Control heuristics for educational robots: a pilot study

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Abstract. Control technology gathers a set of specific devices that can be described by means of two features: *transparency* (i.e. programmability) and *interactivity* (i.e. immediacy of feedback). The main concern of this paper is the interactivity feature, while transparency is included as a secondary objective. Two studies are described: an exploratory inquiry on the command of a Lynx AL5A robotic arm by 6-10 years old children and a pilot study on the programming of a Lego Mindstorm NXT® robot by children of the same age. The aim of the two studies is to investigate and classify control heuristics as applied when approaching the control of a robot at an early age. Results show that three main types of heuristic can be pointed out (procedural, conceptual, and meta-cognitive). Moreover, different degrees of transparency and interactivity seem to lead to different kinds of control heuristics, a result that encourages a further comparative study in this sense.

Keywords: control technology, educational robotics kits, programming heuristics, transparency, interactivity

1. Introduction: Control technology

Technological kits are longstanding tools in pre-schooling and schooling education [1]. Already in the '90s the main authors in this field were able to trace the history of such devices, by operating a distinction between first-generation kits that allowed children to build structures, second-generation kits that allowed them to build mechanisms, and third-generation kits that allow children to build behaviors [2]. Robotics kits belong to this third generation [3], [4]. As a specific kind of educational robots – beside humanoid robot, animat and virtual robots – they are conceived as constructable and programmable devices. That is, children can, opportunely guided by manuals and educators, shape their robot, conceive its mechanisms and give it instructions. In the words of Resnick, they can "build its behavior". For this reason robotics kits have, according to a number of authors, a high educative potential of robotics kits with relation to other kind of educational robots that are not - or that are partially - constructable and programmable [see for a review 5]. The simple fact that children are free to determine almost entirely the functioning of their robot – except for the electronic equipment that in most of the cases is a ready-to-use part of the kit – gives them access to the hidden side of technology, it enables them to *control* the robot (e.g., to program its sensors and its actuators).

Control technology is thus a recent, strong innovation in the skyline of educational technology [6]. Particularly as applied to robotics, control technology ranges from *autonomous* to *remotely* controlled robots, according to how much the robot is in command of the user. In *remote control*, an operator commands the robot by a radio system, an internet system or other: he perceives the environment, he takes decision, and he sends instructions to the robot [7]. In *autonomous control* on the contrary, robot do not need a continuous human guidance: the user programs it to sense the environment to take decisions and to act. Once the program is downloaded on the robot or sent to the robot by wireless communication, it can, for instance, behave in unstructured environment [8]. Robotics kits can exploit both these type of control, as we shall see in the next section. Furthermore, recent researches in educational robotics, propose new kinds of control in which the distance between the command and the robot is more and more reduced so to create a high form of integration between software and hardware [9]. A brief outline of such different kinds of control is proposed in the following section.

1.1 Robotics kits as control technology

We can point out two main features of robotics kits as control technology: *transparency* and *interactivity*.

Transparency has been a subject of debate since the onset of educational robotics [10]. The birth itself of a programmable tool was an invitation for children to go beyond the act of pushing buttons on computers, an invitation to "play piano, not stereos" [11], to conceive control in terms of creation rather than opaque use. The shift from black-box systems (i.e., non transparent devices, that cannot be programmed) to white-box systems

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(i.e., transparent programmable devices) was a turning point in technology kits triggered by educational robotics [12]. A black-and-white box system followed, which, as the name suggests, mixed the previous two systems in order to overcome difficulties that the children encountered with white-box approach when programming a robot from scratch [13].

Interactivity is the second important feature of control technology. As soon as robotics kits have been introduced in classrooms[1], a difference could be remarked between a new dynamic in which children could manipulate by testing and having an immediate and personalized feedback, and traditional lesson where feedback is often delayed and collectively delivered by a teacher [14].

Three kinds of robotics kits can be considered exemplary with respect to the interactivity and the transparency feature of control technology. Let's consider at first **Lego robotics kits**. This kind of kit, today broadly diffused in educational settings, can be both remotely and autonomously controlled: simple programs can be created using the menu on the NXT processor. More complicated programs can be downloaded using an usb port or wirelessly using a bluetooth. Mobile phones can be used as a remote control[2]. For this kind of kit we thus have a high level of transparency. Interactivity is also at play: if we imagine a child studying movements and forces on a workbook, doing its exercises in class or at home, and waiting for teacher's correction vs. a child programming a robot to climb a slope, and executing the program to test if it works, we would agree that the difference in terms of feedback's time is considerable. Let's now consider a second kind of educational kit for robot programming: **TERN** [15]. In this case we have a set of wooden blocks on which different icons are stuck (icons that symbolize the beginning and the end of the program, the sensors, the motors, the parameters, and the flux). Children can thus assemble the blocks to create their own program that will consist in a tangible chain. This chain is then read by the computer through a camera, and translated into a digital program by dedicated software. The program is subsequently executed on a compatible robot (Lego or other). Here again we have full transparency, but interactivity might be different: though tangible bocks create a direct physical manipulation of code, the passage from physical code to virtual code might imply a longer feedback time. A third relevant example is that one of **modular robotics**. Different kits of this type exist: roblocks, cubelets, polybot[3], etc. As mentioned in the previous section, modular robotics aim at reducing distances between commands and robot. More precisely, in modular robotics the robot is the program: programs are embedded in electronic cubes (light cube, sound cube, motion cube, etc. with a specific cube having the function of potentiometer to modify the parameters of the other cubes) that can be combined to build a behavior, so that complex behavior can be observed emerging from simple behaviors. Hence, here transparency and interactivity are inverted: since cubes do not require programming and executing, but only assembling, children can experiment a high interactivity with a very short feedback time. On the contrary, transparency is low, since these blocks are not conceived to be programmed.

Overall, these three robotics kits, described according to the chronological order by which they have been developed in the respective laboratories[4], seem to trace a progression from high transparency and average interactivity to low transparency and high interactivity. We might say that in this sense educational technology seem to mirror a trend of nowadays general technology whose design is based on a predominance of interactivity over transparency (let's think about Apple products, tactile devices, etc.). A pertinent question in this sense would thus be whether this progression is an evolution towards more efficient control system and what a more efficient control system is meant to be: is it an easier-to-use system (e.g., a system that does not require programming but directly assembling robotics modules like cubelets)? Or is it a more transparent system (e.g., a system that allows programming to determine the behavior of the robot)?

However, before undertaking a comparative study on the three mentioned robotics kits and on the extent to which transparency and interactivity affect the mastering of this technology, we believe it important to first identify the approaches children resort to when they have to control a specific type of robot to solve a problem.

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[1] The first educational robot was a floor turtle named "Irving" created by Paul Wexelblat at BBNat implemented at was demonstrated at the Muzzey Junior High in Lexington, Massachusetts. "Irving" was endowed with bump sensors and could give audio feedback with a bell. It was a Logo-controlled robot connected to the computer via hardwire lines. Lately developed by S. Papert, this robot was used to teach children to set commands for four directions (forward or back, right or left), to sound its horn, to draw by an attached pen, and to sense whether contact sensors on its antennas encountered an obstacle.

[2] For an example of remote control with a Lego robot, see: http://homepage.mac.com/mrlaurie/robo/robots/remote/remotebots.html; for an example of autonomous control with Lego robot, see: http://www.legoengineering.com

[3] For Cubelets see: http://www.modrobotics.com/; for Polybot see: http://ieeexplore.ieee.org/xpl/freeabs_all.jsp?arnumber=981854

[4] Lego robots have been developed thanks to a collaboration between Lego (http://www.lego.com/en-us/Default.aspx) and MIT Lab (http://www.media.mit.edu/). TERN has been created by Michael Horn at the Tufts University and it is currently being developed as part of an NSF-funded collaboration between the Tufts Developmental Technologies Research Group and the Tufts Human Computer Interaction Lab (http://hci.cs.tufts.edu/tern/). Roblocks were created at the Computational Design Laboratory of Carnegie Mellon University (http://code.arc.cmu.edu/). Cubelets have been conceived by Modular Robotics, a company that is a by-product of Carnegie Mellon University (http://www.modrobotics.com/). Polybot is the result of researches conducted at the Department of Computer and Information Science at Polytechnic University of New

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To our knowledge there is no study devoted to the impact of control system on children general understanding of the robotics kits functioning in the current literature. More in detail, if several studies document robotics-based courses that focus on developing awareness of technology (e.g., exploring its impact on society), competence in technology (e.g., learning about electronics, programming etc.) capability in technology (see [16]), we have found no available study on what are the basis of such competences and capabilities: control heuristics.

For this reason, we propose an exploratory inquiry and a pilot study conceived to observe how children control a robot in order to point out the different heuristics of control (i.e. different strategies of programming) that can emerge when controlling one specific type of robot (Lego Mindstorm NXT ®).

1.2 Children heuristics of robot control

Heuristics can be defined as general rule or strategies that guide our actions towards a procedure, and that take into account bottom-up as well as top-down information that is contextual constraints as well as final goal of the procedure [17].

Since the arrival of educational robots, a number of studies have been dedicated to children strategies in acquisition of programming skills. Observations on trial and error vs. purposeful strategies [18], on syntactic vs. semantic errors, on common debugging methods [19] have revealed interesting information on how children get to master simple to complex program. For example trial and error strategies seem to be replaced by purposeful strategies as cognitive dissonances appear [20]. Furthermore, although semantic errors are frequent, the very source of difficulty in the first stages of programming learning is syntax [21]. And, when debugging, children seem to employ either a serial or a reasoned search of errors, that is, either they look for the error sequentially, either they try to figure out the cause of the malfunction and consequently to localize the error in a precise chunk of the program.

Altogether, these results have suggested that deeper studies are required in order to grasp the cognitive mechanisms understanding children programming. If a considerable amount of works has been dedicated to the subject of novice/expert acquisition of programming skill [22], we cannot simply consider a child as a novice but as a specific kind of novice, due to the continuous unfolding of his/her cognitive functions [23]. Deeper studies are also required due to the onset of new kinds of robots that propose novel forms of hardware-software integration that, as mentioned in previous section, imply novel forms of control based on the interplay between transparency and interactivity.

1.3 Observing and classifying control heuristics during a robotic competition: an exploratory inquiry

We have thus conducted an exploratory inquiry on children control heuristics during a recent robotic competition[5]. Besides the main activity of this competition - where different teams were engaged in scored matches to solve a given problem and achieve the best score - various stands of educational robotics were available to test several robotic devices, learn to program and face some micro-challenges. Our stand proposed a simple activity with a Lynx AL5A robotic arm (Fig.1a) composed by a shoulder fixed on a table, a forearm, a harm, a wrist, a hand-gripper, an Arduino card, a motor for each of the five components, and a knob for each motor (all the five knobs being identical in their appearance)[6]. Volunteers among children at the competition or in the public could manipulate the robotic arm in order to grasp, lift and drop objects on the table. No programming was done, commands were given by knobs manipulation. This kind of robotic device is thus not characterized by a high transparency, as its control requires the mere handling of knobs for instructing the arm to move along four directions (up, down, left, right) and to open/close the hand gripper. On the contrary, the fact that children can observe the effects of their commands in real time when manipulating the knobs engenders a high interactivity.

Forty children (from 6 to 10 years old) have been volunteers for this activity during the all-day-long competition. Each trial for each child lasted 10 minutes. Throughout the forty trials we had the occasion to observe and classify children heuristics of command. Three heuristics in particular were observed: (i) children used the commands in order to accomplish the task of grasping, lifting and dropping an object (60%); (ii) children used the commands in order to understand their functioning, and then to accomplish the task (30%); (iii) children use the commands in order to explore the functioning of the robotic arm - i.e. what it can do and what he cannot do (10%).

In order to sharpen the definition of such heuristics we took inspiration from the classification of knowledge proposed by Anderson [24], and we named the three heuristics (i) *procedural-oriented heuristics*, (ii) *conceptual- oriented* (iii) *metacognitive-oriented*.

According to Anderson et al., when dealing with a task children exploit a set of knowledge concerning the "what" and a set of knowledge concerning the "how". To briefly recall the theory of Anderson [24] conceptual knowledge is a *what* knowledge and it concerns concepts, categories, principles and models. Procedural

[5] First Lego League 2012, see: http://www.firstlegoleague.org/

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knowledge and metacognitive knowledge are *how* knowledge and they concern respectively procedures and knowledge of own's cognition. The three heuristics are thus operationalized as it follows:

1) *procedural-oriented heuristics* : children uses commands in order to accomplish the task
2) *conceptual-oriented heuristics*: children uses the commands in order to understand their functioning, and then to accomplish the task
3) *meta-cognitive-oriented heuristics*: children use the commands in order to explore the functioning of the robot - i.e. what he can do and what he cannot do.

We thus rely on Anderson classification in order to highlight that children using the *procedural-oriented heuristics* show in fact more attention to the task itself in terms of to-be-achieved goal, while children using *conceptual-oriented* and *meta-cognitive-oriented* heuristics, seem to be more interested in how to realize the task.

This first exploratory inquiry has been used as a basis to further investigate children control heuristics in tasks where programs, and not only knobs commands, was demanded. In the following section, an outline of the aims, hypothesis, procedure and results of the concerned pilot study.

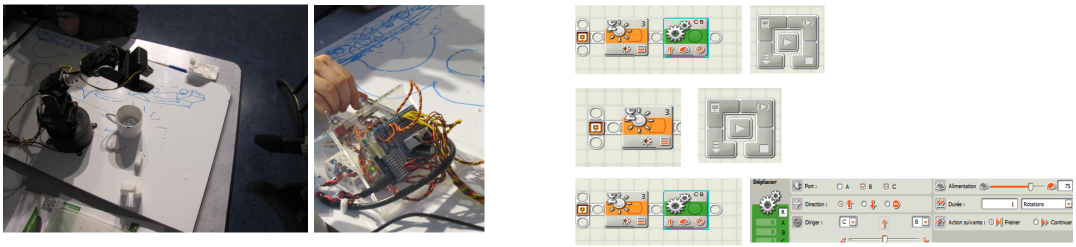

Fig. 1. On the left picture the robot arm the pupils were using during the First Lego League (Fig 1a). On the right picture some screen shots that illustrate the programming based on the three different heuristics (from the top to the bottom: procedural, conceptual, and meta-cognitive) that pupils were using in the pilot study (Fig.1b).

2 The pilot study

2.1 Aims of the study

Our study is about programming heuristics implemented by children when approaching for the first time a robot that is characterized by a specific control mode. The activities were specifically conceived in joint frame which included the educational seminars of *Carrefour Numérique at Cité des Sciences et de l'Industrie* in Paris[7], and the Pri-Sci-Net European Project[8]. The aim of educational seminars of *Carrefour Numérique* is science and technology divulgation to a broad public. The objective of Pri-Sci-Net European Project is the implementing of Inquiry Based Learning (IBL) for Science Education at primary school. Lego Mindstorm NXT ® is a robotic kit that includes a programming interface with graphic code, that is drag and drop icons instead of commands lines are used to program sensors and actuators.

The interest is thus: first to observe which programming heuristics are spontaneously developed by primary school pupils when approaching the control of this kind of robotic kits, second, to observe if the proposed task is perceived as easy or difficult, and how heuristics type and perceived difficulty vary with relation to age.

Age is an important issue in educational technology. An appropriate education cannot be regardless of what we know about important questions on developmental cognition [25]. For example, in educational technology the basic concern of which tool can fit specific educational objectives at which age can be declined in questions like the following by Casati [26]:

> Should we "expose" our children to "engineering settings" (complex Meccanos or Legos) so as to make them develop engineering capabilities which will give them a competitive edge as they grow up as sharp as the edge dividing native and non-native speakers of a language?[9]

Such questions are crucial to both understand children development and design good educational technology. Already robotics kits for different ages have been conceived for instance Lego WeDo® for children aged 5-8 and Lego Mindstorm NXT® for children from 8 years old. Both kits propose sensors control system with differences

[7] See: http://www.universcience.fr/fr/carrefour-numerique
[8] See: http://cordis.europa.eu/projects/100332_en.html

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in number and type[10]. Beyond that, we believe that further studies on children programming heuristics can tell us more about the cognitive profile of the child[11] and on how to exploit the semiotic potential of robotics tools. By semiotic potential of robotics we mean the double semiotic link that the artifact has with both the personal meanings that emerge from its use, and the knowledge evoked by that use of the tool [28] To this aim, our pilot study involved children of different ages (from 6 to 10 years old) using the same robot (Lego Mindstorm NXT®).

Difficulty of the task is a composite factor which also plays an important role in children mastering of an educational technology. For example, it is well known that declarative knowledge is mostly acquired after procedural knowledge, as a shift to a higher cognitive level is demanded when passing from a sequence of actions or procedure to the interiorization and reification of this procedure in terms of a concept [29]. Moreover, recent studies on young children approaching robots for the first time witness that when the task to be accomplished in interaction with the robot is perceived as easy children tend to use a technological perspective (i.e. they use a more technical vocabulary when posing questions, expressing remarks, talking with peers); the higher the difficulty of the task the more the children shifted to a psychological perspective (i.e. they use a more anthropomorphic vocabulary, for instance they attribute to the robot states that are normally attributed to humans like “he believes that”, “he has made a mistake”, etc.) [30]. Hence, in order to investigate the children understanding of a kit that they had never used before, we decompose this factor in two indicators of difficulty. The first indicator concerns children performances in the problem-solving (i.e., time of task completion and number of errors). The second one concerns children verbalization (i.e., ability to explain procedures, concepts and terms, using a technological vs. anthropomorphic vocabulary).

2.2 Predictions

Coherently with the aims of the study, we expect children showing three types of programming heuristics when approaching the control of the robot (Fig1b):

(i) Procedural-oriented heuristics: children program the entire sequence (the sequence being a chain of icons on the interface that allow to command sensors and actuators, e.g. “move forward if detected color is green”), then they execute the entire sequence

(ii) Conceptual-oriented heuristics: children program and execute parts of the sequence separately (e.g., “detect color”), in order to test them before passing to execute the entire sequence.

(iii) Metacognitive-oriented heuristics: children explore all the parameters of an icon or command (e.g., they explore the intensity parameter and the generate/do not generate light parameter of the light sensor) to understand its functioning before passing to solve the given task.

Regardless to participants’ age we expect to observe all the three types of heuristic, with heuristic (i) as predominant because it was the most observed within the exploratory inquiry during the robotics competition (see chapter 2). In particular we expect younger children using heuristic (ii) and (iii) less frequently than older children.

We also expect to register a variation of the occurrence of conceptual heuristics in the pilot study with relation to those registered in the robotic competition: due to the different transparency that characterizes the two robotic devices (see chapter 1 for Lego Mindstorm NXT ® and chapter 2 for Lynx AL5A robotic arm) a different effort to understand the functioning of each command before accomplishing the tasks (as it happens in the conceptual heuristic) might be registered.

Concerning the difficulty of the task we expect anthropomorphic language to be predominant if the task is perceived as difficult and technological language to be predominant if the task is perceived as easy. In particular we expect younger children making more errors, taking more time and using mostly anthropomorphic terms while older children should take less time, do less errors and more technological terms.

2.3 Participants and Material

Twenty-six children participated to the study - 17 boys and 9 girls-, 13 participants of 6-7 years old and 13 participants of 8-10 years old (med = 7.5). Children were divided in groups of three or two, with each group being accompanied by an educator who guided the activity and an experimenter who took note on an observational grid without intervening in the activity. No child had used a Lego robot before this experience.

Each group of children disposed of one Lego Mindstorm NXT® kit including light, sound, ultrasound and touch sensors, and one computer provided with Lego Software. Colored objects and objects of different dimensions

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[10] For instance, Lego WeDo® includes only a presence and a movement sensors and Lego Mindstorm NXT® contains light, sound, ultrousound, touch, temperature and rotation sensors.

[11] By cognitive profile of a child with relation to robotics technology we mean his/her age, logical skills, and preferential control heuristics [27]. This pilot study belongs to a broader study in which we observe children cognitive profile with relation to Lego robotic kits. In this paper we focus the discussion on a specific component of the cognitive profile that is

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where used for groups programming light sensors and ultrasound sensors. Pencils and papers were distributed to let children take notes of values detected by sensors (e.g. intensity of light when detecting a green object).

2.4 Procedure and data collection

The experience includes an introductive phase in which educators engage children in a debate on the difference between automats and robots by showing them images selected by the experimenters and encouraging them to explain why a certain image depicts an automat or a robot. Pre-existing knowledge on human behavior (i.e. the five senses and motricity), light (i.e. color spectrum), temperature (hot/cold objects) and sounds (sound sources) is evoked. This phase aims at investigating prior knowledge of children about robotics and to introduce them to a general understanding of the robot as a particular machine, which can be programmed to sense and act in order to accomplish multiple tasks according to the current status of the surroundings.

A second phase follows in which children are familiarized with execution of programs in a first moment (i.e. execution of programs that are already stored in the intelligent brick) and with programming/execution of programs in a second moment (e.g. the educator show the functioning of the main icons to program and execute on the interface, and explain them how to create a simple program). Then children are introduced to the task to make the robot react to given environmental information, for instance, to move forward if the light sensors detect a green object or to move backward if it detects a red object. Children are prompted to form group, with each group choosing the kind of sensor (either light, sound, ultrasound, or touch) they want to program. The educator shows them how to approach the task using two kinds of flux structure: “wait for” or “commutation”. For each of the two children are invited to have a programming trial. At the end of the two explications and after the two trials, children are again invited to program the sensor to detect further environmental information (i.e. other colors than red and green, other sounds, other distances, etc.). Once the task has been accomplished, children can have further trials or ask for a different sensor to program. Finally, all the groups are invited to a last debate about the appreciation of the activity and suggestion for a future activity.

Behavioral data are collected by the experimenters all along the activity: notes are collected during the introductive and the conclusive phase; actions, interactions and verbalizations are collected during the programming phase through observational grid[12]. A registering software (WebCam Studio) is used for collection of more fine-grained data (movements of the cursor on the screen as well as dialogues among children, and between children and educators) .

3 Results and Interpretation

Thirty trials have been tested (mean average: 2.5 trials each group, 1 trial each child) in the sample, with a completion time of the programming phase of 0.11:47 h (median) each group.

3.1 Which heuristics are spontaneously developed by children when approaching the control of robotic kits?

Overall results show that all the three heuristics are observed (Fig. 2), with each participant having applied more than one type of heuristic. Regardless to participants’ age, procedural heuristics are the more frequently observed (49%), immediately followed by the meta-cognitive heuristic (30%), and conceptual heuristic (21%).

A major difference can be remarked between procedural and conceptual heuristics (28%), than between procedural and meta-cognitive (19%) and between conceptual and meta-cognitive (9%). The considerable difference between procedural and conceptual heuristics is consistent with the main literature on the acquisition of procedural and declarative knowledge (see chapter 2). Furthermore, coherently with our hypothesis procedural heuristics are the most applied by children, i.e. they represent almost the half of the sampled data. Finally, a discrepancy is actually registered between the occurrence of conceptual and meta-cognitive heuristics, with the first one being more applied in the case of robotic arm and less applied in the case of Lego robot, and with the second one being more applied in the case of Lego robot and less applied in the case of robotic arm.

3.2 Do children use the same heuristics according to the age?

Differences in the distribution of the three experimental heuristics are observed according to the age of the participants (Fig. 3). A large use of procedural (50%) and conceptual (50%) heuristics is evident for both the groups. On the contrary, meta-cognitive heuristics are significantly more applied by 8-10 years old children (72.72%) than by 6-7 years (27.27%).

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These results confirm only partially our hypothesis: as predicted procedural heuristic seems to be largely exploited by the two groups of age and meta-cognitive heuristics is more exploited by the older group. However the expected difference concerning conceptual heuristic between the two groups was not registered, as it was on the contrary in the exploratory inquiry on the robotic arm. Moreover meta-cognitive heuristic have also been more exploited than with the robotic arm.

3.3 Is the problem perceived as easy or difficult?

As indicators of the perceived difficulty of the task we considered (1) performances in the problem solving, (2) kind of language preferentially used by children.

Performances in the problem solving have been evaluated on the basis of time needed to solve the task and average number of errors. Concerning task completion time a major discrepancy is observed between children achieving the task faster (75%) rather than slower (25%) when using conceptual heuristics. A minor discrepancy is present between children achieving the task faster (55.56 %) rather than slower (44.44 %) when using procedural heuristics. Similarly, no important discrepancy is present in the case of meta-cognitive heuristics (54.55% faster and 45.45% slower). Concerning number of errors, results show that errors occurred more frequently in case of procedural heuristics (50%) and less frequently when children applied conceptual (25%) and meta-cognitive (25%) heuristics.

Concerning the kind of language, results show that, regardless of group age, the majority of children use technological language (70%), with only the 30% resorting to anthropomorphic language. More in detail, results percentages do not confirm our hypothesis: children preferentially used technological language (79.17%) than anthropomorphic language (20.8%) when children achieve the task slow. Similarly, when children achieve the task fast, used preferentially technological language (64.71%) than anthropomorphic language (35.29%), with the discrepancy between the two kinds of languages being less relevant in this latter case.

3.4 Is the problem perceived as easy or difficult according to the age?

Task completion time was longer for younger children (01:25:27 h) than for older children (01:12:45 h), while number of errors do not differ between the two groups. More in detail, children aged 6-7 do all errors in longer time, whereas children aged 8-10 do all errors in less time.

Concerning the kind of language used according to the age groups, results show that children aged 8-10 verbalize more than children aged 6-10 (Fig. 4). Contrarily to our hypothesis, older children preferentially use anthropomorphic language (64.71 %) than technological language (61.54%) whereas younger children preferentially use technological language (38.46%) than anthropomorphic language (35.39%).

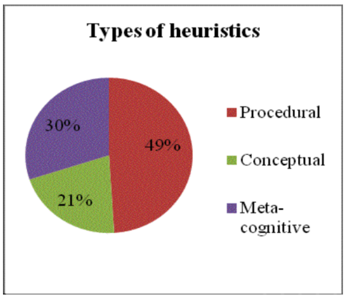

Fig. 2. Type of observed heuristics in the sample data.

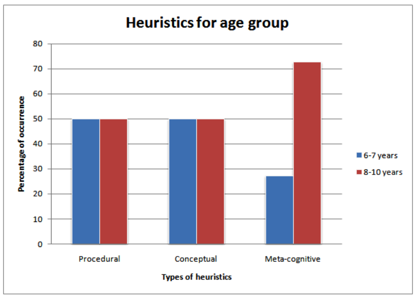

Fig. 3. Type of observed heuristics for age group.

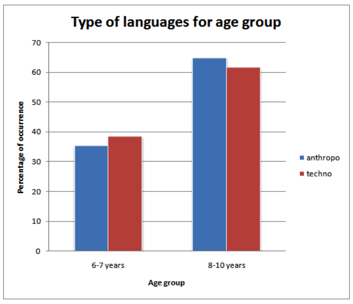

Fig. 4. Type of languages according to age group.

4 Discussion and Conclusions

Relying on a previous exploratory inquiry on the emerging of children control heuristics when commanding a Lynx AL5A robotic arm, we have conducted a pilot study with the aim of classifying the prior observed control heuristics when children approach the programming of a Lego Mindstorm NXT® robot. The two robots have been chosen for their different degrees of *transparency* and *interactivity*. The robotic arm is a low transparent device (i.e. a non programmable device whose commands can be given only by knobs) and a high interactive (i.e. a device whose feedback time is immediate). Lego robot is a high transparent device (i.e. it is programmable) and less interactive (i.e. its feedback time is longer).

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Results of the pilot study show that all the three type of heuristics (procedural, conceptual and meta-cognitive) observed when children controlled the robotic arm were also observed when they controlled the Lego robot.

Procedural heuristics seem to be largely adopted with both the robots. A difference has been registered, regardless to age group, in the occurrence of conceptual and meta-cognitive heuristics: a higher occurrence of meta-cognitive heuristics with relation to conceptual ones has been observed in the case of Lego robot, while a higher occurrence of conceptual heuristics has been observed with relation to meta-cognitive ones in the case of the robotic arm. This could be due to the fact that a less transparent device requires applying conceptual strategies in order to understand the functioning of the commands before elaborating the sequence of instruction to achieve the task. A more transparent device could instead allow passing straight to higher strategies like meta-cognitive ones. Moreover, if immediate feedback might encourage to test commands singularly, longer feedback might give raise to the programming of an entire sequence.

With relation to age group it is possible to point out that use of procedural and conceptual heuristics does not seem to vary in the younger and older group. Meta-cognitive heuristics are instead more applied by older groups. This result confirms only partially the literature on acquisition of procedural and conceptual knowledge in children [28] and adds that meta-cognitive strategies seem however to be developed as last. Here it is interesting to remark that meta-cognitive ability is often invoked as one of the major benefit of educational robotics [30]. Hence, the fact that transparent devices prompt meta-cognitive strategies more than non-transparent devices could be a cue to the design of third generation kits that have meta-cognition as an educational objective.

Finally, in order to investigate the understanding of robots by children, we have evaluated the perceived difficulty of the proposed task. Three indicators were considered: task completion time, number of errors, type of language (anthropomorphic vs. technological). Here again, hypothesis and literature were only partially confirmed. Regardless to age, children were faster at achieving the task and they did it with less errors when using conceptual and meta-cognitive heuristics rather than when using procedural heuristics. When considering age group, younger children make more errors in more time while older children make more errors in less time. Finally, concerning type of used language, technological markers were the most used one, even if anthropomorphic markers were used in slower performances; moreover, younger children used technological language at most.

These results highlight that it is not trivial to define indicators of difficulty of the task when novel technologies are at play. For example, it is not easy to distinguish between the difficulties of the task itself and the difficulties engendered by the features (transparency and interactivity) of the technological object.

Furthermore, other factors might have influenced the outcomes of the pilot study. First, the four different sensors included in the Lego robotics kit might present different level of difficulty. For example, light sensor presents a more complicated calibration than touch sensor: where the programming of the former implies the comparison among quantitative values in order to set the parameters (e.g. the sensors detect a light intensity higher or lower than 50), the programming of the latter requires manipulation of quantitative values (i.e. the sensor can only assume the following states: pressed, released, hit). This different level of difficulty could have affected the perceived difficulty of the task according to the chosen sensor in terms of task completion time and number of errors.

Second, even if sample data have been analyzed with relation to age group (6-7 and 8-10 years old group), each group could contain children of same age (e.g. three children of 6 years old) or of different age (e.g. two children of 6 years old and one child o 9 years old) so that individual performances and group performances might have been determined by the interaction of younger and older children.

Third, the present analysis of sample data does not take into account group dynamic (e.g. collaboration, competition, leader-attitude etc.) that can accelerate or slower the achievement of the task.

Fourth, different scaffolding style can be applied by different educators within each group, certain educators showing a proclivity for a strongly structured guidance and others being more open to children initiative.

For these reasons, our future research aims at refining the experimental protocol (e.g. replacing touch sensor with temperature sensor, monitoring group assortment, and providing educators with precise instructions) in a broader frame which will take other important aspects of the children cognitive profile (i.e. development of logical thinking skills and of social attitudes). Further data will also be collected before and after the educational robotics activities, by a pre-test and a post-test in which quantitative/qualitative thinking, logical skills and technology fluency will be evaluated. Finally, the results of the present study encourage to exploit the three emerged heuristics as independent variables, as well as to vary the difficulty of the task and to realize a comparative study between robotics kits characterized by different degrees of transparency and interactivity.

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