01$

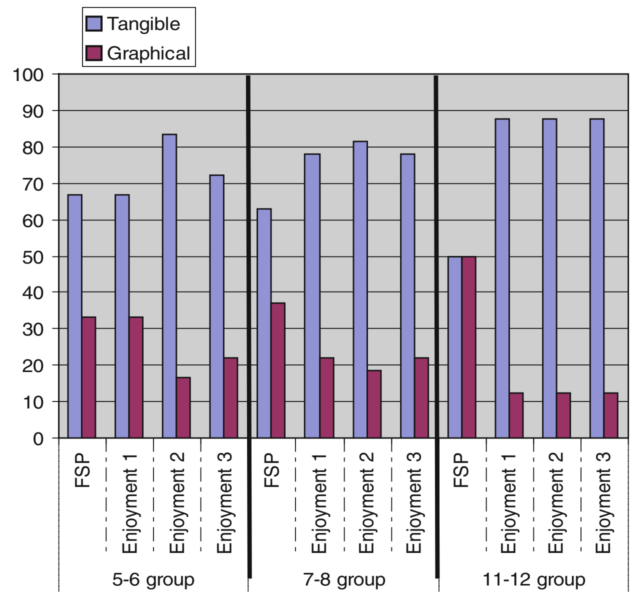

Fig. 4 Percent frequencies of children's choices for tangible and graphical, for FSP and *enjoyment*, during the course of session

5.1.2 Easy-to-use variable

The analysis of pupils' responses to the items asking which interface was easier to use revealed an interesting effect. The tangible interface was found to be easier to use for the younger children and this effect is changing with age.

Accordingly, the *easy-to-use* variable appears to decrease in elder ages. Figure 5 depicts the effect, which is statistically significant, (Cramer's $V = 0.61$, $p < 0.0001$).

Since these effects on tangible were measured relatively to graphical, any positive or negative changes across the categories of the independent variables could be considered as negative or positive changes, respectively, for the graphical case. However, the *easiness-to-use* is not affected by gender or team synthesis

5.1.3 Effect of gender and age on rating easy-to-use

In order to further explore for possible interaction effects of independent variables, gender and age on tangible *easy-to-use* rating, a two-way ANOVA was implemented. The ANOVA revealed a significant effect of age ($p = 0.025$), while the effect of gender is insignificant ($p = 0.098$). However, a significant interaction effect between gender

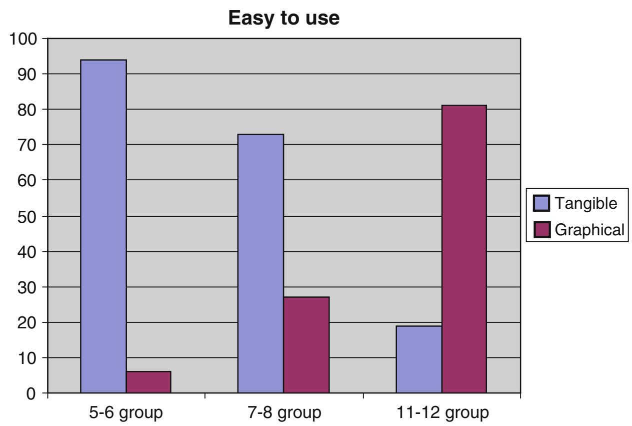

Fig. 5 The easy-to-use variable for tangible and graphical as a function of age group

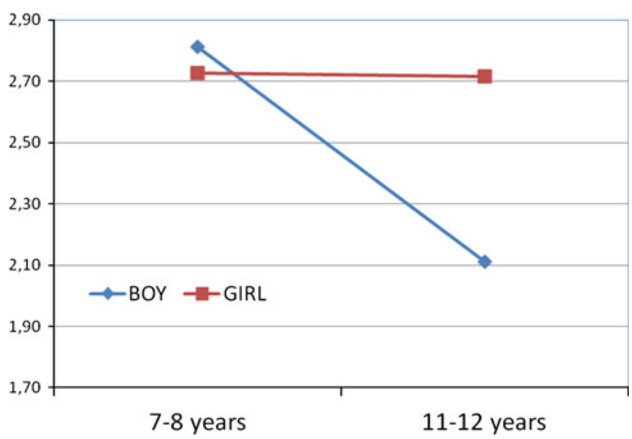

Fig. 6 Factorial ANOVA for age and gender on tangible

and age ($p = 0.030$) exists. The results of the above factorial design are depicted graphically in Fig. 6 and show that for elder boys contrary to the girls, their *easiness-to-use* rating is degreased for the tangible. The age category 5–6 years is not shown here because children responses were not differentiated from age category 7 to 8 and between genders.

5.2 Observations and interviews

In this section, we present the major findings from observations and students' interviews. The codes "O" and "I" are used when referring to observations and interviews, respectively, throughout the next sections.

Both systems worked quite well and helped children to successfully complete the programming tasks. The assigned tasks were on purpose selected to be easily accomplished by the children, within the available time, so that they were successful and satisfied by the outcome. Indeed, the goal to complete successfully the programming process was satisfied for all groups and conditions. All age groups, especially the younger, seem to be attracted from the robot and were engaged with the tasks. The children, particularly during the free interaction period, showed high interest to learn all the available commands and features.

5.2.1 Age group: 5–6

For this group, the interaction with the tangible system was a collaborative process where both children with four hands worked together on the same task (O1). A few arguments were recorded when both kids wanted to press the sole execution button (O2). Although the kids were familiar with the mouse, we noticed small problems when using the virtual system, mostly with the drag and drop process (O3). Students' collaboration started in some cases with a dispute about who should control the mouse (O4). In all cases, team self-organization solved the problem with the sharing of the mouse between the kids. However, in some cases, "the observer" kid lost his/her interest and start looking around and in three cases went back to interact with the tangibles (O5).

Interviews revealed some interesting factors that influenced the children's preference, such as: (a) the similarity of the tangibles with other games they had (LEGO bricks, etc.) (I1), (b) the connection affordance among the cubes, which seemed to be a pleasurable and easy process, "*I liked to play with the cubes because it was easy to connect them*" (I2), and (c) the difficulties they faced with the mouse (I3) "*it is quickly to connect than move the pictures on the computer with mouse.*"

5.2.2 Age group: 7–8

In this group, the problems with "drag and drop" process in the graphical system were significantly reduced (O6). The kids were better users, and we noticed that they were able to easily understand and use parameters with both systems. Children used to share the mouse with fewer arguments and were better self-organized (O7). Again, in some cases with the graphical system, "the observer" kid loosed his/her interest (O8), while when using the tangibles, both children engaged and four hands worked together (O9). Noticeably, three girls in the beginning of the graphical session refused to interact with the virtual system. Their explanation was that: "*I want to work with the tangible because I want to do it myself. Working with the computer, the computer does it for me*" (O10).

The interview findings were modified slightly compared to the previous group age. We concluded that the factors influencing the children's preference were as follows: (a) the similarity of the tangibles with other games like puzzles as above (I4), (b) the assembly process of the cubes which was found to be more pleasurable and easy (I5), (c) the difficulties they faced with the mouse (I6), (d) their small, but existing experience with other computer games (I7) "*I prefer to program the robot with computer because I can play other games and surf to the internet for a while.*"

5.2.3 Age group: 11–12

This group exhibited obvious familiarity with mouse interface (O11). The children exhibited high interest for the tangible system, and during the free interaction, they used a lot of commands and created large programs with both graphical and tangible systems. They, also, used easily repetition (loop) and conditional structure, showing high understanding and engagement. In two cases while using both systems, the children with their initiative used extra paper to make some drawing that resembled flow chart.

During the interview, children stated more sophisticated explanations for their preferences. The factors influencing their preferences were as follows: (a) the novelty of the tangibles—"*we prefer the tangible because although we have computer at home it is the first time we have the chance to work with something like this*" (I8), (b) the ability to better see, touch, assembly, and organize collaboratively the tangible commands (I9), (c) the familiarity with the mouse, the speed and the easiness they could use it (I10), (d) their experience with other computer games (I11) and (e) the convenience that is offered by a graphical system (I12)—"*I preferred the computer because I can change easily everything, there is no need to have a long table and if I want to stop, I just turn off the computer.*"

6 Discussion

In this paper, we used the PROTEAS kit to study comparatively children's preferences regarding the use of a tangible and an isomorphic graphical interface to program a robot. This comparison involved three dependent variables, namely *first-sight preference (attractiveness)*, *enjoyment* and *easiness-to-use*, which were examined as a function of independent variables: age and gender.

The results illustrate how the above variables might be varying by children's age and gender, when they interact with the two interfaces under investigation. Our aim is to make a contribution to the ongoing investigations on tangibles and inspire TUI researchers to further explore specific contexts in programming activities for children. In addition, teachers and programming instructors could benefit from the present work be taking into account children's preferences and find new directions to teaching by taking advantage of the unique features of TUIs in real classrooms. Under this perspective, our results are informative for designers and researchers in children–computer interaction (CCI) to better understand children's thoughts and preferences about different interface modes and computing [44].

6.1 First-sight preference

Children's *FSP,* which can be considered as a measure of the attractiveness of the interface, showed a trend toward the tangible interface that was not significant for the whole sample. However, this trend was stronger and statistically significant for girls. Our quantitative results are also supported by the observation (O10) and interview data [(I1),(I4),(I8)] showing that tangibles as a programming tool is more attractive for these ages because they look more familiar and innovative for the children.

Our qualitative results reinforce observation data from other studies suggesting that gender and application-type differences may exist [45]. Our quantitative results are also consistent with two other studies, where gender effects have been found in comparisons between different interfaces [5, 40]. Particularly, Horn et al. [23, 40] who compared the use of a passive tangible against a graphical programming language reported that in informal learning environment tangible interface was more inviting for girls.

6.2 Enjoyment

Regarding *enjoyment*, children's self-reports indicate that tangible environment is more enjoyable. This evidence was equally strong and apparent in all age groups, for both genders, and it is consistent in all measurements that took place during the interaction process. Particularly notable is the oldest children preference which remains stable (Fig. 4) during all stages of the session, while in younger children, although they found tangibles more enjoyable, their opinion was unstable over time.

A possible justification for the children's increased enjoyment with tangibles can be found in their recorded interviews elements [(I2),(I5),(I9)] which show that the manipulation of the physical objects along with the increased ability to see and organize the working plane with the collaborators may increase enjoyment. However, our results are not in line with those presented by Xie et al. [5], who reported that in a comparison with three user interfaces (physical, tangible and graphical) in jigsaw puzzle activities, children's self-reports of enjoyment were similar. This could be explained as an effect of the specific domain [30].

Our results that concern enjoyment indicate that the tangible interface, in the context of programming activities, has an advantage and supports the hypothesis that tangible programming may be more enjoyable and engaging than graphical programming. Moreover, tangible programming through enjoyment can reinforce intrinsic motivation which is crucial to cognitive and social development [46].

6.3 Easiness-to-use

Regarding *easiness-to-use*, the results interestingly indicate that the tangible interface is evaluated as easier than the graphical, but this holds only for the younger children. These results partially support the assumption that tangibles, when used for introductory programming, are easier to use and can reduce the age limit for participation. On the contrary, for older children, the tangible even though is more enjoyable, it is not considered as the easiest-to-use environment. This could be explained by their increased familiarization with computers and the use of mouse.

The above are indicated by the observation [(O3),(O6),(O11)] and are justified by the interview elements [(I3),(I6),(I7),(I10),(I11)]. These elements indicate that on the one hand, younger children faced some problems using the mouse, and on the other hand, elder children have gained considerable experience with computers (by playing games, etc.), and thus, they find the graphical interface with the mouse easier to use.

One surprising result was the interaction effect between gender and age indicated by ANOVA. In order to explain this finding, one may look at some of the observation elements that were recorded during the interaction. It was noted that some boys in the 11–12 group reported that the graphical interface was more convenient and thus easier to use, because they did not have to settle anything afterward when using it at home (I11). On the contrary, if they were to use the tangible, they would have also to put back the blocks into their original place after use. Interestingly, this concerned only the boys in this particular age group, while the girls overlooked this matter by stating that settling the blocks was not an issue. The results of the present study relevant to the *easiness-to-use* confirm and simultaneously extend those reported by Xie et al. [5] who observed that children's (aged 7–9 years old) interaction with physical pieces was easier than interacting with the mouse. Other observation elements, such as [(O1),(O4),(O5),(O8),(O9)], recorded during the interaction, support the view that the tangible interface offered more opportunities for equal participation. Equal participation, in turn, seems to reduce antagonism between the members of the team [(O2),(O4),(O7)]. These observations support the findings reported by Horn et al. [40] and altogether suggest that tangibles in introductory programming activities may foster improved conditions for partners' active collaboration.

Overall, we conclude that tangibles have certain benefits in comparison with graphical environments, but this effect may be altered depending on age. It is also possible that tangibles are beneficial in certain domains and not for all. We argue that the user's age and the specific domain, as revealed in this study and those presented in the background section, are important factors in determining whether tangibles are worth employing or not. Our result support the hypotheses that the use of tangibles may has certain advantages, such as improvement of accessibility, reduction of the age threshold of participation, rise of the invitation to interact with, enjoyment and maybe enhancing collaboration [26]. Finally, we suggest that possibly a fluid and balanced transaction between the tangible and graphical interface, in relation to the age and the user experience, may be a beneficial approach in certain domains [40].

7 Conclusion

This study explored children's opinions and preferences regarding two subsystems of the PROTEAS kit, a tangible and an isomorphic graphical. Both subsystems were used by the children to accomplish introductory programming activities in counterbalanced processes and have shown to be quite effective and reliable.

The results indicated that the tangible interface was more attractive (*FSP*) especially for girls, more enjoyable and easier to be used by younger children. On the contrary, older children, who were more experienced with computers, considered the graphical system as easier. Factors that seem to have influenced children's preferences include the prior familiarity with the tangibles (from other games experiences), the novelty of the actions that a user can accomplish and the assembly process of the tangible elements with hands. On the other hand, the experience with computers, the speed and the convenience that a graphical environment offers seemed to attract older children.

Moreover, we recorded instances where the cooperation between the members of the team offered more opportunities for equal participation when using tangibles, while the control from one child seemed to reduce the interest of the other when using the graphical interface. In any case, this observation needs further exploration.

8 Future research

Our immediate plan is to extend our research and examine these effects in a long-term study. In addition, we intend to explore the advantages of tangible interfaces in relation to learning outcomes and the effects of the nature and the complexity of the tasks, size of the team and the level of previous experience among members of the same age group. Furthermore, it is our interest to investigate the different opportunities for participation offered by the two user interfaces, the impact of tangible tools on issue such as peer interaction and knowledge construction and the possibility of training individuals with special needs, such as blindness or kinetic problems.

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