THE IMPACT OF DESIGN METHODS ON THE CREATIVITY OF 1ST-YEAR ENGINEERING STUDENT PROJECTS: THE CASE OF COMPUTER PROGRAMMING

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Abstract

Engineers able to produce creative products are very much required everywhere. However, classical engineering courses – especially the courses of the first two years of the career- tend to be content-intensive, focused on technical skills, with little space to foster creativity. As a result, when faced with the requirement of devising a creative product, engineering students often are unprepared to do so. In this paper we show that the introduction of design methods into the 1st-year engineering course of Computer Programming significantly improved the novelty of final-term projects. Each design-method was selected according to the stage of the creative process the course was going through: preparation, incubation, illumination or verification. Our hypothesis is that by blending design and engineering teaching with enough time to go through the creative process, novel ideas emerge more fluently. In this paper we provide a weekly description of the course activities and the results obtained. We expect this work helps to re-design some engineering courses towards a more design-engineering blended teaching to trigger creative thinking.

Keywords: Creativity, Engineering education, Design methods, User centred design

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1 INTRODUCTION

Creativity, understood as the ability to produce novel and useful products or services, is one of the most valued professional skills of engineers (Boyyet et al. 2010; Chak, 2011; Tomasco, 2010). However, engineers are not normally trained to be creative: according to the results reported by Kourzanian and Foley (2007), engineering students are not often exposed to practices that foster a creative educational environment during their academic life. This result is coherent with the fact that traditional engineering teaching practice tends to focus on the technical aspects of engineering (Andersson and Andersson, 2010) rather than "soft" skills, such as creativity is perceived.

The need for creative engineers has triggered intensive research on the topic of creativity in engineering education. As a result, there is an enormous amount of literature reporting efforts aiming to increase creativity in engineering education. Such efforts can be classified in three lines:

- **Identification of barriers and fosterers of creativity in engineering education**, as in Kazerounian and Foley (2007), Zappe et al. (2013), Liu and Schönwetter (2004) and Stouffer et al. (2004). They can be classified as pre-conceived ideas about creativity (e.g. "creativity is a soft construct", "creative people are born, not made"), personal factors (e.g. fear/embracement of failure/ unknown, impoverished/enriched emotional life) and specific practices that block or foster creativity. Ten of these practices, identified in Kazerounian and Foley (2007), are summarized in Table 1.

Table 1. Practices that block or foster creativity in engineering education

	Creativity fosterer practice	Creativity blocker practice
STUDENT THOUGHT PROCESS	Keep an open mind Search for multiple answers Ambiguity is good	Test/assignments with a unique right solution that students must recognize. In class, not leaving time for the students to experience ambiguity when searching for a solution. Teachers tend to give the right answer very soon.
	Iterative process that includes idea incubation	The value of working efficiently being translated to getting to a solution quickly, no time to "incubate" a better/more creative solution
TEACHING METHOD	Reward for creativity	Marks assigned for correctness of the final answer/product and not for the creativity shown in the process or the final product itself
	Learning to fail Encouraging risk	Grades being immediately decreased for giving a wrong answer, with little opportunity to learn from mistakes.
MOTIVATION & INSPIRATION	Lead by example	Lessons focused solely on technical aspects, not mentioning stories of innovators in the field.
	Internal motivation	Little time and emphasis devoted to show how the topic affects the student life beyond marks and class requirements. Assignments equal for all students, not tailored to their individual interests.
	Ownership of learning	Few elective classes, rigid curriculum

- **Description, compilation and evaluation of different idea-generation methods** that might help to devise creative products or solutions, as in Berk, (2013) and Liu and Schönwetter, (2004). This type of work is very helpful, as Chulvi et al. (2013) have reported that using any of these methods generates more creative ideas than using no method at all. However, the teaching and use of these methods alone is not enough for students to develop a truly and permanent creative thinking, as the creative process occurs in stages: preparation, incubation, illumination and verification (Wallas, 1926; Mumford et al. 1991, Stouffer et al. 2004) and the idea-generation techniques are used in only one of these (illumination).
- **Course-specific experiences** that helped students to improve their creative thinking, as in the Problem/Project-Based Learning courses reported by Zhou, (2012) and Stouffer et al. (2004) or creativity-focused courses, as in Morin et al. (2014).

We realized that none of these previous efforts focused on blending design methods with the engineering teaching so as to provide activities and enough time for all the stages of the creative process to take place. We hypothesize that by applying the right design method at each stage of the creative process novel ideas might emerge more fluently. Such practice is a common place in industrial design education, but it is seldom found in engineering education.
In this paper we describe a teaching experience - applied to the course of Computer Programming for 1st year engineering students - where classical design methods were included since the very beginning of the course, in parallel with the programming technical contents. As a result, the course included - in different degrees- the 10 creativity fosterer practices identified by [Kazerounian2007]. Results were promising: a significantly higher percentage of students projects of the modified course were classified as of high/medium novelty than those in a normal Computer Programming course.

2 ENGINEERING-DESIGN BLENDED TEACHING EXPERIENCE

Before implementing the new engineering-design blended course, the 17-week Computer Programming devoted the first 13 weeks (2 lessons per week, 70 minutes per lesson) to cover technical contents of a given programming language. During week 14 students formed teams of 5 people. Each team was required to propose a programming project where they would apply the contents learnt during the course. The projects had only technical requirements establishing the minimum complexity of the code developed. The progress made by the groups on the project was checked during weeks 15 and 16 and the final project presentation (fully functional prototype presented to the teacher of the course) was carried out on week 17.
The new engineering-design blended teaching for fostering novel projects in the course of Computer Programming had three main changes. First, the project had a real client the students had to solve a problem for: 3-5 year old kids from poor nurseries that had to improve their mathematical/logical reasoning. Thus, human-centered design methods had to be included. As small kids are not necessarily proficient in the use of keyboard and mouse, students were required to include ad-hoc interfaces in their projects. To do so, a second major change was introduced in the course: students had to use Arduino boards and accessories. Third, the project work started as soon as the course did to allow time for all the stages of a creative process to take place: Preparation, Incubation, Illumination and Verification. Figure 1 shows a schematic of the course organization, identifying the 4 stages of the creative process.

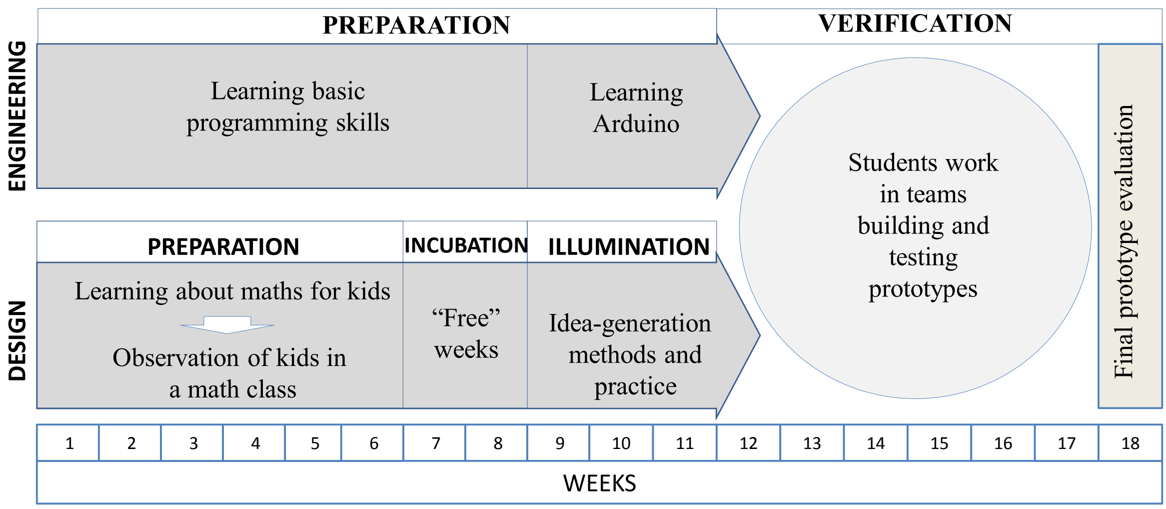

Figure 1. Course structure under the new methodology

The figure shows that during the first 11 weeks the course lessons were divided in 2 main parallel areas: engineering and design, each taught by an engineering/design teacher in separated but coordinated lectures. The engineering teacher was present in all the design lectures. The engineering area was entirely devoted to the preparation stage of the creative process. That is, making sure the students understood the technical problem to solve and had a sound knowledge of computer programming and Arduino. During these lessons students learnt about the concept of algorithm, variables, operators, conditional execution of code, loops, arrays, files, the Arduino board, sensors (mics, flex sensors, keypads, buttons and infrared sensors) and actuators (LEDs, motors, speakers). During the same time, the design area covered 3 stages of the creative process. The first 6 weeks were devoted to the preparation stage: knowing the final user and his/her needs in the framework of the project topic (math for kids). Thus, during those lessons students had to identify the key concepts of the project (kids, math, technology and inequality), get familiar with the learning outcomes set by the Chilean Education Ministry for Math for 3-5 year old kids, collect information about commercially available games that would help to achieve those learning outcomes, propose improvements to those games and sketch new games (not necessarily electronic games). The preparation stage of the design area finished with the students applying several human-centered design methods while visiting different nurseries to observe a Math class for kids as well as their behavior during playtime and to interview the teacher. During the next 2 weeks students were given “free” time, to leave time for the incubation stage. Finally, the illumination stage lasted for 3 weeks and it started with a practical lesson on creativity, characteristics of creative products and idea-generation methods (e.g. brainstorming, brain-writing, bio-inspired design, cross-domain inspiration, structural matrix). During the second week, each group was required to generate 100 project ideas. The third week was devoted to select the 3 best ideas to be presented to the teachers of the course. The verification/evaluation stage started with the selection of the project to be built, based on the creativity of the idea and its technical feasibility. This stage took 6 weeks and during that time students built several prototypes, with incremental and improved functionalities. Every week the students had to present their evolving prototype and they were encouraged to test their prototypes with kids close to them. The work of the following week was agreed with the instructors of the course. The final week the prototypes were tested by the 3-5 year old kids along with their teachers, who came to the university premises for this evaluation. Table 2 shows the week-by-week schedule of the course with the name of the design-methods used in each week.

Table 2. Weekly activities for the Computer Programming course under the new approach

	Design activities	Engineering activities
1	- ***Word-Concept Association*** (IDEO Method Cards): Recognizing the key concepts of the project: math, kids (final user), technology and inequality from a motivational video prepared by the teachers - ***Publications Research/ Secondary research*** (Kumar2013, IDEO Method Cards): Understanding the 28 learning outcomes set by the Chilean Education Ministry for children of 3-5 years old by selecting 5 out of 100 images of math games for children and identifying the learning outcome of each.	- Understanding and applying the concept of algorithm
2	- ***Competitive product survey/Analogous models*** (IDEO Method cards, Kumar 2013): Each team presents 5 selected games, focusing on main features, learning outcomes and improvement suggestions	- Entering and displaying information via the computer screen
3	- ***Paper prototyping/Concept sketches*** (IDEO Method cards, Kumar 2013): Each team uploads a document with their own game sketches addressing the first 12 learning outcomes	- Using variables and operators
4	- ***Paper prototyping/Concept sketches*** (IDEO Method cards, Kumar 2013): Each team uploads a document with their own game sketches addressing the next 16 learning outcomes	- Using if-else
5	- ***Lesson about user observation techniques***: Fly on the wall, shadowing, rapid ethnography, still-photo survey, surveys & questionnaires (IDEO Method cards)	- Using loops

6	- ***Field visit*** *(Kumar 2013):* Teams visit nurseries to apply observation techniques while attending a Math class for kids and observe playtime. - ***Subject matter expert interview*** (Kumar 2013): students interview the Math teacher	- Using arrays
7	- Incubation time	- Using functions
8	- Incubation time	- File handling
9	- ***Workshop on creativity and idea-generation methods***	- Introduction to Arduino - Demos of Arduino games
10	- ***Concept Catalog*** *(Kumar, 2013):* Each team presents a document with 100 ideas of Arduino+web-based math/logical games for kids	- Working with keypads and led screens
11	- ***Concept evaluation*** (Kumar, 2013): Each team presents the 3 best ideas (out of 100). Teachers (who previously studied the 100 ideas) help selecting a novel & technically feasible idea	- Working with motors, buttons, and photo-resistors
12-14	- ***Concept prototype*** (Kumar 2013): Prototype partial construction	- Project coaching
15-17	- ***Solution prototype*** *(Kumar 2013)*: 1st /2nd /3rd version of functional prototype tested with kids	- Project coaching
18	- ***Final prototype evaluation*** by kids and teachers from 4 council nurseries	

We observed that this way of implementing the course used several of the creativity fosterer practices identified by Kazerounian and Foley (2007), as shown in Table 3.

Table 3. Relationship between creativity fosterer practices and activities of the course

Creativity fosterer practice	**Course activity**
Keep an open mind Search for multiple answers Ambiguity is good	During at least 10 weeks, students know they have to come up with a project idea, so they are forced to keep on looking for an idea during this time. Finally, they must propose 100 different ideas.
Iterative process that includes idea incubation	"Free" weeks. Refinements to the project due to unexpected technical difficulties or idea improvements.
Reward for creativity	Marks assigned for novelty of projects
Learning to fail Encouraging risk	Project final mark given at the final presentation. Intermediate mistakes during prototype construction did not decrease grades
Lead by example	Innovative games for children shown during the course
Internal motivation	Benefits beyond the class (impact in life of poor children). Different projects for different students.
Ownership of learning	Project chosen by the group. Learning adapted to the needs of each project.

3 RESULTS

The 65 students of the course presented the 13 projects described in the Appendix. To evaluate the novelty of the projects we used the algorithm shown in Figure 2, by Sarkar and Chakrabarti (2011).

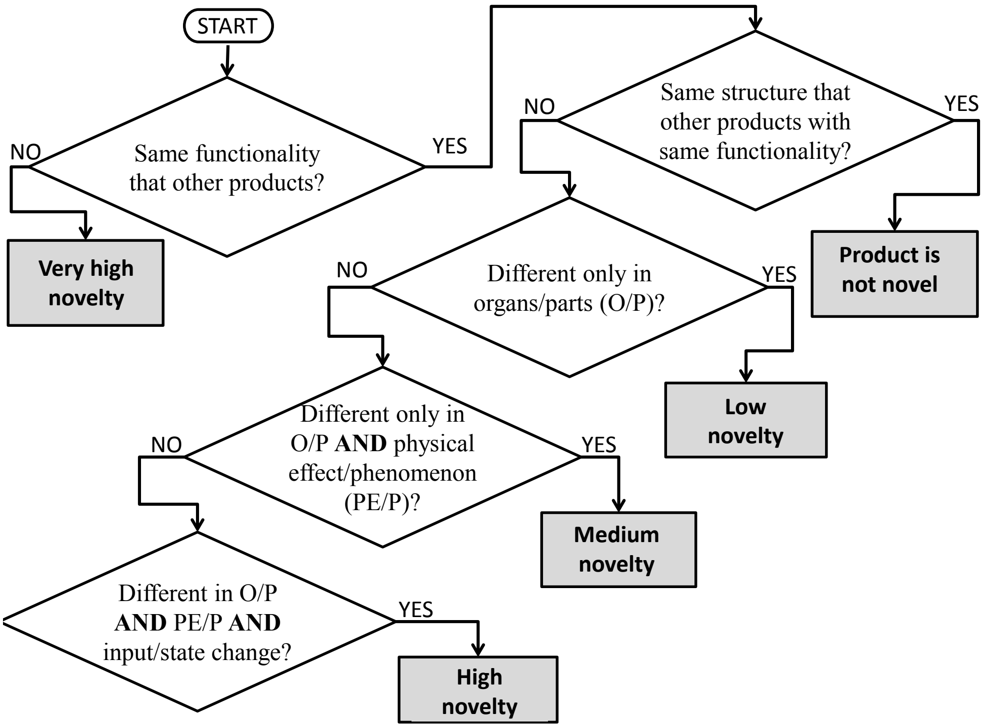

Figure 2. Flowchart of the algorithm applied to evaluate the novelty of projects

Figure 3 shows the distribution of the degree of novelty of the 13 presented projects. It can be seen that about 65% of projects can be classified as of medium or high novelty. According to the algorithm proposed by Sarkar and Chakrabarti (2011), very high novelty can only be achieved when the product performs a completely new function (e.g. X-Ray machine). Therefore, as the function of helping kids to think logically/mathematically is not new, no project could be evaluated as of very high novelty.

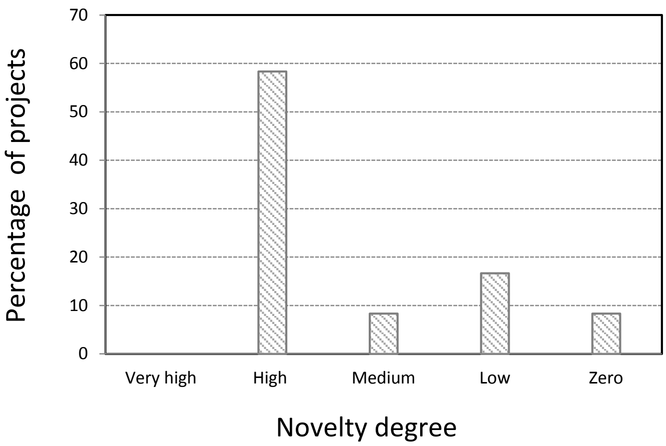

Figure 3. Percentage of projects as a function of their degree of novelty for the modified Computer Programming course

To know whether this percentage of novelty can also be achieved without the engineering-design blended teaching strategy, the following semester 4 sections of the same Computer Programming course were also asked to propose Arduino projects. This time, no final user was given and the course was taught as usual. Figure 4 shows the novelty results under this conventional approach.

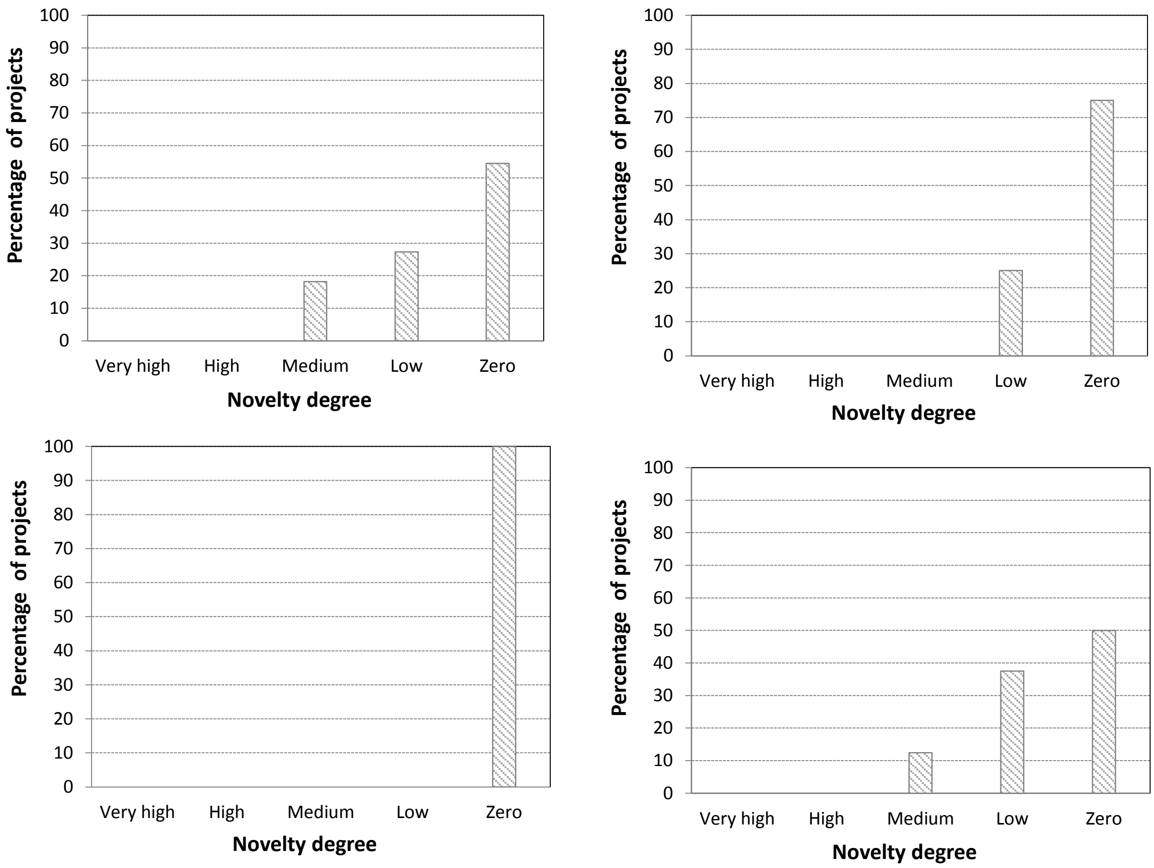

Figure 4. Percentage of projects as a function of their degree of novelty for the unmodified Computer Programming courses (upper left: section 1, 11 projects; upper right: section 2, 8 projects; lower left: section 3, 6 projects; lower right: section 4, 8 projects).

A brief description of the projects of each section is given in the Appendix. It can be seen that the level of novelty drops significantly: in 2 out of 4 sections there was not a single project that could be classified with a medium or high novelty. In the remaining sections, only 12% and 18% of projects could be classified as of medium novelty. It is worth noticing that one of these sections (section 4) had one practical lecture on idea-generation methods.

We could observe that without the design-methods inclusion:

- The project preparation stage of the design area was not present. No secondary research, competitive product survey or observation techniques were carried out. In many cases, the lack of a specific final user resulted in lack of focus and difficulties to find specific needs to meet.
- Once a project was chosen, no group researched further about the final user of their project, his/her needs/problems or different solutions to the same problem.
- Students did not allow themselves time enough to think for a while on a project idea or to look for new ideas. The trend was to adopt the first feasible idea that emerged in the team.
- As a result of the previous facts, the projects tended to be a small-scale copy of a system that already exists (e.g. a crossing with synchronized traffic lights, a lamp activated by touch, a car remotely controlled, an Arduino-based version of a very known game), which make them no novel at all.

4 CONCLUSIONS

In this paper we reported the results, in terms of the novelty shown by the projects proposed by students at the end of the semester, obtained after modifying a course in Computer Programming for 1st year engineering students. By blending design methods and programming techniques since the beginning of the course, the students were given enough time to go through the 4 stages of the creative process assisted with a variety of design methods.

As a result, we could relate different activities carried out during the semester to the fosterers of creativity identified by Kazerounian and Foley (2007) and thus, the novelty of the projects proposed by the students increased significantly with respect to the proposals made when no design techniques intervention were made.

It is worth highlighting that the inclusion of the design methods did not degrade the learning of the technical skill in computer programming (measured as the percentage of students that fail the course). Quite the opposite, by being motivated by their creative projects and their impact on the life of the children, students worked very hard in learning programming and improving their projects.

We think that this engineering-design blended teaching experience can be adapted to engineering courses where an applied final project could be used to evaluate learning. In this way, we can produce engineers better prepared to the challenges of the professional environment.

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APPENDIX

Table A. Description of projects in the modified Computer Programming course

Project name (learning outcome)	Description
Pianomat (association number-quantity)	The kid uses gloves equipped with flexion sensors. In the screen a piano made of ten keys, numbered from 0 to 9, is shown. The kid must flex the finger with the number corresponding to the right answer to the question displayed on the screen. By answering at the right speed, the kid listens a melody as s/he flexes her/his fingers.
The farm (pattern recognition, association sound-image)	Farm animal sounds are played following a pattern (a sequence of 3-4 sounds). Using an ad-hoc keypad, the kid must press the images of the corresponding animals, following the same sound pattern.
Magic cubes (simple arithmetic operations)	The kid must select the answer to a question by lifting one of 4 cubes. Each cube has numbers or images printed on their sides. A photo-resistor detects the lifted cube. The first kid to get 3 right answers wins the game.
Led ruler (length/distance estimation)	A line of LEDs in a small wall allows measuring distance. By placing a distance sensor at one extreme of this wall, the number of LEDs that turn on depends on the distance of an object place along the wall. The kid is asked to position an object at a given distance from a reference point. After the kid has made his/her guess, the corresponding LEDs are turned on to check how close the estimation was.
Children barnyards (simple arithmetic operations)	Two "barnyards" made with wood, with capacity for 8 kids each, have different shapes (triangle and square). On a screen, the number of kids that must be inside each barnyard (identified by its shape) is displayed. Two groups of 8 kids compete to get the right number of children inside each barnyard. The detection of the number of kids is made by infrared sensors located at the entrance of each barnyard.
Supermarket (shape recognition)	Real-life products found in a supermarket are shown in the screen. Using an ad-hoc keypad with basic geometric shapes, the kid must press the buttons with the geometric shapes found in the object shown in the screen. Feedback is given as the kid looks for the geometric shapes.
The trip (object-situation association)	According to the destination of the trip shown in the computer screen (beach, mountain, countryside, etc.) the kid must choose the elements it must take to his/her trip. Selection is done by clicking on an ad-hoc keypad.
The knowledge race (shape and quantity recognition)	Simple trivia game. Every right answer turns a led on. The first kid to get 10 LEDs on wins.
The climber (shape and quantity recognition)	Trivia game. Every right answer lifts a toy up to a mock mountain using a servo motor. The kid wins when the climber gets to the top of the mountain.
ArduinoCars (shape and quantity recognition)	Trivia game for two kids. After answering correcting a question, the car of the kid advances a few centimeters in a racetrack with the help of a servo motor. The first car to get to the goal wins.
Light mazes (spatial skills)	On a LOL shield (matrix of 14x9 LEDs) the kid must drive a little ball to the exit pressing arrows (back, forward, right and left) in a keypad to get through a maze.
Magic carpet (spatial skills)	By stepping over a carpet with numbers and shapes on it, the kid must select the right answer to a question. The position of the kid in the carpet is registered by a distance sensor.

Table B. Description of projects in normal Computer Programming courses

Project	Description
SECTION 1	
1.1	Arduino-version of the Fourth King card game
1.2	Sound-activated mobile for babies
1.3	Arduino-based metronome
1.4	Digital clock made of LEDs
1.5	Drink dispenser
1.6	Remotely controlled toy car
1.7	System to detect when a toddler approaches a stair
1.8	Police car controlled by Arduino (controlling movement and lights)
1.9	Pac-man game in a screen made of 14x9 LEDs (LOL Shield), controlled by Arduino
1.10	Memory game with buttons and LEDs
1.11	Lights that turn on and off according to the rhythm of the music
SECTION 2	
2.1	Liquid dispenser: depending on the button pressed, the content of one of three bottles is delivered by turning on a valve
2.2	Temperature-activated fan
2.3	Light pattern repetition: the user must repeat the light pattern shown in a led screen made of 14x9 LEDs
2.4	Breath alcohol meter
2.5	Digital clock
2.6	Volume control (once a limit of dB is reached, the volume of the speaker cannot be increased)
2.7	Sound-activated lamp
2.8	Reaction speed game: the first player to press the button of the light that turns on, wins
SECTION 3	
1.1	PetSmart: Pet food dispenser
1.2	Temperature-activated fan
1.3	Digital environment thermometer
1.4	Small-scale smart parking (red light when no more parking spaces are available)
1.5	Backward counter (simulating a bomb)
1.6	Presence detector (when someone enters a room, a light flashes)
SECTION 4	
4.1	Small-scale crossing with two synchronized traffic lights
4.2	Light clock: lights turn on as the hours pass
4.3	Cheeky monsters: a reaction speed game, where different monsters are illuminated (one at a time, at fast speed). When the light of a monster remains on for more than 1 second, the user must touch that monster before 1 second has elapsed since the light went on
4.4	Football time: trivia game, right answers get a ball shoot to the “enemy” arc
4.5	Trivia game: right answer is registers by turning a light on. The first team to get 5 lights on wins
4.6	Follow me: in a 3x3 led matrix a figure is shown. The user must select the right figure from a keypad.
4.7	Vane & anemometer
4.8	Drinking trivia game: if the user does not get the right answer, s/he must drink in a random quantity of liquor displayed in the screen