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Learning Robotics: Users' Representation of Robots

1.1. Introduction: the ontological and pedagogical status of robots

In recent years, there has been a growing interest in users' representations of robots within several complementary fields of study: cognitive psychology [KAH 06, JIP 07, BER 08, BER 11], science and technology education [e.g. SLA 11] and anthropology [GRI 12]. The reason for this interest lies in a shared wonder at a new technology which, despite being a manmade entity, i.e. an artifact, has enough power to surpass people in the accomplishment of several physical and decision-making tasks. This mixed definition of the robot, as an entity that possesses at the same time something that is greater than and something that is less than living and non-living beings, seems to challenge traditional ontological categories [SEV 10]. The difficulty involved in assigning robots either to the category of living entities or to that of non-living entities has led researchers from different fields not only to postulate the creation of a completely new category of objects but also to revise the traditional concept of "being alive" itself. In the words of MacDorman and colleagues [MAC 09, p. 486]:

> "Among all human artifacts, perhaps robots share the most in common with their maker. Like computers, and in fact because they are controlled by computers, they

> can process huge amounts of information. Like powered equipment, they can manipulate their environment and move within it. And like dolls, mannequins and other effigies, they can resemble us – either abstractly or down to the dimples of our cheeks. Nevertheless, the differences between machine and maker are profound. Metabolism, life span, sexual reproduction, ancestry, culture and consciousness for now distinguish us from robots. Thus, the similarities and differences between us and them circumscribe a chasm that is at once narrow and deep".

Robotics kits, in particular, have an interesting status. On the one hand, they are engineering objects that Slangen *et al*. [SLA 11] describe as "a system, that is, any group of interrelated parts designed collectively to achieve a designed goal. The system maintains its fundamental structure notwithstanding the possibility of infinite transformations. Systems have input, processes, and output. In order to perform a task a robot integrates solutions to sub-problems from different technological domains (e.g. mechanics, electronics, pneumatics, calculation) into one machine. The robot is a construction and consists of a frame with static components (bricks, pins, beams), dynamic mechanical components (gears, axles), electronic components (sensors, display, bulbs) and electro-mechanical components (motors). Robots should be well designed and constructed with the right components, and be stable and strong enough to enable the execution of the function(s). This requires understanding of concepts like stability, sturdiness, motion, etc. (…) The robot is controlled by means of software designed to enable the robot to function. (…) The performance of a robot is based on the three basic capabilities of sensing (S), reasoning (R) and acting (A), which repeat in succession and form the so-called S-R-A loop [VAN 06]. A robot that is able to sense, reason and act needs hardware components like sensors, a PLC, and actuators (motors, bulbs, speakers, displays)".

On the other hand, there is something unique about robotics kits. To explain this uniqueness, we refer to the work of Severson and Carlson [SEV 10], who first applied the expression "creative control" to robots, meaning that users of this kind of robot experience a form of simulation, projection and personification similar to that experienced by children during imaginative play. That is, the fact that this kind of robot has to be physically created from scratch through assembly procedures and progressively "tamed" through algorithms, implies that users are simultaneously engineers and interpreters of robots' behavior [ACK 91]. This, we believe, requires an imaginative effort consisting of shaping a representation and reshaping it through time, as the robot is developed by its users.

1.2. What do we mean by robot representation?

Representations have a pivotal role in cognitive psychology research. They are generally described as mental constructs that may concern the physical world, but also social and mental entities [LE 05]. They can be permanent or occasional, that is stable or triggered by some specific activity or context [STE 09]. Within the robotics literature, the term "representation" often occurs as an umbrella concept that incorporates different meanings. These meanings have been investigated using methods that are traditionally employed to find out how users perceive innovative technologies, but, interestingly, also to examine the status of imaginary or fictional entities such as made-up companions or the characters of cartoon movies [SEV 10], as well as of strangers or out-group members [KUC 12].

In this context, we use the term "representation" of an educational robot to mean (1) the place teenagers assign to robots within their common-sense ontology and (2) the different pedagogical roles (i.e. an object to be constructed and programmed, a tool to learn school subjects, a classmate) they attribute to such robots.

1.2.1. *The place of robots in our common-sense ontology*

Each society marks in its own way the boundaries between the categories of beings (living or non-living, real or imagined). These boundaries depend on the features that we use to attribute or deny to the entities that surround us. In general, such features form a system within what is traditionally called ontology [DES 10].

Recent studies, which have addressed the issue of whether robots are considered closer to inanimate objects than to living entities, have demonstrated that robots are considered to be “kind of alive” [TUR 11]. This would imply that being alive involves degrees instead of being a matter of all-or-nothing. More precisely, the literature indicates a considerable variability in young people’s ability to classify robots. Robots are sometimes seen as being characterized by features of both living and non-living entities, but at other times depicted as only having machine-like features [OKI 06, JIP 07, SAY 10]. Although disparate, these features can be classified according to three main types: biological, technological and psychological. When we examine children’s judgments about robots, such features often occur in couples, particularly in antithetical couples. For instance, children from 3 to 5 years old say that robots are non-living but real [JIP 07], non-living but aware [TUR 11, p. 62], and mechanical but intelligent and capable of emotions [BER 11]. Similarly, adults show inconsistent or paradoxical judgments: they see robots as machines, but “alive enough” to substitute people when they lack the ability to do something (e.g. the ability to listen and understand others) [TUR 11]. Another interesting study performed at the Museum of Quay Branly by Vidal and Gaussier [VID 14] witnesses that when interacting with a robot people show two attitudes that are apparently in contradiction: on the one hand, they try to understand the mechanical functioning of the robot; on the other hand, they interact with the robot as it was a real person. In summary, it seems that neither children nor adults feel comfortable assigning robots solely to either the category of living entities or the category of non-living entities.

1.2.2. *Categories: essentialist versus graded*

A category is traditionally defined as set of items which are built upon the broad and defined differences between those items [GEL 03]. According to the essentialist school, an entity contains core features that allow people to decide if it belongs to a certain category or not [GEL 04]; for example, we may decide that an entity is a bird because it flies. As Gelman [GEL 03] remarks, essentialism is a "pervasive, persistent reasoning bias, that affects human categorization in profound ways, a sort of cognitive predisposition that emerges early in childhood, particularly for understanding the natural world" (p. 6). According to Gelman, it seems that people unconsciously believe in hidden essential qualities that are responsible for the observable similarities between different members within a category. In contrast, antiessentialism states that there are no defined essential features of objects, no sufficient and necessary characteristics, and that category membership is not a matter of all or nothing, but is instead graded; for example, a penguin might be judged to be partly a bird and partly a fish, but not completely, because we do not recognize all the features of a bird in this animal, namely the ability to fly rather than swim [KAL 95].

The difficulty that adults, as well as children, experience in trying to build a coherent representation of robots could mean that neither children nor adults adhere to an essentialist view of ontological categories when dealing with the entity "robot". Strikingly, robots seem to threaten the long-established essentialist way of interpreting the world.

In cognitive psychology, the antiessentialist position is explained through models like that of graded representations [MUN 01], according to which representations are not an all-or-nothing phenomenon, but are graded. The strength of a representation would then depend on the contextual cues (e.g. the societal environments) that favor it. That is, being able to assign an entity neatly to a specific category (essentialist) or in a graded way (antiessentialist) is not simply a matter of personal preference, but rather the product of a contextualized common-sense ontology.

The literature shows that if living entities (e.g. animals, plants) and social status (e.g. gender, nationality) are mostly categorized in an essentialist manner, at least in western cultures, the same does not hold for artifacts. Artifacts do not have an essence [SLO 03]; they are a composite set of elements that are continuously replaced and renewed, and they mainly serve a particular function. This contributes to the difficulty we face when we are asked to categorize artifacts like robots. This is such to the point that, according to several authors [KAH 04, SEV 10], robots represent the emergence of a new ontological category (NOC) that is neither alive nor not alive, but something altogether different: one of personified or behavioral technologies.

1.2.3. *The NOC hypothesis*

The NOC hypothesis [KAH 12] states that an NOC is emerging, a category that does not map onto humans, animals or artifacts. This means that although natural and artifactual categories have remained relatively stable for tens of thousands of years – so that it has been possible since the origins of modern psychology to study how children develop their categories of the physical and social world – in recent decades, the rate of technological change has increased so rapidly that children's cognition is now constantly in flux and will continue to be so [KAH 12].

Kahn and colleagues believe that this incoming NOC will become more identifiable as other embodied social computational systems (e.g. personified "smart" phones, cars and homes of the future) become increasingly advanced and pervasive.

A similar view is proposed by Turkle [TUR 11] who points out that robots are different, both from living entities and from non-living functional objects or toys, for the reason that people cannot simply project their beliefs onto them. In this respect, robots seem to break the traditional subject–object opposition [KAP 05, p. 142]: they are interactive, they can develop under our guidance and they have a memory. Severson and Carlson [SEV 10] provide five criteria to recognize whether robots constitute an NOC. The first and most relevant of these criteria is that attributions to robots must cut across prototypic categories (e.g. alive and not alive).

Another relevant finding within the literature that we have considered for this study is that gaining experience with robots leads to more nuanced [VAN 96] and species-specific views of robots [BER 08a]. After interacting with a robot, both adults and children seem to treat it as an intelligent entity, but intelligent in a unique way, which is different to the way that living or non-living entities are intelligent. A convincing explanation for the "species specificity" and "uniqueness" that characterizes our mental images of robots, once we have become acquainted with them, is given by Kahn *et al*. [KAH 11]: "just as we perceive the color orange as a unique color, and not merely as a combination of red and yellow, once we become familiar with robots we will see, conceptualize, and interact with them as a unified entity, and not merely a combinatorial set of constituent properties".

1.2.4. *Shifting between the different pedagogical roles of a robot*

According to Kaplan [KAP 05], it is because young people are able to perceive the same robot either as a peer, a construction game, or a domestic animal that they are naturally directed to construct their own idea of what these creatures really are. Turkle [TUR 11, p. 62] observed that after the interactions with an AIBO robotic dog, when interviewed, the participants (aged 17 years) revealed that they saw AIBO both as a creature and a machine. In addition, being involved with the inner technical details of the robot did not diminish their attachment to it.

Concerning robots used to learn robotics, as outlined by Severson and Carlson [SEV 10], young people's ability to shift from one role to another is based on a special form of imagination that children develop from 3 to 12 years of age through play. Such a form of imagination implies that any object can acquire a specific status during playtime and become an inert object again once playtime is over [FLA 87]. The shift among the different roles of the robot is precisely what intrigues young people [KAP 05, p. 158]: they generate "multiple parallel representations" [KAP 05, p. 159] or "simultaneous visions" [TUR 11, p. 62] and they behave accordingly to the type of interaction at play. Robotics platforms seem to evoke, in this sense, the very essence of play.

1.2.5. *How do we investigate robot representations and the impact of learning robotics on these representations?*

Several studies have addressed the representation of a robot as the concept or the mental image of a robot that people hold based on their familiarity with imaginary or real robots. This kind of representation has mostly been investigated using explicit measures, that is, through closed-question surveys, mostly using a scale format. For example, the Negative Attitude toward Robots Scale [NOM 06] evaluated adults' negative attitudes toward robots by asking respondents to rate first-person sentences expressing situations of interaction with robots (e.g. "I would feel uneasy if I was given a job where I had to use robots"), the social influence of robots (e.g. "I feel that if I depend on robots too much, something bad might happen"), and emotions in interactions with robots (e.g. "I feel comforted being with robots that have emotions"). The Human Likeness Questionnaire [HO 10], again tested with adults, addressed the "humanness" of robots through semantic differential ratings (e.g. "mortal versus without definite lifespan"). The PERNOD (PERception to humaNOiD [KAM 14]) included items such as admiration for technology (e.g. "I could open my heart to this robot"), utility (e.g. "This robot seems to be able to perform only structured routines") and familiarity (e.g. "I feel an affinity toward this robot"). The Interpersonal Attraction Scale [VEE 11] evaluated friendship, bonding, physical proximity and care for robots among children aged 6–10 years. The Social Credibility Scale [JOO 13] examined the social appearance of robots during interactions (good natured versus irritable, cheerful versus gloomy, dishonest versus honest, etc.).

Two methodological aspects of studies using such instruments to examine people's representations of robots deserve discussion. The first aspect concerns the experimental materials used as inputs: participants were dealing with specific kinds of robots, i.e. robots with specific appearances and behaviors. As a result, their representation was irrevocably biased by the specific kind of robot rather than on their purported representations of robots, preventing people from placing it inside or outside a category of entities – since the robot was already presented as belonging to its own category (e.g. in the study by Berstein and Crowley [BER 08a], pictures of robots are labeled as "robot"). Moreover, in these studies, the robots were either artificial animals or humanoids but in all cases they were all prebuilt devices, black box type technologies preprogrammed to react with a definite behavior [KYN 08]; that is, robots used in these studies were not constructed or programmed by participants. The second aspect is that these studies rarely took into account the influence of non-scientific information (science fiction, advertisements, etc.) or previous exposure to robots or people's ideas about them. Nonetheless, prior robot exposure is an important factor. Bernstein and Crowley [BER 08a] showed that children with little prior experience tended to group the robots with familiar objects of similar living status (i.e. various kinds of animals). In contrast, children with greater prior experience attributed a unique pattern of intellectual and psychological characteristics to the robots (e.g. robots were as smart as a cat, but were less psychological) [BER 08a].

1.3. Study 1: Robot representation

1.3.1. *Aims and rationale*

In order to understand how students shape representations of robots when learning robotics, we designed a pre- and post-questionnaire addressing the following three issues:

1) the place assigned to robots among living and non-living entities;

2) the educational role(s) attributed to robots;

3) whether building and programming a robot has an impact on (1) and (2).

The two questionnaires (pre- and post-) were presented to teenage students participating in a 3-day robotics event (RoboParty®[1]), where they had to build and program a Bot'n Roll® kit. In an attempt to overcome the methodological limitations of previous studies on robots' representations (section 1.2.5), our questionnaire did not

1 http://www.roboparty.org/.

present a specific kind of robot to participants. This precautionary measure was taken intentionally to avoid biasing participants' answers: we did not wish to evoke a particular typology of robot in the students' minds while investigating their representation, as this might influence their responses. Instead, we asked participants to carry out a picture-rating task and a sentence-rating task.

In the first task, participants look at a set of 10 pictures and to answer the question "how much do these images make you think about a robot?" by providing a score on a 1–5 point Likert scale, where 1 indicated "not at all" and 5 indicated "a lot".

In the second task, they had to answer the question "In the classroom, would you prefer: (1) building and programming the robot, (2) using the robot as a tool to learn school subjects, (3) learning with the robot as a classmate", again by providing a score to each of the three sentences on a 1–5 Likert scale. The answer to each question of the questionnaires was considered graded, if the score provided was different from 1 or 5 on the Likert scale.

A higher graded score reflected a non-essentialist categorization, that is a more nuanced assignment of robots to specific ontological categories (living or non-living) and to specific educational roles (object to build and program, tool to learn school subjects and classmate); in contrast, a lower graded score reflected an essentialist categorization, that is a more defined assignment to these ontological categories and educational roles. The questionnaire was filled in twice, before and after building and programming a Bot'n Roll® kit.

1.3.2. *Hypotheses*

HYPOTHESIS 1.1.– Students have beliefs about what a robot is and which educational roles it may serve. However, these beliefs can be stable or triggered by some specific activity or context [KAL 95, STE 09] and are probably influenced by previous exposure to robots [BER 08a]. That is, participants hold a representation of robots, in terms of ontological and educational status. Such representation can be more or less graded [MUN 01], which means that robots can be seen as more or less belonging to the categories of living or non-living entities and as serving specific educational role(s). This first hypothesis has engendered the following predictions:

PREDICTION 1.1.– In the picture-rating task of the pre-questionnaire participants should mostly assign a low graded score. That is, we expected to find a global predominance of "1" and "5" on the Likert scale as an answer the question "How much do these images make you think about a robot?". Moreover, we also expected to find a difference between participants who were already familiar with robots and participants who were not: the former should opt for a stronger essentialist categorization (low graded score), than the latter (medium graded score). Thus, according to this prediction, the less familiar participants are with robots, the more they will show an essentialist categorization of robots, that is an all-or-nothing judgment about robots' belonging to living or non-living categories.

PREDICTION 1.2.– In the sentence-rating task, participants should mostly assign a low graded score. That is, we expected to find a global predominance of "1" and "5" on the Likert scale as an answer the question "Would you like your robot to be an object to be constructed and programmed, a learning tool, or a classmates?". Specifically, the mean graded score would be low for participants who were not familiar with robots and medium for participants who were already familiar with robots. Thus, according to this prediction, the less familar participants are with robots, the more they will tend to neatly attribute one specific role to a robot, that is an all-or-nothing judgment about robots' educational status.

HYPOTHESIS 1.2.– The effect of building and programming a robot on common-sense ontological categorization (essentialist versus graded). Consistent with work by Van Duuren and Scaife [VAN 96], Bernstein *et al*. [BER 08a] and Kahn *et al*. [KAH 11], we hypothesized that, after assembling and programming a robot, participants should show a more nuanced and refined view of a robot; that is a robot's association with a specific ontological category should no longer be a question of all-or-nothing (essentialism), it should instead be a question of degree (non-essentialism). Hence, we formulated the following predictions:

PREDICTION 1.3.– The mean graded score for ontological categorization would be generally higher in the post-questionnaire than in the pre-questionnaire.

PREDICTION 1.4.– Participants would tend to revise their general ontological categorization by demonstrating a dichotomous living /non-living categorization in the pre-questionnaire and a tripartite living/life-like/non-living categorization in the post-questionnaire. Thus, we expected that the distribution of prequestionnaire scores would suggest a categorization of pictures in two groups (living/non-living), while three groups (living/non-living/new category) would be identified in the post-questionnaire.

For predictions 1.3 and 1.4, there should be less variation in the score distributions before and after robot programming for participants who were already familiar with robotics kits prior to their participation in RoboParty®.

HYPOTHESIS 1.3.– The effect of building and programming a robot on attribution of educational role(s) to it. Consistent with work done by Kaplan [KAP 05] and Severson and Carlson [SEV 10], we hypothesized that, after the robot-making experience, participants would ascribe different educational roles to the robot, and this to different degrees. Therefore, we made the following prediction:

PREDICTION 1.5.– The mean "graded score" for educational roles would be greater in the post-questionnaire. Again, there should be less variation in score distributions before and after robot programming for participants who were already familiar with robotics kits prior to their participation in RoboParty®.

1.3.3. *Method*

1.3.3.1. *The RoboParty® context*

RoboParty® is a 3-day robotics event organized and facilitated by lecturers and volunteers from the University of Minho. The participating teams are invited to create a robot from scratch using only paper and video instructions, with the support of the University staff. The first day of the event is dedicated to building the robot (soldering electronic components, assembling the mechanical parts and personalizing the robot by reproducing or inventing a fictional character). The second day is dedicated to programming the robot (*Basic* for *Picaxe*) and the third day to the testing of the robot, by taking part in three competitive arenas (*rescue, dance* and *chase*). During the three days, participants can also benefit from lectures on robotics by invited speakers, sports and various leisure activities. The objective for the event is to learn mechanics, electronics and programming through an entertaining and hands-on approach [SOR 11]. A special focus is thus given to pedagogy, collaboration and creativity, in contrast with other robotics events that promote competition instead (e.g. First and Junior LEGO® leagues and RoboCup).

1.3.3.2. *Participants*

111 teams participated in RoboParty®, with each team including a maximum of four participants and an educator; a total of 400 participants were involved, all from urban and rural state schools in Portugal, and from a wide variety of socioeconomic environments. These students were particularly appropriate as a sample population for the purposes of this investigation because, due to the nature of their scientific and technical studies, they already possessed generic knowledge about computer science. Among the 400 RoboParty® participants, 226 volunteered for this study. From the 226 (pre-) and 197 (post-) individual questionnaires collected, only 89 participants had correctly filled in both the pre- and the post-questionnaire. This was due to the fact that, although team leaders had been correctly briefed and the staff had ensured the proper delivery of instructions, data were collected during a robotic event and not in a laboratory setting, so it was not possible to control any eventual disturbing factor without altering the inherent nature of the event. In order to have a consistent set of data for the age range (14–18 years old), only 79 pre- and 79 post-questionnaire (68 boys and 11 girls; $M_{\text{age}} = 15.36$; $r = 1.49$) were finally retained for the purposes of analysis.

1.3.3.3. *Materials*

The pre- and post-questionnaires were designed for the purposes of this study. All the questions were asked in a closed form so that participants' answers consisted of scores on a 5-point Likert scale. The questionnaire filled in by participants before the RoboParty® had four main sections (see Appendix 3). Section 1 consisted of four questions about the sample population (age, gender, team and school names) and was designed to collect students' profiles. Section 2 consisted of five questions designed to measure participants' familiarity with robots. For example: "How often have you watched or read something about robots?", "How often have you built or programmed a robot?". Section 3 consisted of one question: "How much does this picture make you think about robots?". This question was repeated for 10 items presented in the form of 10 different pictures, printed in color. The items presented in 10 pictures were selected because they were representative of the two ontological categories: living (i.e. *plants, animals and human beings*) and non-living entities (i.e. *single-function and multifunction machines, scientific instruments, toys*), which included some ambiguous entities (i.e. *anthropomorphic objects, animated characters, bionic components*). For each item, participants had to indicate on a 5-point Likert scale if the item made them think about a robot (1: "not at all" and 5: "a lot"). This section was designed to investigate whether and to what extent robots belong to living or non-living categories of entities according to students. Section 4 consisted of three questions designed to investigate the educational role(s) envisaged for the robot by participants (*an object to be constructed and programmed, a learning tool, a classmate*). Just as for the previous question, participants were invited to answer using a 5-point Likert scale (1: "not at all" and 5: "a lot").

The post-questionnaire (see Appendix 3) had the same format as the pre-questionnaire but it differed in the following respects: it did not include section 2 on familiarity with robots; furthermore, the pictures used in section 3 were replaced by different pictures, although they still represented the same categories of entities in order to prevent any potential habituation effect. The pre- and post-questionnaire had been tested previously by 30 volunteers at the Cité des Sciences et de l'Industrie, Paris. This first test aimed to assess the understandability of the instructions, the accessibility of the questions and how the proposed pictures (section 3) were interpreted, that is if the pictures selected for the pre- and post-questionnaire were representative of the categories we intended to investigate. 20 of the selected images were considered to be more than 80% "good examples" of our 10 categories. Subsequently, the questionnaires were refined and translated into Portuguese and English, the two official languages of the RoboParty®. In order to avoid biased responses to both the pre- and post-questionnaire, both the order of the items in each section and the order of the sections were randomized across the questionnaires.

1.3.3.4. *Procedure*

Each participant who volunteered for the study was requested to fill in two questionnaires: one before the robot building and programming task and the other after the task. The pre-questionnaire was handed out in the form of a paper sheet to each team leader on the first RoboParty® day at the welcome desk. The team leaders were in charge of distributing these paper sheets, one for each member of the team. Participants wrote their answers directly onto the questionnaire sheet before opening the Bot'n Roll® kit, over a 15–20 minute period approximately. As soon as the participants had filled in the sheets, we collected them, with the help of volunteers from the University of Minho. Similarly, on the last day of the RoboParty® the team leaders were provided with the post-questionnaire, which was filled in individually by participants after they had built and programmed the robotics kit, over a 10–15 minute period during the last phase of the competition.

1.3.3.5. *Data collection and analysis*

Responses to the pre- and post-questionnaire were used to create quantitative measures. Two types of raw scores were computed and used as a basis for compound scores:

1) *absolute scores*: scores given by the participants to each question;

2) *graded scores*: to assess the nuance of participants' representations, each participant's answer was categorized either as a graded answer, if the score provided was 2, 3 or 4, or as an absolute answer, if the score provided was 1 or 5.

Three compound scores were computed and used as dependent variables to evaluate participants' representations of robots before and after robot-making in an educational learning context and whether previous exposure to robots had an impact on these representations.

Familiarity: A global familiarity score was attributed to each participant. This score was the average of the scores obtained for the four familiarity questions in section 2 of the questionnaire ("How often have you watched or read something about robots?"; "How often do you play with robots?"; "How often have you built or programmed a robot?"; and "How many times in the past have you attended robot-related lessons, exhibitions, competitions, or other events?"). We considered that a score between 1 and 3 (3 not included) indicated a low level of familiarity with robots and that a score between 3 and 5 (3 included) indicated a medium–high level of familiarity with robots. According to the familiarity score obtained, two independent groups were created.

Essentialist versus non-essentialist robot categorization: We attributed a graded score to each participant consisting of the number of graded answers to the question "How much does this picture make you think about a robot?" (section 3 of both questionnaires). Similarly, a graded score was attributed to each question, calculated as the total number of participants who provided graded answers to each question. A higher graded score reflected a non-essentialist categorization, that is a more nuanced judgment about robots' membership in relation to the categories of living and non-living entities; in contrast, a lower graded score reflected an essentialist categorization, that is a more defined judgment about this.

Shift among the educational roles envisaged for robots: As was the case for robot categorization, a graded score was attributed to each participant, calculated as the number of the graded answers given by each participant to the question "In the classroom, would you prefer: (1) building and programming the robot, (2) using the robot as a tool to learn school subjects, (3) learning with the robot as a classmate?". Similarly, a graded score was attributed to each of the proposed three options, which was calculated as the total number of participants who provided a graded answer for each option. A higher graded score reflected a more nuanced attribution of a given educational role to robots. In contrast, a lower graded score reflected a more defined attribution of a given educational role.

Statistical analyses were performed with SPSS 21 with a significance level set at 0.05. An unpaired samples Student's *t*-test was carried out to compare familiar and unfamiliar groups with respect to robot categorization and educational role. A paired analysis of variance (ANOVA) with two variables (general linear model) – picture and moment (before and after robot-making); educational role and moment – was carriedout to compare the gradation and shift scores obtained at the pre- and post-questionnaire. A paired samples Student's *t*-test was conducted to assess whether any picture and any proposed educational role was given a different score in the pre- and post-questionnaire. A χ^2 test was performed to compare the number of graded scores for each picture and each proposed educational role on the pre- and post-questionnaire, and Yule's Q to examine the direction of the observed variation when significant differences were found.

1.4. Results

1.4.1. *Which representation of robots for familiar and unfamiliar students?*

The mean familiarity score was 2.49 (r = 1.58). 44 (55.7%) participants obtained a familiarity score between 1 and 3 (3 not included), that is they demonstrated a low level of familiarity with robots. 35 (44.3%) participants obtained a score between 3 and 5 (M = 4.11; r = 0.79), which reflected a high level of familiarity with robots.

1.4.2. *The living and non-living items most frequently associated with robots (pre-questionnaire)*

For all participants, two items were most frequently associated with robots: bionic components and multifunction machines (Figure 1.1 and Table 1.1). These results were observed both for participants who were already familiar with robots and for participants who were not. However, familiar participants seemed to preferentially associate multifunction machines, rather than bionic components, with the robot (bionic components: M = 4.06; r = 1.3; multifunction machines: M = 4.09; r = 0.85). The opposite trend occurred for unfamiliar participants (bionic components: M = 4.14; r = 1.17; multifunction machines: M = 3.73; r = 1.17).

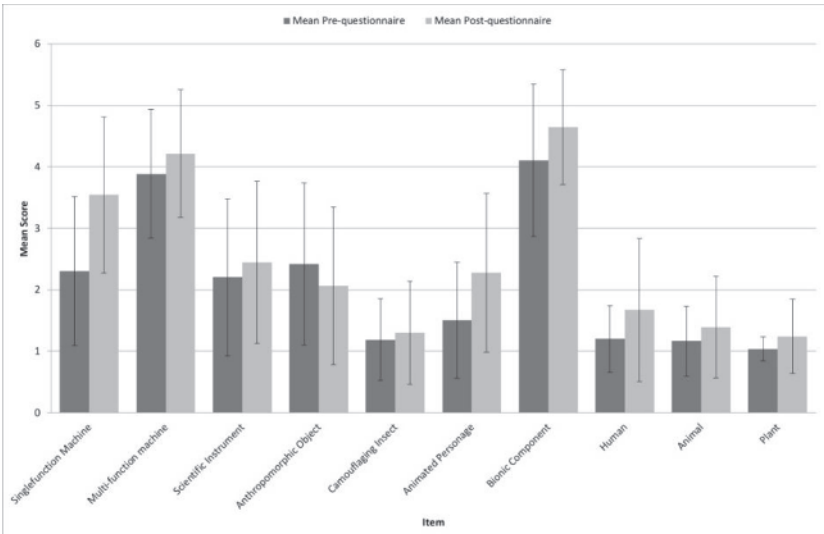

Figure 1.1. *Mean score for each picture on the pre- and post-questionnaire*

Item	*Structural, functional and relational features*	*Category*
Single-function machine	A functional non-organic object, which is designed to serve one single purpose, and whose activation depends on users (e.g., a coffee machine)	Non–living
Multi-function machine	A functional non-organic object, designed to serve several purposes, whose activation depends on users (e.g., a computer)	Non–living
Scientific instrument	A functional non-organic object, designed as a tool for scientists (e.g., a microscope)	Non–living instrumental
Anthropo-morphic object	A social object with a human appearance, designed for playful interaction and on which it is possible to project human attitudes (e.g., a doll)	Non-living anthropomor-phic
Animated character	An object acting as a living entity, belonging to imaginary settings, designed to be watched rather than to interact with, and which is susceptible to personification (e.g., Pinocchio)	Non-living imaginary
Bionic component	An object designed to replace a living component, which is not organic and which becomes functional only when integrated with the living organism (e.g., a bionic eye)	Non-living ambiguous
Camouflage insect	An animal camouflaging with its surrounding environment, which is organic, autonomous, and which can be mistaken for stones, leaves, engendering unpredictable interactions etc. (e.g., a stick insect)	Living ambiguous
Plant	Vegetation growing with or without human care, which is organic, autonomous, but not responsive to human interaction (e.g., a tree)	Living vegetal
Animal	An animal growing with or without human care, which is organic, autonomous, and responsive to human interaction (e.g., a dog)	Living animal
Human being	A human individual, organic, requiring human care, becoming progressively autonomous and responsive to human interaction (e.g., a child)	Living human

Table 1.1. *Description and categorization of 10 items represented in the 10 pictures in section 3 for the pre- and post-questionnaires. Participants were requested to look at these pictures and to answer the question "How much do these pictures make you think about a robot?" by giving a score on a 5-point Likert scale*

1.4.3. *Gradation in robot categorization: essentialist versus non-essentialist stance (pre-questionnaire)*

The mean graded score for all participants for the pre-questionnaire was 3.43 (r = 1.52). This low score suggests an essentialist categorization of robots; the familiar group obtained a mean graded score of 3.51 (r = 1.56) and the unfamiliar group obtained a mean graded score of 3.36 (r = 1.50). No significant difference was found between familiar and unfamiliar groups using a Student's t-test ($t(79) = 0.181$; ns). Hence, familiarity seemed to have no effect on categorization: both familiar and unfamiliar participants seemed to opt for an essentialist categorization of robots.

1.4.4. *The educational roles most frequently envisaged for robots (pre-questionnaire)*

For all participants, the option "object to be constructed and programmed" appeared to be the most frequently envisaged educational role for robots, followed by "learning tool" and "classmate" (see Table 1.2; Figure 1.2). This result was observed for both familiar and unfamiliar participants.

1.4.5. *Gradation in the educational roles envisaged for a robot (pre-questionnaire)*

The graded score relating to the educational roles envisaged for robots for all participants was 1.41 (r = 1.06). This graded score indicates a medium level of nuance in the given answers. The graded score for familiar participants was 1.37 (r = 1.11), while the score for unfamiliar participants was 1.43 (r = 1.02). No significant difference was observed between the two groups of participants on the pre-questionnaire ($t(79) = 0.61$; ns). Hence, neither the familiar nor the unfamiliar group seemed to have a definite preference for one educational role in particular.

Role	All	Familiar	Unfamiliar
Object to be created	$M = 4.61$; $\sigma = 0.608$	$M = 4.63$; $\sigma = 0.598$	$M = 4.59$; $\sigma = 0.622$
Learning tool	$M = 3.43$; $\sigma = 1.317$	$M = 3.26$; $\sigma = 1.421$	$M = 3.57$; $\sigma = 1.228$
Classmate	$M = 2.75$; $\sigma = 1.531$	$M = 2.80$; $\sigma = 1.549$	$M = 2.70$; $\sigma = 1.534$

Table 1.2. *Means and standard deviations for scores given by familiar and unfamiliar participants to three educational roles of the robot envisaged in educational contexts*

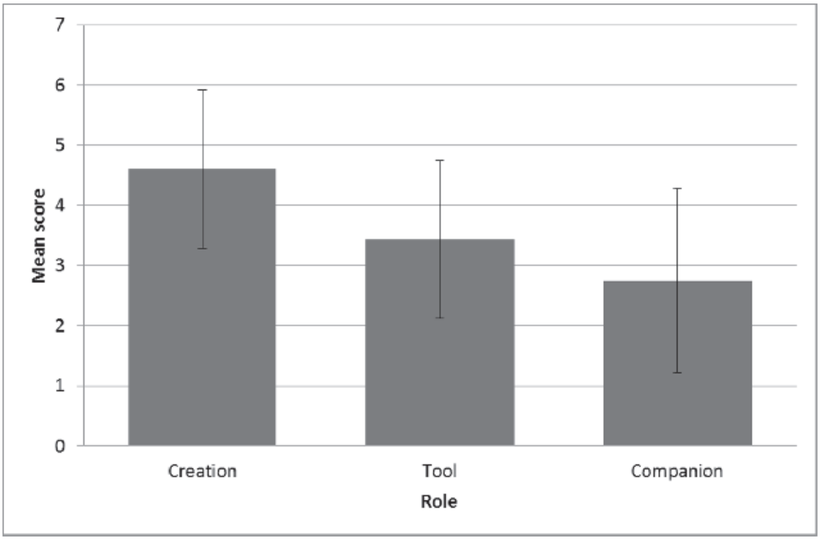

Figure 1.2. *Mean score for each educational role on the pre-questionnaire*

1.4.6. *The impact of building and programming a robot on students' judgment about the ontological status of robots*

In order to assess whether robot making had an effect on participants' categorization of the robot in their common-sense ontology, we initially performed a paired ANOVA with two variables (general linear model): picture (1–10) and moment (before and after robot making). The results showed a significant effect for picture ($F = 148.8$; $P < 0.001$) and moment ($F = 36.7$; $P < 0.001$).

A significant interaction effect ($F = 7.53$; $P < 0.001$) between picture and moment was observed, indicating that robot making had an effect on the representation of robots, when measured with our questionnaire.

In order to assess whether any picture was given a different score in the pre- and post-questionnaires we performed a paired Student's *t*-test on the scores given for the whole set of 10 pictures in both the questionnaires as post hoc comparisons. Table 1.3 shows the mean scores given by participants before and after building and programming robots, when they were asked to answer the question "How much does this picture make you think about a robot?" using a 5-point scale for each of the 10 displayed pictures. The results showed significant differences in the scores given for 7 of 10 of the presented pictures (Table 1.3).

More precisely, the mean score for the post-questionnaire increased for seven items: single-function machine, animated character, human being, bionic component, multifunction machine, plant and animal. In contrast, it remained relatively stable for the anthropomorphic object, scientific instrument and camouflage insect items (see Table 1.3 and Figure 1.3).

Item	Pre-test mean SD (N = 79)	Post-test mean SD (N = 79)	T-test
Bionic component	$M = 4.10$ $\sigma = 1.236$	$M = 4.65$ $\sigma = 0.934$	$t(79) = 3.36$ $P < 0.001$
Multi-function machine	$M = 3.89$ $\sigma = 1.050$	$M = 4.22$ $\sigma = 1.034$	$t(79) = 2.79$ $P < 0.01$
Single-function machine	$M = 2.30$ $\sigma = 1.213$	$M = 3.54$ $\sigma = 1.269$	$t(79) = 7.94$ $P < 0.001$
Scientific instrument	$M = 2.20$ $\sigma = 1.275$	$M = 2.44$ $\sigma = 1.318$	$t(79) = 1.28$ ns
Anthropomorphic object	$M = 2.42$ $\sigma = 1.317$	$M = 2.06$ $\sigma = 1.284$	$t(79) = -1.819$ ns
Animated character	$M = 1.51$ $\sigma = 0.946$	$M = 2.28$ $\sigma = 1.290$	$t(79) = 4.71$ $P < 0.001$
Camouflage insect	$M = 1.19$ $\sigma = 0.662$	$M = 1.30$ $\sigma = 0.837$	$t(79) = 0.92$ ns
Human being	$M = 1.20$ $\sigma = 0.540$	$M = 1.67$ $\sigma = 1.163$	$t(79) = 3.65$ $P < 0.001$
Animal	$M = 1.16$ $\sigma = 0.565$	$M = 1.39$ $\sigma = 0.823$	$t(79) = 2.58$ $P < 0.05$
Plant	$M = 1.04$ $\sigma = 0.192$	$M = 1.24$ $\sigma = 0.604$	$t(79) = 2.69$ $P < 0.01$

Table 1.3. *Mean score given by participants (N = 79) for each picture (N = 10) in the pre- and post-questionnaire for the question "How much does this picture make you think about a robot?" (1–5 Likert scale) and comparison results (t-test). The items are ordered from the one most associated with a robot to the one least associated with a robot*

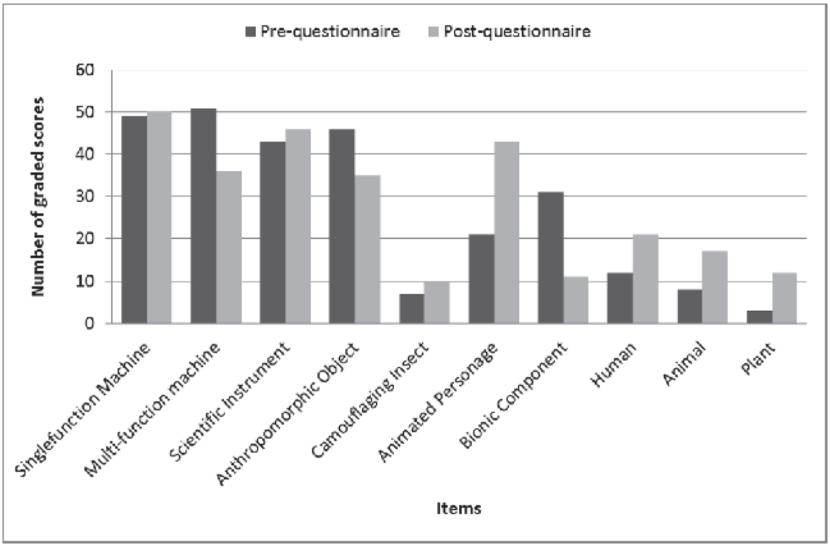

Figure 1.3. *Number of graded scores given for each picture on the pre- and post-questionnaires*

However, as in the pre-questionnaire, the bionic component (M = 4.65; r = 0.93) and multifunction machine (M = 4.22; r = 1.03) were the items that were most frequently associated with robots.

1.4.7. *The impact of robot making on graded versus all-or-nothing categorization*

In order to assess if building and programming robots had an effect on students' robot categorization, we compared the mean graded scores across the pre- and post-questionnaires. The mean graded score was 3.43 (r = 1.52) in the pre-questionnaire and 3.56 (r = 2.4) in the post-questionnaire, thus revealing that participants provided slightly more nuanced answers after making a robot.

Differences in the graded score obtained from the association between each picture and the idea of a robot that each participant had in their mind ("How much do these pictures make you think about a robot?"), before and after making a robot, may be considered as an indicator of how essentialist versus non-essentialist their assignment of the robot to living and non-living – and potentially to a new third category of entities – was. The paired Student's *t*-test performed on the graded scores for the whole set of pictures showed no significant difference across the pre- and the post-questionnaires ($t(79) = 0.043$; ns). Overall, participants' answers did not appear to become significantly more graded after making the robot.

Furthermore, we sought to investigate whether this result held for each picture individually. To this end, we performed a χ^2 test in order to compare the number of graded scores for each picture on the pre- and post-test questionnaires. In accordance with the limits of the χ^2 test, we also performed a *t*-test between the mean number of graded scores on the pre- and post-questionnaires when there were fewer than five graded scores on the pre- or post-questionnaires. The results showed that, although the average graded score for the 10 pictures taken all together remained globally constant between the pre- and post-questionnaires, the distribution of these scores varied across the pictures (Table 1.4 and Figure 1.3).

Specifically, we observed that for 7 of the 10 items, creating a robot from scratch had an effect on the number of graded scores given; this was the case for the multifunction machine, anthropomorphic object, animated character, bionic component, human being, animal, and plant (see Table 1.4). In contrast, no significant differences in the number of graded scores were observed before and after the robot making task for the remaining three items: single-function machine, scientific instrument, and camouflage animal (Table 1.4).

Finally, in order to assess whether the observed association could be interpreted in terms of an increase or a decrease in the number of graded categorizations in the post-questionnaires, we performed a Yule's *Q* test on the seven items, which were assigned significantly different graded scores in the pre- and post-questionnaires (Table 1.4). The results indicate that participants assigned a lower graded score for bionic component, multifunction machine and anthropomorphic object, and they assigned a higher graded score for the other items: animated character, animal, plant, and human (Table 1.4). In particular, the animated character and the bionic component appear to be the items which were most affected by the robot-making task, but affected in a different way: participants demonstrated a more graded and thus a non-essentialist categorization of the animated character; in contrast, they moved to a less graded and thus an essentialist categorization of the bionic component.

Item	***N* of graded scores in pre-test**	***N* of graded scores in post-test**	χ^{2a}	**Yule's *Q***
Single-function machine	$N = 49$	$N = 50$	$\chi^2 (1) = 0.054$ ns	–
Multi-function machine	$N = 51$	$N = 36$	$\chi^2(1) = 12.447$ $P < 0.001$	–0.370
Scientific instrument	$N = 43$	$N = 46$	$\chi^2(1) = 0.459$ ns	–
Anthropomorphic object	$N = 46$	$N = 35$	$\chi^2(1) = 6.297$ $P = < 0.05$	–0.273
Camouflage insect	$N = 7$	$N = 10$	$\chi^2(1) = 1.411$ ns	–
Animated character	$N = 21$	$N = 43$	$\chi^2(1) = 31.392$ $P < 0.001$	0.535
Bionic component	$N = 31$	$N = 11$	$\chi^2(1) = 21.237$ $P < 0.001$	–0.599
Human	$N = 12$	$N = 21$	$\chi^2(1) = 7.959$ $P < 0.01$	0.338
Animal	$N = 8$	$N = 17$	$\chi^2 = 11.266$ $P < 0.001$	0.417
Plant	$N = 3$	$N = 12$	$M_{Pre} = 0.04$ ($\sigma = 0.192$) $M_{Post} = 0.15$ ($\sigma = 0.361$) $t(79) = -2.584$ $P < 0.05$	–

[a]: A T-test was performed if the number of graded scores was lower than 5 in the pre- or post-test questionnaires.

Table 1.4. *χ^2 and Yule's Q results for the graded scores for 10 pictures on a 1–5 Likert scale in response to the question "How much do these pictures make you think about a robot?"*

In summary, after having assembled and programmed the robotics kit, participants demonstrated a more nuanced positioning of robots in relation to animated characters, but a more clearly defined positioning of robots in relation to bionic components (Table 1.4).

1.4.8. *Does familiarity with robots influence their categorization?*

In order to assess whether participants who were unfamiliar with robots would change their categorization of robots after robot making more drastically than those who were familiar, we performed a paired Student's *t*-test on the mean graded scores between pre- and post-questionnaires for both the unfamiliar and familiar groups.

In the pre-questionnaire, the mean graded score for the familiar group was 3.51 (r = 1.56), while for the unfamiliar group it was 3.36 (r = 1.50). In the pre-questionnaire, the score was 3.57 (r = 2.82) for the familiar group and 3.55 (r = 2.12) for the unfamiliar one. These scores thus reflect a slightly higher level of gradation in participants' answers. A paired Student's *t*-test did not reveal any significant difference in graded scores between pre- and post-questionnaire, both for the unfamiliar ($t(44) = -0.579$; ns) and familiar groups ($t(35) = -0.106$; ns). The results of the χ^2 test, comparing the number of graded scores for each item before and after robot making, indicate that the scores given by unfamiliar participants tended to stay stable across the pre- and post-questionnaires, except for half of the items. Similarly, responses by participants who were already familiar with robots tended to stay stable across pre- and post-questionnaire, except for three items (Table 1.5 and Figure 1.4.).

Unfamiliar participants have a higher number of graded scores to the animated character and plant and fewer graded scores to the multifunction machine, scientific instrument and bionic component. In contrast, participants who had previous exposure to robots gave a higher number of graded scores to the animated character and fewer graded scores to the multifunction machine and anthropomorphic object. One of the items, the bionic component, seemed to really differentiate the two groups of familiar/unfamiliar participants: although the number of graded scores was constant between the pre- and post-questionnaires for the familiar group, it tended to be markedly lower for the unfamiliar group in the post-questionnaire (Table 1.5 and Figure 1.4).

Items	χ^{2a}		Yule's Q	
	Unfamiliar	*Familiar*	*Unfamiliar*	*Familiar*
Single-function machine	$N_{Pre} = 24$ $N_{Post} = 28$ $\chi^2 = 1.467$; ns	$N_{Pre} = 25$ $N_{Post} = 22$ $\chi^2 = 1.260$; ns	–	
Multi-function machine	$N_{Pre} = 29$ $N_{Post} = 21$ **$\chi^2 = 6.474$; $P<0.05$**	$N_{Pre} = 22$ $N_{Post} = 15$ **$\chi^2 = 5.997$; $P<0.05$**	–0.386	–0.323
Scientific instrument	$N_{Pre} = 20$ $N_{Post} = 26$ $\chi^2 = 3.300$; ns	$N_{Pre} = 23$ $N_{Post} = 20$ $\chi^2 = 1.141$; ns		–
Anthropo-morphic object	$N_{Pre} = 24$ $N_{Post} = 21$ $\chi^2 = 0.825$; ns	$N_{Pre} = 22$ $N_{Post} = 14$ **$\chi^2 = 7.820$; $P<0.01$**	–	–0.435
Camouflage insect	$M_{Pre} = 0.07$ ($\sigma = 0.255$) $M_{Post} = 0.11$ ($\sigma = 0.321$) $t(44) = 0.813$; ns	$M_{Pre} = 0.11$ ($\sigma = 0.323$) $M_{Post} = 0.14$ ($\sigma = 0.355$) $t(35) = 0.329$; ns	–	–
Animated character	$N_{Pre} = 13$ $N_{Post} = 25$ **$\chi^2 = 15.722$; $P<0.001$**	$N_{Pre} = 8$ $N_{Post} = 18$ **$\chi^2 = 16.204$; $P<0.001$**	0.517	0.562
Bionic component	$M_{Pre} = 0.43$ ($\sigma = 0.501$) $M_{Post} = 0.07$ ($\sigma = 0.255$) **$t(44) = 4.200$; $P<0.001$**	$N_{Pre} = 12$ $N_{Post} = 8$ $\chi^2 = 2.029$; ns	–	–
Human being	$N_{Pre} = 8$ $N_{Post} = 12$ $\chi^2 = 2.444$; ns	$M_{Pre} = 0.11$ ($\sigma = 0.323$) $M_{Post} = 0.26$ ($\sigma = 0.321$) $t(35) = 1.406$; ns	–	–
Animal	$N_{Pre} = 6$ $N_{Post} = 10$ $\chi^2 = 3.088$; ns	$M_{Pre} = 0.06$ ($\sigma = 0.236$) $M_{Post} = 0.20$ ($\sigma = 0.443$) $t(35) = 1.966$; ns	–	–
Plant	$M_{Pre} = 0.05$ ($\sigma = 0.211$) $M_{Post} = 0.11$ ($\sigma = 0.321$) $t(44) = –1.354$; ns	$M_{Pre} = 0.03$ ($\sigma = 0.169$) $M_{Post} = 0.20$ ($\sigma = 0.406$) **t(35) = 2.240; $P<0.05$**	–	–

[a]: A *t*-test was performed if the number of graded or absolute scores was lower than 5 in the pre- or post-test.

Table 1.5. *χ^2 and Yule's Q results for graded scores on a 1–5 Likert scale given as an answer to the question "How much do these pictures make you think about a robot?" for 10 pictures*

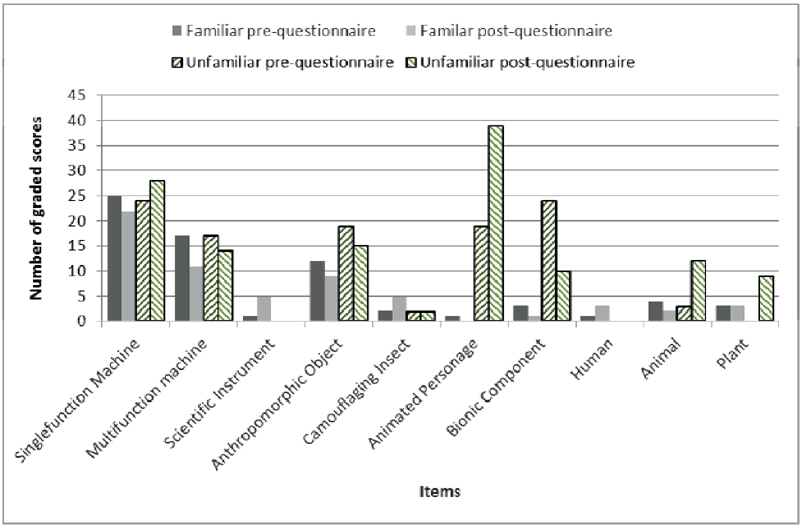

Figure 1.4. *Number of graded scores given for each picture on the pre- and post-questionnaire by familiar and unfamiliar participants*

1.4.9. *Dichotomous versus multiple categorization of robots*

We wished to assess whether the distribution of scores suggested (1) two groups of pictures in the pre-questionnaire – that is a clear living/non-living categorization of items in relation to the idea of a robot that participants had in mind – or (2) three groups of pictures in the post-questionnaire – that is a clear living/non-living/new entities categorization for the same items, again in relation to participants' mental images of robots.

Therefore, we performed an affinity propagation clustering algorithm [FRE 07] on the correlation matrices of scores given by participants on the pre and the post-questionnaires for each of the 10 pictures. Results did not show the emergence of a third category of items.

Two clusters (Table 1.6) emerged from the data, both in the pre and the post-questionnaires, showing that participants tended to make a clear distinction between "pure" machines (*single-function machine,* *multifunction machine, scientific instrument and bionic component*) and living or life-like entities (*human, animal, plant, camouflage insect and animated character*), in both the pre- and post-questionnaires. However, it has to be noted that one of the items, the anthropomorphic object, moved from the non-living cluster to the living entities cluster after the robot-making task (Table 1.6).

	Pre-questionnaire		Post-questionnaire	
Clusters	*Cluster 1*	*Cluster 2*	*Cluster 1*	*Cluster 2*
Single-function machine	X		X	
Multifunction machine	X		X	
Scientific instrument	X		X	
Bionic component	X		X	
Anthropomorphic object	X			X
Camouflage insect		X		X
Animated character		X		X
Human		X		X
Animal		X		X
Plant		X		X

Table 1.6. *Results of an affinity propagation clustering algorithm performed on the scores on a 1–5 Likert scale given as an answer the question "How much do these pictures make you think about a robot?" in the pre- and post-questionnaires*

1.4.10. *The impact of robot making on the educational roles envisaged for robots*

To assess whether robot making had an impact on a shift between different educational roles for robots, we performed a paired ANOVA on two variables (general linear model): role (object to be constructed and programmed, learning tool and classmate) and moment (before and after robot making). The results indicated no significant interaction effect between role and moment (F = 1.22; ns). Therefore, participants did not appear to change their preference for the different educational roles for the robot after they had built and programmed it (Figure 1.5 and Table 1.7).

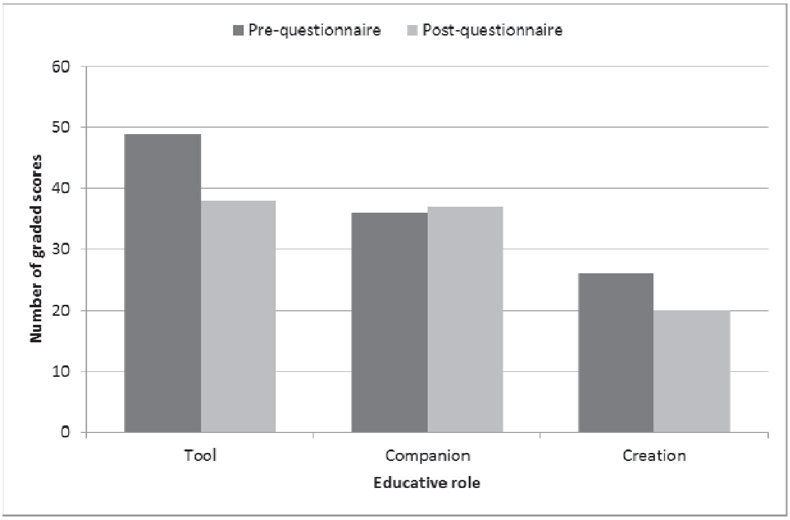

Figure 1.5. *Number of graded scores given for each educational role envisaged for robots on the pre- and post-questionnaires*

Educational role	χ^2	**Yule's *Q***
Tool	$N_{Pre} = 49$ $N_{Post} = 38$ $\chi^2 = 6.503$; $\boldsymbol{P<0.05}$	–0.276
Classmate	$N_{Pre} = 36$ $N_{Post} = 37$ $\chi^2 = 0.051$; ns	–
Creation	$N_{Pre} = 26$ $N_{Post} = 20$ $\chi^2 = 2.064$; ns	–

Table 1.7. *χ^2 and Yule's Q results for the score given in response to the question "Would you like your robot to be a) a tool, b) a classmate or c) an object to be created"*

1.4.11. *The impact of robot making on shift between the educational roles envisaged for robots*

In order to assess whether building and programming robots had an effect on the educational role participants attributed to the robot, we compared the mean graded scores for participants on the pre- and post-questionnaires. The mean graded score related to the educational roles envisaged for robots and could be scored from 0 to 3; the mean score was 1.41 (r = 1.06) in the pre-questionnaire and 1.06 (r = 1.07) in the post-questionnaires.

The paired Student's *t*-tests performed on the average scores for all the three roles revealed a significant difference between the graded scores obtained before and after the robotics activity ($t(79) = 2.2$; $P < 0.05$). Robot making appeared to have an impact on the graded score given for the different educational roles envisaged for the robot (the robot as an object to be constructed and programmed, the robot as a tool for learning school subjects, the robot as a classmate).

In order to assess whether this result held for each of the three proposed educational roles separately, we performed a χ^2 test to compare the number of graded scores given by participants for each of the three options in the pre- and post-questionnaires (see Figure 1.5). The results of the χ^2 test indicated that robot making had a weak impact on participants giving graded scores in the post-test (Table 1.7): only the gradation of the score for the "learning tool" option significantly changed across the pre- and post-questionnaires.

Finally, in order to assess whether we observed a prevalence of graded scores in the post-questionnaires, we performed a Yule's Q (Table 1.7) for the question for which scores differed significantly across the pre- and post-questionnaires, that is on the scores given for the "tool for learning school subjects" option. This analysis shows that participants gave fewer graded scores in the post-questionnaires for this option indicating that they did not attributed multiple educational roles to the robot.

1.4.12. *Does previous experience influence the educational role attributed to robots?*

In order to assess whether previous exposure to robots determines a lesser striking impact of robot making on students' attribution of educational roles to robots, we carried out several analyses. In the pre-questionnaire the mean graded score for the familiar group was 1.37 (r = 1.11), whereas the mean score for the unfamiliar group was 1.43 (r = 1.02). In the post-questionnaire, the mean graded score for the familiar group was 1.37 (r = 1.17), while that of the unfamiliar group was 0.82 (r = 0.922). No significant difference between the two groups was found using a Student's t-test. A significant result was obtained instead for the unfamiliar group (t = 3.14; $P < 0.01$). After robot making, unfamiliar participants thus appeared to provide less nuanced answers concerning the educational roles for robots, while the answers given by familiar participants seemed to stay stable.

We then verified whether these results were valid for each role separately. To do this, we performed a χ^2 test to compare the number of graded scores before and after robot making and a Yule's Q to examine the direction of the observed variation when significant differences were found (Table 1.8 and Figure 1.6).

Participants who were familiar with robots tended to give more graded scores for the "classmate" option after robot making, but no effect was found for the other two options ("object to be constructed and programmed" and "learning tool"). Participants who were new to robotics appeared to give fewer graded scores to the "learning tool" and "object to be constructed and programmed" options, while the number of graded scores given to the "classmate" option tended to remain constant (Table 1.8 and Figure 1.6).

To summarize, for familiar participants, only the role of classmate was affected in the sense that a higher number of graded scores were given. For unfamiliar participants, there were no changes across the pre- and post-questionnaires in terms of the number of graded scores; on the contrary, these participants appeared to have a more clearly defined idea about whether robots could be a learning tool or an object to be constructed and programmed.

Educational role	χ^2 *Unfamiliar*	*Familiar*	**Yule's *Q*** *Unfamiliar*	*Familiar*
Tool	$N_{Pre} = 28$ $N_{Post} = 17$ **$\chi^2 = 11.884$; $P<0.001$**	$N_{Pre} = 21$ $N_{Post} = 21$ $\chi^2 = 0$; ns	–0.471	–
Classmate	$N_{Pre} = 20$ $N_{Post} = 15$ $\chi^2 = 2.292$; ns	$N_{Pre} = 16$ $N_{Post} = 22$ **$\chi^2 = 4.145$; $P<0.05$**	–	0.335
Creation	$N_{Pre} = 15$ $N_{Post} = 8$ **$\chi^2 = 4.956$; $P<0.05$**	$N_{Pre} = 11$ $N_{Post} = 12$ $\chi^2 = 0.133$; ns	–0.399	–

Table 1.8. *χ^2 and Yule's Q results for scores given on a 1–5 Likert scale as an answer given by familiar and unfamiliar participants to the question "Would you like your robot to be (a) a tool for learning school subjects, (b) a classmate or (c) an object to be created"*

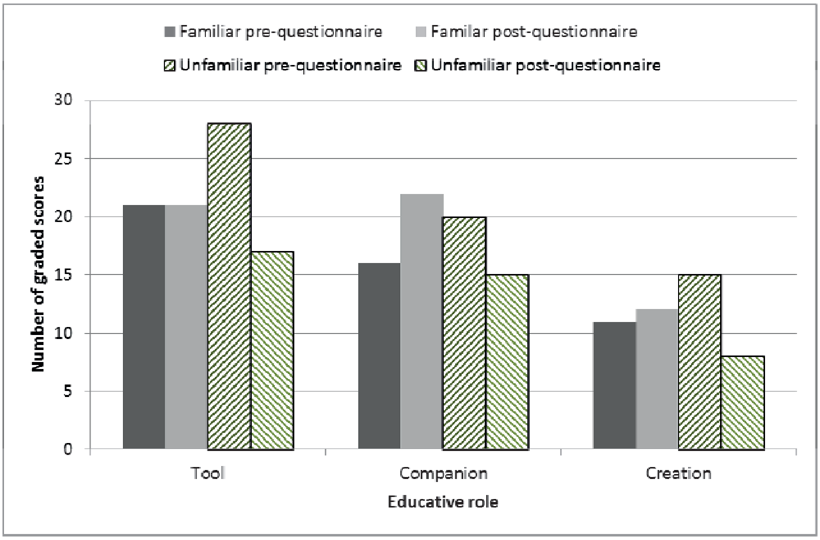

Figure 1.6. *Number of graded scores given for each educational role envisaged for robots in the pre- and post-questionnaires by familiar and unfamiliar participants*

1.5. Discussion

Prior studies have suggested that acquaintance with embodied artificial intelligences produces a more nuanced [SCA 95] and species-specific view of them [BER 08a]. In particular, the more young people become experienced with robots, the more they show a nuanced categorization of robots, as being somehow in between living and non-living entities [TUR 11]. This has led some authors to argue for the hypothesis that a new category is emerging, one that does not map onto humans, animals or artifacts (NOC hypothesis [KAH 12]). In this respect, ER kits possess an interesting peculiarity: in order for users to have a fully functional interaction with these robots, they have to build and to program them. Therefore, they continuously play the intermittent roles of creator and user, treating the robot as an animated and non-animated object at the same time [ACK 91, KAP 05, TUR 11].

These theoretical arguments and experimental findings have led us to question the status of robots for a sensitive target of users, that is students. The underlying idea was that, due to the particular status of robotics kits, the use of this kind of robot demands: (1) a non-obvious ontological categorization and (2) a continuous shift between different educational roles of the robot.

We thus carried out an experimental study where 79 participants completed two questionnaires, before and after getting involved in a 3-day robot-making event. The objective of these questionnaires was to assess which ontological category robots belong to and which educational role(s) they may cover, according to students.

To achieve this aim, we asked participants to associate their idea of a robot to a set of 10 images (representing living and non-living items) and to three kinds of educational roles (i.e. an object, a tool and a classmate). In particular, by using a system of graded scoring for participants' answers, we were interested to understand to what extent students' ontological and functional categorization of robots was essentialist (i.e. all or nothing) or non-essentialist (i.e. nuanced).

"Nuance" of categorization has been considered as an indicator of the sophistication of participants' representation of robots: the more the score was graded, the more the representation has been esteemed finely grained and species specific.

As expected, in the pre-questionnaire, participants mainly demonstrated an essentialist categorization of robots. This means that, before having concrete experience of constructing and programming a robot, students neatly assign robots to one specific ontological category. Additionally, results show that the more a student is familiar with robots, the more he/she tends to consider them as a sort of boosted computer; on the contrary, the less a student is familiar with robots, the more he/she tends to consider them as a hybrid item.

With regard to the educational roles envisaged for robots, the option "*object to be constructed and programmed*" appeared to be the most frequently attributed role for robots, followed by "learning tool" and "classmate". In line with our expectations, we observed no gradation in participants' scoring, that is no nuance in their judgments. This result can be explained by the fact that participants filled in the pre-questionnaire just before taking part in an event where they were going to construct and program a robot, so expectations about the event itself might have biased their answer. On the other side, contrary to our expectations and to the studies who have pointed out that familiarity with robots makes users assume different perspectives – once as engineer and once as psychologist [ACK 91] – and that they tend to attribute different roles to a robot [KAP 05, TUR 11]; no significant difference was noted between the familiar and unfamiliar groups.

To this concern, we have to acknowledge that even though familiarity with robots was calculated as a single indicator, familiarity should rather be considered as a composite indicator (e.g. having watched a robot in a science fiction movie does not engender the same kind of familiarity as having interacted with a real robot). In addition, we did not ask participants when they acquired such familiarity, whether it was at a recent time or longer ago. Thus, we cannot know how vivid the representations of robots they had in their minds actually were.

With concerns to the main focus of the study, which is the impact of robot making on the ontological and educational status of robots, results of the post-questionnaire show that robot making has an impact on categorization of robots among living and nonliving entities: as we expected and in line with the literature [SCA 95, BER 08], participants assigned a more graded score to four of the items represented in the pictures (*animated character, animal, plant and human*), whereas, contrary to our prediction, they assigned a less graded score to three of the items (*bionic component, multifunction machine and anthropomorphic object*), and their scoring stayed stable for the remaining items (*single-function machine, scientific instrument, camouflage insect*). Hence, it seems that when dealing with boundary or ambiguous items – that is non-living entities that borrow their appearance or functions from living entities (*the bionic component, anthropomorphic object and multifunction machine*) – participants made more clearly defined judgments about the degree of closeness between robots and these items after they had built a robot from scratch. In contrast, when dealing with living (*animal, plant, human*) or at least life-like items (the *animated character*), participants made more nuanced judgments about the degree of closeness between robots and such items. Furthermore, we noted that the bionic component and the multifunction machine were already the items most frequently associated with robots on the pre-questionnaire, with no particular gradation in their scoring. This result suggests that becoming acquainted with the functioning of a robot confirms previous beliefs about robots' place in common-sense ontology, but it also makes such beliefs more nuanced or sophisticated.

With regard to the differences between the familiar and unfamiliar, we observed that one of the items, the bionic component, seemed to mainly differentiate these two groups: while the number of graded scores stayed constant between the pre- and post-questionnaires for the familiar participants, there were much fewer graded scores for the unfamiliar participants. It thus seems that this kind of hybrid entity, like bionic components, becomes a sort of referential boundary when robots enter our ontology, a boundary which helps us to position robots among the range of the already known entities.

However, despite our predictions and previous studies (NOC [KAH 12]), no new specific category for robots seems to emerge from our data: participants seemed to make a clear distinction between "pure" machines (*single-function machine, multifunction machine, scientific instrument* and *bionic component*) and living or life-like entities (*human, animal, plant, camouflage insect* and *animated character*), both in the pre- and post-questionnaires. Interestingly, the anthropomorphic object was the only item that did not belong to the same cluster before and after the robot-making task: participants categorized it among the non-living entities on the pre-questionnaire and among the living ones on the post-questionnaire. This result suggests that while gaining experience in robotics does not lead to the creation of an NOC, we cannot exclude the fact that gaining familiarity with robots could progressively produce changes in our common-sense ontology, in terms of considering "alive" entities that we used to consider to "not alive". Of course, this point would require deeper investigation, and we consider it to be a plausible starting point for future research about the emergence of an NOC.

Finally, concerning the educational roles attributed by participants after the robot-making event, contrary to our predictions, there were no changes in nuance of judgment for unfamiliar participants; on the contrary, these participants appeared to have a more clearly defined idea about whether robots could be a learning tool or an object to be constructed and programmed. On the other hand, consistent with our prediction and to current literature on the issue [KAP 05, TUR 11], the role of classmate received a higher number of graded scores from familiar participants. This result can have two possible explanations. First, we shall remark that the robot the participants dealt with during the RoboParty® was a robotic kit; it thus may have been difficult to attribute to this kind of robot, created from a kit, a different role like that one of a classmate – at least, more difficult than if it had been another kind of robot, such as a humanoid, for instance. Second, investigations about people's ability to shift among different robot's roles can be ascribed to a more comprehensive debate concerning cognitive flexibility. Shifts dealing with the roles ascribed to a technological device are in fact made possible thanks to the flexibility of the human cognitive system, that is the ability to have multiple representations of the same object [CHE 06].

Familiarity and expertise are often said to affect cognitive flexibility, and thus the resulting ability to perform perspective shifts [SAN 13]. According to a number of authors (for an exhaustive review on this subject, see [CAÑ 05]) and contrary to our hypothesis, familiarity and expertise could cause cognitive inflexibility, since an individual who is familiar with or expert about something changes his/her perspective less often than a novice. Our experiment seems to confirm these findings by showing that once we acquire a comfortable level of expertise in relation to the role of the robot we tend to stick to it, rather to envisage another possible role.

Overall, our results show that, on the one hand, the more students get acquainted to robots, the more they tend to a nuanced categorization of robots in their common sense ontology (i.e. their assignment to an ontological category is not a matter of all or nothing, but rather a matter of degree). On the other hand, the more students get acquainted to robots, the more they tend to attribute a definite role to a robot. In this sense, as previous studies have already pointed out [SLO 03, KAP 05, TUR 11] robots share something with living entities and something else with non-living ones: (1) as living entities, they are susceptible to non-essentialist categorization; (2) as non-living entities, they need to have a precise role or function in order for people to interact with them. Moreover, while no third ontological category, beyond those of living and non-living entities, seems to emerge in the students' representation, one of the items presented in the task-rating pictures has passed from the non-living to the living category in the post-questionnaire. This might be interpreted as a minor cue of a prospective redefinition of classical ontological categories.

1.6. Conclusions, limits and perspectives

Our investigation on the impact of robot making upon robot representation points out that acquaintance with robots may have an impact on the place assigned to robots by students in their common-sense ontology, while their point of view about the roles served by the robot stay mostly unchanged. Hence, when providing judgments about robots, while ontological status seems to admit degrees, educational status seems not to admit degrees.

We consider this an interesting clue on the way toward answering the main question of this chapter, which is how firm robot's representations are. In fact, even if further studies are of course designed for a deeper understanding of the issue, we cannot exclude the possibility that the early exposure of students to robotic technologies, accompanied by a massive growth in the use of technology within daily tasks, in private and public environments, could lay the basis for a culture in which our common-sense ontology is slowly redesigned, until we reach an "environmental generational amnesia" [KAH 09]: a sort of illness of the new generation, who will forget preexistent natural and artificial categories and continuously elaborate new boundary categories.

On the contrary, when it comes to a robot's role, we might say that, in order for the user–robot interaction to be meaningful and efficient, the robot should have a precise function or role.

As frequently happens with studies investigating new research topics, our study had a number of different limitations in terms of materials and procedure. First, the 10 pictures displayed in both the pre- and post-questionnaires presented slight differences in form and content that could have influenced participants' answers. In terms of formal differences, some pictures were drawings while others were photos. Photos and drawings may trigger distinct interpretations of the items, which can, for example, be understood as real (photos) and imaginary (drawings) entities. However, because we were aware of such bias in the visual supports, we took care to maintain a one-to-one correspondence between the pre- and post-questionnaires: if an item (e.g. *an animal*) was presented in a photo in the pre-questionnaire (e.g. a photo of a dog), it was presented in a photo (e.g. a photo of a horse) in the post-questionnaire as well; in the same way, if an item (e.g. a single-function machine) was presented as a drawing (e.g. an illustration of a computer) in the pre-questionnaire, it was depicted using a drawing (e.g. a comic strip depicting a PC) in the post-questionnaire as well. In our future studies, this limitation could be overcome by displaying either only photos or drawings to represent all 10 items. Another interesting option that would provide a more rigorous semantics for the pictures has been proposed by Rakinson and Poulin-Dubois [RAK 01], whereby the category judgment concerns living and non-living entities with a high level of similarity (e.g. bird/airplane, animal/car). Moreover, although we took care to test such images in a previous test, in order to assess whether they were actually representative of living and non-living categories, we did not verify which ideas about living and non-living entities the participants of RoboParty® implicitly held, as Bernstein *et al.* [BER 08a] did in their study.

However, the emergence of dichotomous scoring for pictures displaying living entities versus pictures displaying non-living entities suggests the choice of items could be considered as valid. Second, the use of a Likert scale, which was deliberately selected because it is rather difficult to obtain yes/no answers to questions about robots [KAH 12], may have biased participants to express a graded judgment. This limitation, already highlighted by Kalish [KAL 95] in his study on categorization, is relevant in relation to our second hypothesis, concerning the increased number of graded scores in the post-test as one of the effects of robot making. As a possible solution, implicit methods could be envisaged (e.g. recording reaction time when participants are asked to associate their idea of robots with pictures representing a range of living and non-living category items).

Third, even though we referred to familiarity with robots as a single factor in the context of our study, this is, as discussed above (section 1.5), a resultant of several sources of acquaintance with robots, ranging from observation of robots (movies, cartoons, advertisement, etc.) to active interaction with robots (at school or at home). In future developments of this kind of study, we should therefore take into account different connotations of familiarity, and find more robust methods to assess whether such familiarity is a recent or older acquisition. This is even more relevant if we consider that, as pointed out by Dautenhahn [DAU 14, Chapter 38.2) differently to living species, the robots that populate our classrooms or robot competition today do not share a common evolutionary history, they are just very different robotic "species": "Thus, what we mean by 'robot' today will be very different from what we mean by 'robot' in a hundred years' time. The concept of a robot is a moving target, and we constantly reinvent what we consider to be 'robot'".