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Computational thinking in Montessori primary school

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Abstract

Here, we contribute to the debate on the relationship between Montessori's pedagogy and new technologies. In this longitudinal study we used a mixed methodological approach, relying on structured evidence, field observations and notes. We show how in children, following the use of technological material aimed at developing computational thinking, in the five years of primary school in a Montessori class in Grottaferrata (RM), creativity and a sense of community have increased. The sense of community has consistently remained at a good level. The pervasiveness due to the error at a low level. Our evidence indicate how technological materials must respect the typical characteristics of Montessori development material to be integrated in school job: freedom of choice, error control, aesthetic attractiveness, autonomy of use, manual interactivity, possibility of collaborating with peers, repetition of the exercise, quantity limits are essential characteristics.

Il lavoro si propone di contribuire al dibattito sul rapporto tra pedagogia Montessori e nuove tecnologie. Attraverso un approccio metodologico misto, che usa sia prove strutturate sia osservazioni e note sul campo, questo studio longitudinale mostra come, durante i cinque anni di scuola primaria di una classe Montessori in una scuola di Grottaferrata (RM), l'uso di materiale tecnologico mirato allo sviluppo del pensiero computazionale si è accompagnato, nei bambini, a un aumento della creatività e del senso di comunità e al mantenimento di un buon livello di autoefficacia e un basso livello di pervasività dovuta all'errore. L'esperienza sottolinea in particolare come, per integrare i materiali tecnologici nel lavoro scolastico, essi debbano rispettare i caratteri tipici del materiale di sviluppo Montessori: libertà di scelta, controllo dell'errore, attrattività estetica, autonomia di utilizzo, interattività manuale, possibilità di collaborare tra pari, ripetizione dell'esercizio, limiti di quantità.

Keywords: computational thinking; innovation; Montessori; robotics; creativity

Parole chiave: pensiero computazionale; innovazione; Montessori; robotica; creatività

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1. Introduction and definition of the study problem

Montessori pedagogy was born in Rome in the early twentieth century and today it is a consolidated and widespread reality in more than 30 countries. The development thereof has always moved inside an inevitable dynamic between innovation and maintenance of tradition, and it can be said that tradition prevailed, above all due to the approach given by Montessori to her pedagogy from the beginning, through an intense and incessant training of teachers. In our opinion too, the defence of Montessori orthodoxy is important, but without it becoming a rigid sectarian closure. Basically, we agree with what the pedagogy historian Giacomo Cives writes:

> «We understand the reasons for the protection of the system, and we understand how the tension has accompanied Montessorism, especially in America, between orthodoxy and heterodoxy, fidelity to the original setting and mediations with other scientific relationships. But safeguarding the originality of the Montessori identity does not seem to have to preclude an opening towards developments in the education sciences, which are growing and developing. The right defence of the original basic choice cannot in any way mean isolation from the educational research in progress and from the comparison and integration with the new pedagogical, didactic and psychological contributions, as long as they do not cancel off and distort the qualifying characteristics of the Montessori approach» (Cives, 2001, p. 128, *auth. trans.*).

One of the strongest innovations that has affected pedagogy is undoubtedly the arrival of the so-called information and communication technologies (ICTs). ICTs changed and keep changing our lives and, consequently, have opened wide debates among those involved in education, including teachers and Montessori scholar(s). The range of possible opinions with respect to the introduction of ICTs in Montessori classes lies in a continuum that goes from the total refusal of every electronic device up to an uncritical enthusiasm of those thinking that the use of material can be entirely replaced by technologies. A good example are Apps that reproduce on Tablets the "iron geometrics", one of the development materials. Such substitution however forgets that working with iron geometrics goes beyond placing figures in special spaces and a whole series of direct and indirect purposes are present in it. Along this continuum, is more common to find intermediate opinions, which often welcome a computer in the classroom, but sometimes the use thereof is only the prerogative of teachers or is regulated by different rules in each class. It is evident that today, to guide the choices of those who work in Montessori schools, a reflection is necessary on the part of the scientific-pedagogical community that deals with Montessori pedagogy. This exercise should be based on controlled experiences, in a virtuous circle between research and teaching.

Our study contributes to this debate, focusing on the introduction of technological materials for the development of computational thinking in primary schools with Montessori differentiated teaching, reporting an experience in which technological development materials have been successfully introduced in a manner consistent with the principles of this pedagogy that was born in the early twentieth century.

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2. Literature review

In Italy, an important contribution to this topic was proposed by Valle (2017), who gathered the lessons held for teachers trained at the Montessori National Opera. Valle, who is neither a teacher nor a pedagogist but an engineer who works at the Swiss Center for Scientific Computing, first remembers how fascinated Montessori was by the technological development and what was her opinion on introducing technologies at school: «I believe [...] that the introduction of mechanical aids will become a general necessity in the schools of the future. [...] However, I would like to underline that these aids are not sufficient to achieve the totality of education» (Montessori, 2015, p. 5). This sentence already provides an answer to the question concerning the introduction of technologies in Montessori classes because it underlines how it cannot replace the sensory, motor, and social development of the child, which takes place above all within six years of life. For this reason, Valle establishes a first criterion he clearly expresses in two statements.

> «Avoid the use of technology until six or eight years of age, at least in school. Children must have acquired the ability to abstraction before having access thereto. Make concrete experiences, afterwards it is too late. It goes without saying that experiences in front of a screen are not concrete» (Valle, 2017, p. 21, *auth. trans*.).

Without prejudice to this limitation, technological materials must be thought of as any other development material.

> «We need to think about the educational purpose of using any technological material. If it serves to this purpose, fine, otherwise it should be eliminated. It is necessary, as she did for all materials, to try and study them, but above all to observe the use that children make of them. Only at this point, if the specific technology proves to be up to the task, we can use it in the same way as other development materials» (*Ivi*, p. 17, *auth. trans*.).

In the international context, the director of the courses for the primary school of the AMI (Associazione Montessori Internationale), Greg MacDonald (2016, p. 99), states the same principle: «sensorial avenues should be "explored and exhausted" before turning to digital devices». Secondly, he specifies that it is possible to do this from the primary school years onwards, when such devices become tools for the self-construction of knowledge and the search for knowledge in general. Finally, he argues that «these devices should be material for the classroom and should be fully compliant with Montessori's philosophy and practice». In MacDonald's opinion, considering a technological material as a development material means, as it will be seen better later, making sure that it allows free choice and self-correction, respects the child's timing and spontaneous repetition, facilitates sensory exploration and the use of the hands, makes abstractions concrete, makes concentration possible, proposes tasks with a clear objective, isolates a dominant activity.

Elkin, Sullivan and Bers (2014) analyzed the integration of new technologies into Montessory pedagogy, with a particular emphasis on robotics. The authors start from some assumptions. First, they report the conclusions of

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research according to which children who receive an education in STEM when they are little, when they choose careers in science-technology as adults, demonstrate fewer gender stereotypes and encounter fewer obstacles. Second, the authors consider robotics as one of the ways to teach STEM disciplines most aligned with Montessori educational principles, because it allows children to participate in creative explorations, develop motor skills and eye-manual coordination, engage in collaboration and teamwork, and develop a stronger understanding of the mathematical concepts of number, size and shape. Furthermore, robotics promotes "debugging", that is the resolution of problems through the identification of process errors and the creative search for different solutions. Third, research shows that children as young as four can successfully build and program simple robotics projects while learning a range of engineering and computer science concepts, and that teachers can successfully integrate robotics with other curricular areas. Finally, noting that there is very little research on integrating technology into Montessori early childhood education, the authors set out to identify guidelines for effectively integrating robotics teaching materials into a Montessori class.

To this end, a three-day university training, controlled with questionnaires, interviews and learning tests on how to develop a curriculum using LEGO® WeDo™ material was provided to some educators. Then, the case study on an educator emerged who made, and constantly documented on a blog an integrated robotics curriculum with a social science unit in her Montessori class of 19 students of mixed ages, from grade 1 to grade 3, corresponding to the first three years of the Italian primary school.

The result of this research is a set of criteria that suggest how to effectively integrate the fundamental concepts of programming and engineering in Montessori education: 1) the robotics material must be self-corrective, it must be able to be used autonomously, and stimulate different senses: touch, sight and hearing; 2) the confidence on the part of the teacher in the use of robotics materials; 3) the material still must foster collaboration between the students.

In conclusion, this study argues that implementing a system of knowledge and application of robotics, and more generally of computational thinking, in Montessori classes not only is possible but the very structure of Montessori practices facilitates this integration. Not surprisingly, one of the criteria for a correct integration of robotics material in the complex Montessori system is the need for it to maintain the typical characteristics of the Montessori material. The study suggests that robotics should be a means through which new contents can be made known, a new way of exploring different areas of knowledge, favouring the holistic approach typical of Montessori classes, where body and mind work incessantly together. Also for this reason the authors suggest developing robotic materials as open and multifunctional as possible, so that each student can develop computational thinking, following their own interests, inclinations and specific levels of sensory and motor development. The material used in this case study, LEGO® WeDo™, in addition to being intuitive, maintains the typical characteristic of LEGO®, namely versatility, and for this reason makes this pedagogical approach possible. The same material has also been used in the work discussed in our article, as it gives the possibility of developing divergent thinking in problem solving. The LEGO® bricks, in fact, open up the solution of a problem towards many different paths: each brick can become the key in the solution and lead to new ideas and new paths. The development of this creative and divergent thinking is also necessary and implemented in the solution

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of robotics and programming problems, especially when it is purely playful. When we are busy playing, our brain naturally tends to look for new ways to face the challenges, it focuses not much on the problem but rather on how to overcome it and how to reach the goal. These game features are maintained identical within the programming challenges with LEGO®, which allow to focus one's attention on different ways of solving the same problem (Romero & Kamga, 2016).

Furthermore, Elkin, Sullivan & Bers' study emphasizes how children easily became passionate not only about robotics itself, but also about the content it conveyed. The proposed didactics maintained a playful aspect, which is fundamental for structuring a motivational path that is functional to learning. The children involved tended to go beyond the mere use of the robot because, to make it work better, they had to activate a more in-depth research process than the simple method of trial and error.

As a conclusion to this review, we report Jones' study (2017), which highlighted how the use of technology in Montessori classes depends very much on the school context (the software and the purchased aids) and on the beliefs of each teacher about how technology can be integrated into Montessori pedagogy. Specifically, this study examines the experience of four Montessori primary school teachers, through interviews, observations, analysis of programming documents and other qualitative tools. It highlights how, although the teachers had a generally positive attitude towards technology, they also had a disinclination linked to the need not to replace human interaction with the time spent on the computer. Among them, the way in which technological devices were used with students is very variable, but in no class it was done in a social-constructivist perspective. The amount of time students spent on the computer is also variable. Jones concludes that «For the Montessori community to address this issue in an informed way, rigorous qualitative and quantitative research is needed to better understand the impact of technology on students' motivation, learning, and development» (Jones, 2017, pp. 27- 28).

3. Hyphotesis

Our longitudinal study aims to provide a controlled empirical contribution to the problem of introducing technological material in Montessori classes. We want to verify the hypothesis that, by keeping some Montessori characteristics fixed also regarding the technological materials used for the development of computational thinking, students from the first to the fifth year of primary school improve their level of creativity, maintain a good sense of belonging to the community, a good level of self-efficacy (Bandura, 1997) and a low pervasiveness due to error (Seligman, 1996).

The hypothesis of a relationship between the use of technological material and the development of divergent thinking is borrowed from the study by Elkin, Sullivan & Bers, according to whom robotics promotes "debugging", or the creative search for solutions to problems through the identification of errors. Our study aims to verify that the exercise of this type of mental operation on technological material is accompanied by a growing development of creativity in general.

Furthermore, since the beginning of the course, in 2015, the technological materials were thought to be used to create individual, group and collective jobs (for example, the website opened and managed in the fifth year).

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Consequently, it was decided to also keep the sense of community of the class under control, assuming that the frequency of inclusive and collaborative behaviours would have increased over the years.

A final group of hypotheses is linked to the playful dimension of the proposed materials. In this regard, Lillard (2013) points out how Montessori rejects the game as a fiction, but her material features «freedom to choose activities, interactive hands-on lessons, and the ability to involve peers in learning activities» (Lillard, 2013, p. 163). Moreover, Lillard points out that Montessori pedagogy is open to innovation even more than other pedagogies, but the effects of any innovation should be tested empirically, since research has currently shown that learning outcomes, both cognitive and social-affective, are better in orthodox Montessori schools than in non-conventional ones. Therefore, the game can be introduced, but only if the typical characteristics of the development material are observed.

In our work, it was decided that the proposed activities should be very similar to games, to increasingly complex challenges which are to be faced because during the game making mistakes is often an important step to understand. Through errors it is possible to understand new aspects of the game that were not clear before: positive errors encourage to do better and try again by treasuring what was learned. Banfield & Wilkerson (2014) have shown how gamification in learning is linked to high levels of intrinsic motivation and self-efficacy for post-secondary students. In our study was hypothesized that the use of "playful" technologies would have been accompanied by the maintenance of a good sense of self-efficacy and a low pervasiveness due to error.

4. Method and procedure

A mixed methodological approach was chosen to test the hypotheses. Such method can «combine phases of possible "positivist" investigation, with observations, actions and interventions [. . .] that require a greater "interpretative" and "critical" approach "by exploiting" the potential of the two methods, the qualitative and the quantitative one» (Welcome, 2015, pp. 44-45).

In particular, the choice fell upon what Campbell & Stanley (1963) classified as the first type of quasi-experimental design, that is the "over time" experiment, «in which in a sequence of measurements periods an "experimental change" is introduced on a certain group or individual, the results of which are highlighted through the detection of a discontinuity in the succession of the measurement» in order to verify that there has been a growing trend in the measurements of creativity and sense of community (Becchi, 1997, p. 177, *auth. trans.*). Considering the most recent classification by Cook, Campbell & Peracchio (1990), the design can be considered as a single group design, where there are both pre-test and post-test, which «does not allow for comparisons and therefore the elimination of risks for the internal validity» (Becchi, 1997, p. 189, *auth. trans.*).

An ethnographic model, «whose main methods and tools are participant observation, the analysis of authentic documents, the analysis of the point of view of the subjects studied» was chosen to monitor the sense of self-efficacy and pervasiveness due to the error (Benvenuto, 2015, p. 149, *auth. trans.*).

From a "post-positivist" point of view, which «postulates that causal connections are "real", but are perceived imperfectly» (Cook & Campbell, 1979, p. IX), we can consider creativity, sense of community, self-efficacy and pervasiveness due to error as dependent variables, whereas the independent variable is the inclusion of

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technological materials among the development materials of a primary school class of the Istituto Comprensivo San Nilo in Grottaferrata (RM), from the first (school year 2015/16) to the fifth (school year 2019/20) grade. As mentioned, these materials had to maintain the same characteristics as the developing material, as defined by Montessori (1950/1999):

1. error control: each technological activity had an intrinsic error control, so that the child could correct a possible mistake by himself;
2. aesthetics: the materials were treated to be attractive to the students;
3. autonomy of use: in Montessori education, in order to use some new and complex materials, children must first pass some theoretical and practical tests and acquire a sort of "license" to use them. Specific licenses have also been established for some technological materials;
4. repeatability: each job could be carried out several times, partially changing its development;
5. quantity limits: the material available was limited, so that not everyone could access it at the same time.

The purpose of the material introduced was the development of computational thinking and of the habit of carrying out tasks that included multiple solutions, thus pushing the pupil to avoid a single solution, thinking about the multiple resources available to them. For this reason, the material always had a unique result as error control (for example the result of an operation) and there was no correction on the procedure, which could be differentiated. Prepared materials are as follows, divided by years.

During the first year, in a first task, children were required to colour squares following sheets that recalled the pattern of the naval battle. In the second activity, they were required to make a drawing following a pattern of their choice, so they could choose whether to colour or leave the squares white. The purpose of these exercises was to get the students used to reasoning with the 0-1 scheme.

During the second and third year, we introduced the Ozobot robot. In a first activity, the children were required to solve multiple choice grammar analysis questions: each choice was matched with a colour and the right set of colours allowed the robot to perform the desired action. The correct resolution of the problem was evident from the behaviour of the robot himself, which usually danced at the end of the path. This first step was necessary to make the pupils understand how the robot worked. In a second activity, the children were required to invent crossroads stories using the robot, with a guideline and an end goal. The material consisted of a sheet defining a goal (e. g. a girl must bring bread to her father), of limits on the number or repetition of commands that the pupil could impart (e. g. the robot can only perform three commands) and of obstacles already traced (e. g. an impassable wall or a traffic light always red). The pupil had to reach the goal, in any way they could think of, and make up a story about what was going on. Some sheets were specifically designed to be done in pairs or in small groups.

Over the past two years, we have been using WeDo™ 2. 0, a programmable LEGO® set. A first task involved the construction of a basic set robot (e. g. a crocodile) to be instructed with simple programs (e. g. opening and closing the mouth). As time went on, the robots to build and the programming challenges that pupils faced using the software with logic blocks that allowed numerous functions and always different solutions became more and more complex.

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During the last year, the website www.parolediscienza.it was created, entirely planned and managed by the students, who were asked to elaborate and insert scientific articles and insights, using Wordpress.

The group that followed this path consisted of 19 students (all of them born in 2009, except for one born in 2006), of which 12 were females and seven were males. Three pupils with disabilities were present. The social-economic-cultural background is a medium-high level: more than 2/3 of the parents have at least a university degree. Finally, it should be noted that this class was the opening class of a Montessori section in the primary school of the Institute, where a Children's home did not yet exist. As a result, the teachers in the class enjoyed some freedom of action, but their children were not used to working with Montessori pedagogy, nor did they have the full set of materials, which was completed in the following years for the entire section. Over the five years, the class was followed by a permanent support teacher and two curricular teachers, one permanent and other one who changed every year.

4.1 Tools

4.1.1 Creativity

To measure creativity, it was decided to build a tool borrowed from the Italian version of *Torrance Test of Creative Thinking* (Torrance, Sprini & Tomasello, 1989), which measures individual ability in the four pragmatic dimensions of a creative job: fluidity, flexibility, originality, elaboration. In particular, two tests were used of this test battery, as summarized in Table 1.

Following the pattern of the four pragmatic dimensions of creativity, each drawing received a score from 1 to 7 according to the following criteria.

1. Fluidity: finishing it before the set time, by providing more than one solution to the drawing, inserting the drawing in different scenarios, reversing the figure in the axes of symmetry.
2. Flexibility: the figure tells a story, it is inserted in a precise context, it is realistic and not abstract.
3. Originality: the figure is not present in the other drawings of the participants, it was not inspired by elements present in the classroom, it enters the world of fantasy, takes real elements and decontextualizes them.
4. Processing: the edges of the frame are respected, the stroke is precise, the colour is well-finished, the sheet is not wrinkled.

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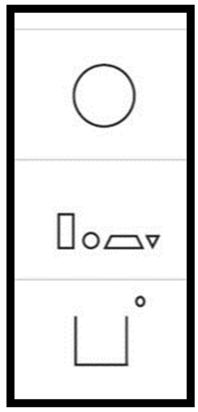
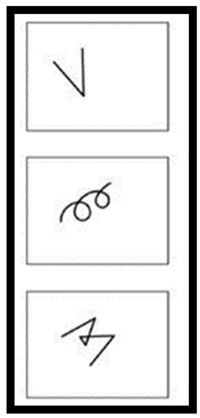
Administration	**Test**	**TTCT figures**
May 2016 (first year) May 2017 (second year)	Completion of the drawing For each of the images, the child was asked to complete it or place it in a context. Three images were chosen from one of the basic tests of the TTCT, which seemed to us the simplest and the most intuitive to create.	
May 2018 (third year) April 2019 (fourth year)	Construction from an incomplete image For each of the images, the child was asked to complete it by placing it in a given context (for example in a typical school scenario). Three images were chosen from one of the most advanced tests of the TTCT, which seemed to us the most suitable to raise the level of abstraction required.	

Table 1: Tests for measuring creativity

The tests were included among the development materials to adapt the administration to the job rhythms of a Montessori class and each pupil was free to choose both the day and the time on/at which to carry out the test. For this reason, the administration lasted about one month for each year. This allowed to eliminate the imposing and stressful component of the collective test, making the test live as a normal job among others. The difference with the other jobs was that, if the pupils had chosen to start this job, they would have had a limited time (30 minutes in the first and second year, 45 in the third and fourth year) and could not be interrupted.

In addition to administering this structured tool, the teachers used the field notes technique to write down the creative ways in which children could use the technological materials to solve problems or issues that arose during school life. Finally, particular attention was paid to how much the children managed to be autonomous, in the fifth year, in the management of the site www.parolediscienza.it.

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4.1.2 Sense of Community

The sense of community of the class was monitored by observing the following three behaviours in the children during collective or small group jobs.

1. Is the pupil with motor and mental disabilities integrated into the job?
2. Is participation collective or are there isolated pupils?
3. Are there moments of exchange of ideas among pupils?

As regard the first question, we observed how much the children talked to him, how much they involved him in the activity by finding something he could do. For example, when the class wrote a book, the children assigned him the role of drawing the backgrounds of the pages.

On a prepared grid, for each observation and each question the teacher had to write down "yes" (1) or "no" (0). In addition, the teachers wrote down some particular episodes in their field notes.

4.1.3 Self-efficacy and pervasiveness due to error

To keep under control the sense of self-efficacy and the pervasiveness due to the error, it was decided to have the teachers note the observations and the answers given by the pupils to some questions asked when they opted for the jobs to be kept in a portfolio intended as the folder of all their most significant jobs which was presented to each of them, from the first year. Each child chose a task to be included in the portfolio and, for each task, the teachers asked them: 1) why that task had been chosen, 2) if they had found it easy or difficult, 3) how many times they had to repeat it. Furthermore, they were asked to carry out a small metacognitive process, that is to describe the thought or process that had led to the realization of that product. The answers to these questions gave the teachers an idea of each one's self-efficacy. Regarding the pervasiveness due to the error, the ease with which each pupil abandoned a job that they could not complete, changing it with a new one, was also observed. We wanted to observe the pupils' resistance to failure and the ability to move on to another topic in order to then be able to face it again with a new impetus and perhaps from another point of view.

5. Data analysis and results

5.1 Creativity

Cronbach's Alpha was calculated to verify the reliability of the four scales used to measure creativity, considering for each of them the four measurements in successive times: 1) fluidity $\alpha = 0.78$; 2) originality $\alpha = 0.52$; 3) flexibility $\alpha = 0.71$; 4) processing $\alpha = 0.73$. All scales have a value greater than 0. 70, except for the originality scale. As a reference for acceptability, we consider the parameters established by De Vellis (1991): $\alpha < 0.60$ *unacceptable*; $0.60 < \alpha < 0.65$ *undesirable*; $0.65 < \alpha < 0.70$ *minimally acceptable*; $0.70 < \alpha < 0.80$ *respectable*; $0.80 < \alpha < 0.90$ *very good*; $\alpha > 0.90$ *very reliable* (see Table 2).

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	Fluidity	Originality	Flexibility	Processing
Measurement in the first year	.794	.773	.812	.714
Measurement in the second year	.703	.358	.454	.542
Measurement in the third year	.630	.082	.495	.572
Measurement in the fourth year	.754	.287	.701	.783

Table 2: Cronbach's alpha if the element is eliminated

To improve the Alpha of the originality scale it was decided to eliminate the first measurement (so α reaches 0.77) and, to verify the hypothesis of a linear increase over the years, it was decided to use only the measurements made in the second, third and fourth year. For this purpose, the usage of the trend analysis would have been ideal. In this analysis the independent variable is the use of technological materials during the years of primary school, which is divided into four levels (i.e. four times) as to the dimensions of fluidity, flexibility, processing, (T1 in the first year, T2 in the second year, T3 in the third year, T4 in the fourth year) and on three levels as to the dimension of originality (T1 in the second year, T2 in the third year, T3 in the fourth year). The dependent variable is the score on each of the four interval scales. It is a one-factor one-way varied analysis of variance among subjects (a certain number of observations repeated over time on the same group of subjects). However, since the group consists of only 19 students, and since the distributions of scores on at least one of the measurements for all four dependent variables do not have acceptable asymmetry and kurtosis values (i.e. between -1 and +1, according to the parameters established by Barbaranelli, 2003), the assumption of the normality of the distributions is not possible and the use of the non-parametric Friedman test is required, which is significant with $p < 0.001$ for all four dimensions considered.

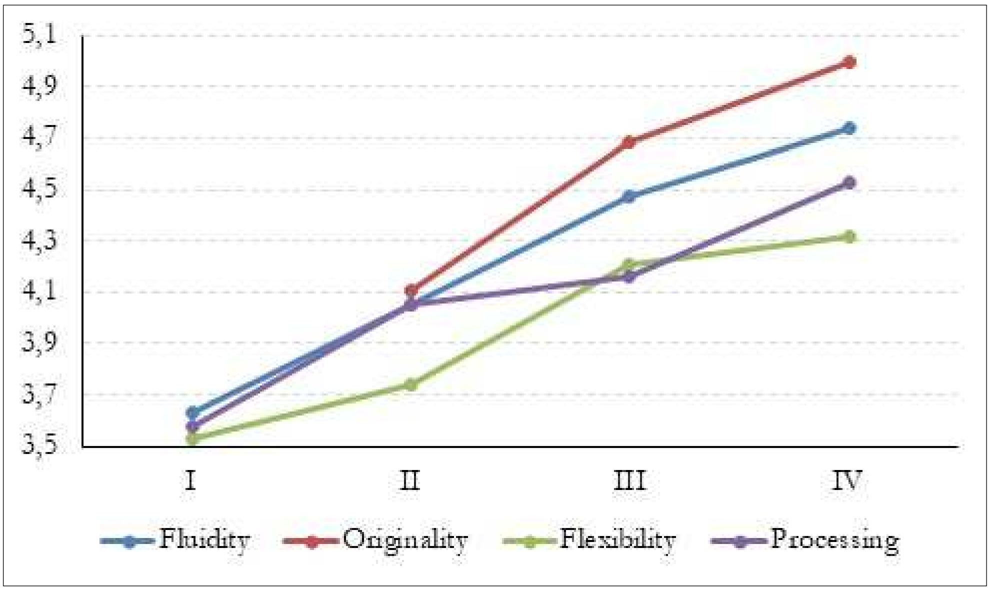

Figure 1: Trend of creativity measures

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It can be seen in Fig. 1, the test performance increases steadily over the years for all four dimensions of creativity. A proof of how the job with the technological material has stimulated the creativity and curiosity of the pupils is given by three anecdotes that took place in the fourth year, reported by the teachers in their notes.
The first occurred before the Christmas holidays: the children were afraid that someone might come in and steal their jobs and so they programmed a burglar alarm with WeDo™ that would emit alarm signals when the visual cell was interrupted. The second occurred during the realization of a project that involved writing a book on immigration. Since there was a Skype call with a Syrian school class, in which there was a girl without a limb, the Italian children wondered how it would have been possible for a robotic hand to perform all the functions of a normal one. To understand this, they programmed a gripper with WeDo™ that could perform some simple functions that were normally performed by a hand. The third occurred during the lockdown in March-May 2020 when, in order to carry out some projects started during the year, the pupils independently managed a padlet, that is a virtual billboard, opened by the teachers, in which they entered doubts and resolved them by confronting themselves. The billboard had different colours depending on the topics and the possibility of creating links between questions and answers.
Beyond the individual anecdotes, regarding the use of WeDo™ 2.0, the notes show that in February 2020 most of the students successfully developed basic programming paths, and about 4 students out of 10 also complex paths, finding solutions to more elaborate challenges. With regard to the self-managed site, it was noted that during the Distance Learning period due to Covid-19 (March-June 2020), almost all the students were able to respond to the request to process and publish content from home, that is even without the help of the structured school setting.

5.2 Sense of community

Also with regard to the sense of community, the frequency with which the three established behaviours were observed was expected to increase over the years. Since a different number of observations were made each year (in the first year five observations, in the second year 11, in the third year 16 and in the fourth year 19), the ratio between the number of times in which the objective behaviour was recorded and the total number of observations for the school year were calculated. For example, as regards the behaviour of including the pupil with disabilities in the group job, if this ratio assumes the limit value 0 it means that the pupil was not included in any of the observations of the year, if instead it assumes the value limit 1 it means that it has been included on all observed occasions.
As it can be seen in Fig. 2, all the three observed behaviours have an increasing trend over the years. Secondly, we note a decrease in the frequency with which it was observed that there were no isolated pupils: the teachers reported that during this year some female pupils, when they met in groups with some pupils, tended to exclude them who were then isolated. The teachers worked on this behaviour and, in fact, in the following years it was not observed again.

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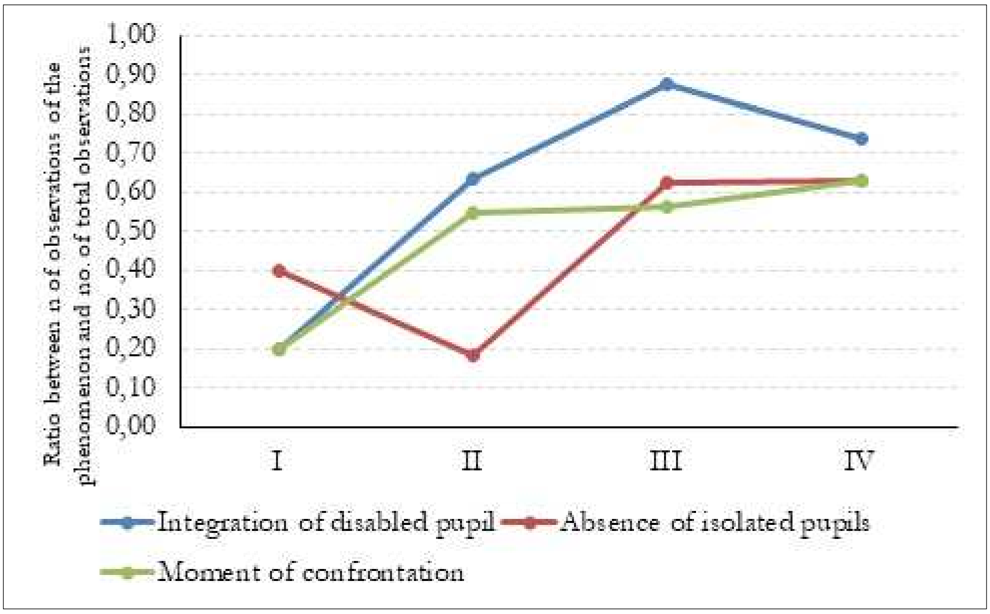

Figure 2: Trend of the behaviour related to the sense of community

In this regard, we report a couple of anecdotes noted by the teachers in their notes. The first occurred in the second year, when the children had to organize an exhibition called the "Exhibition of golden trees", which exhibited artworks produced by the pupils and had to be set up by the same children who had to choose how to position the different artworks within a set up space. While they were working, the teachers pointed out that the path must also be accessible for the pupil on wheelchair. To solve the problem, the children chose to work out a path using the Ozobot robot, making several attempts until they found the optimal solution. The second episode occurred in the fourth year when, during the break, the children noticed that the pupil with wheelchair was able to interact little with them while they were playing ball. Therefore, they decided to design a support to allow him to do this. Initially, they built it with LEGO® and, to check if it worked, they made some tests by programming the robot to make the various movements. Once it was verified that it worked, they built the wooden support. Finally, the notes also show that, in the first and second year, most of the pupils, when they did not succeed in a job, asked for help to the teachers, or tried again by themselves until they succeeded. From the end of the second year onwards, however, the request for help to classmates has become increasingly frequent, both in individual jobs and in group jobs: when a group was unable to perform a task, help was often asked to a friend of another group, and it happened that then the classmate involved inserted that job in their portfolio.

5.3 Self-efficacy and pervasiveness due to error

The field notes of the teachers were collected mainly in relation to the observation of children's behaviour on the jobs they chose to include in their portfolio and the answers they gave on why they had chosen each job,

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whether they had found it easy or difficult, how many times they had to repeat it, what process had led them to the realization of that product.

From the analysis of the notes, it emerges that the portfolios were very different and varied: some pupils mainly chose mathematical or scientific jobs (microscope, direct observations, etc.), others artistic products, other texts or stories. It is interesting to note that, from the second year onwards, in each portfolio there was at least one job produced with the technological material.

Almost all the jobs included in the portfolio were considered by the pupils as difficult or challenging and this led the teachers to conclude that the class had maintained, from the first to the fifth year, a good sense of self-efficacy.

The metacognitive process has also evolved over the years, bringing greater awareness on the part of the pupils. Initially, when each pupil was asked why they had chosen a certain job to be included in the portfolio and the word "beautiful" was predominant: the common responses were "I did a good job", "I think my job is good". Perhaps this was also due to the fact that at first most of the portfolios were composed of artistic artworks. Then, over the next few years, the word "commitment" began to appear very often with responses such as "I worked hard", "I think I put all my effort into it". From half of the third year onwards, however, the meaning of fun linked to meaningful activity has increasingly appeared: "while I was doing it, I had fun", "time flew by and I enjoyed it a lot".

Regarding the pervasiveness due to the error, it was noted that most of the jobs had required more than one attempt, which can lead us to deduce that from the beginning the pupils did not feel very sad for the mistakes made, therefore their pervasiveness seems to have remained low and stable over time. Herein we assume that working with technological material, being it playful (according to the meaning explained by Lillard) and challenging at the same time, has contributed, together with the rest of the development material, to get children used to a process of learning in which the error is necessary, and therefore to reinforcing the tolerance of frustration in the face of the error itself. Moreover, it was noted that the reaction to failure changed. Initially the children tended to abandon the activity and to resume it only after a long time, over the years the tendency to try again immediately, asking for help or changing approach strategy has increased.

6. Research perspectives and conclusions

To draw conclusions, we start from the analysis of the limits of the research and from the perspectives it leaves open. The limits are fundamentally related to the internal and external validity of the research design. Internal validity means the approximation by which «we infer that a relationship between two variables is causal» (Cook & Campbell, 1979, p. 85). The validity of the statement that the Montessori use of technological materials (independent variable) is a contributing factor to the development of the recorded creativity and of the sense of community, as well as to the maintenance of a good sense of self-efficacy and of a low pervasiveness due to error (dependent variables) is under threat from:

a) the maturation of students which could explain by itself the trend of the values of the dependent variables;

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b) history, or other events that occurred in the five years that could influence the variation of the dependent variables;
c) the measurement errors of the instruments, which are not validated instruments, but constructed ad hoc and, since they are based on the teachers' observations, very influenced by their expectations;
d) the interaction between all these variables.

The research design does not allow to aspire to any external validity, understood as «the approximation by which we can infer that the presumed causal relationship can be generalized [...] to different types of people, contexts and times». There are several threats that invalidate the validity of the statement according to which, even in other Montessori classes, a use of technological materials similar to that adopted in this experience can have positive effects on creativity, self-efficacy, sense of community and pervasiveness due to error. These threats concern the interaction that the treatment (this use of technological material) can have with: the other materials, testing, the characteristics of the class group, the characteristics of the social-economic-cultural context, the historical moment in which this experience took place.

To reduce the strength of some of these threats, new research is desirable that includes: a) a control group as similar as possible to that in which technological materials are tested (e. g. a Montessori class from the same institute, which was not available at the time of conception and realization of this study), b) a selection of validated tools for the measurement of dependent variables. Furthermore, if we were to replicate the research, we would probably choose only some of the dependent variables considered and we would rely on a more founded operationalization of the following constructs: creativity, sense of community, self-efficacy and pervasiveness due to error.

Despite the aforementioned limitations, we would also like to affirm that this controlled experience has allowed us to reiterate the importance of the characteristics that an innovative material that is supposed to be inserted in a Montessori class must have these flaws limit the power of the study, but, since our conclusions are qualitative in nature, we still believe in the inherent validity of our observations and reasoning. In the first place, it must have that playful (not fictional) aspect that is typical of the development material, an aspect that Lillard (2013) identifies with the freedom of choice, manual skills, the possibility of using it in collaboration with peers. The innovative material must not be a purpose, but a fun and stimulating medium, which encourages pupils to play and compare, have fun with each other and make mistakes without fear of having to try again. The activities we proposed in the classroom stimulated interest and fun in the pupils since they were a game to deal with and in doing so, learning was linked to positive emotions. As Vygotsky (1934/1966) affirms:

> «The thought itself originates not from another thought, but from the motivational sphere of our consciousness, which contains our passions and needs, our interests and impulses, our acts and emotions. The sphere of the active and volitional tendencies is concealed behind the thought which, alone, can give an answer to the last "why" about the analysis of thought» (p. 226, *auth. trans.*).

When learning is linked to positive emotions it becomes stable, lasting, because, as Dewey would say, it produces continuity. In Montessori terms, the technological material used lent itself to "repetition of the exercise", which

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allowed students to train divergent thinking, making them find new solutions to problems already faced, in front of which the students were no longer focused on the solution, but on the different paths they could follow to get there. In this way the paths multiplied, became interconnected and fed one another. Second, we can say that the technological material must not replace the classic development material but be integrated harmoniously in it. To this end, it is important to reiterate that it cannot be introduced into the Children's Home, that is, in a phase in which the child needs to develop the basics of their sensory, motor and social faculties. In primary school it can be introduced as one of the many materials that each pupil chooses freely. As shown by some anecdotes, as well as by the more quantitative results of the research, the experience of the Montessori class in Grottaferrata shows that between technological material and classic development material it is possible not only a co-presence, an integration, but also a harmony such that it generates virtuous circles of creativity, metacognition and learning. Computational thinking is the basis of the technologies that fill the extracurricular environment and the time of the new generations. Being aware of their functioning serves to avoid being their slaves and to use them to go beyond the technologies themselves, to solve other problems (such as accessibility to an exhibition, the safety of a place, the functioning of a hand, etc.). The world our pupils live in is permeated by technology, the environment they deal with is largely based on technological interactions and exchanges. And what would Maria Montessori say if she knew that many teachers ignore, or worse still disregard, the environment in which their pupils operate?

As Honneger Fresco says in the preface to Valle (2017),

> «the advance of technology is so massive and rapid that it causes sudden changes that were unthinkable only twenty years ago: a real cyclone. The problem that arises is: how will the (traditional) school graft the brand-new tools on the same old modalities (children sitting in silence and adults talking, surprise tests and continuous competition)? Would they risk unprecedented collision?[...] First of all, it is urgent to overturn (as long as there is real time to do it) the relational quality in teaching (which, after all, many, on the sly and on their own, have already reached). This involves changing the thinking of adults, their habits, language, the distrust with which they turn to children and teenagers» (pp. 5-6, *auth. trans.*).

An education in technology that is harmoniously integrated with the education of the person requires a school environment in which there is free choice, dexterity, collaboration, autonomy, metacognition, multi-sensoriality. In short, a school that is different from the still dominant one, mainly transmissive, frontal, anti-inclusive and is equal on unequal parties.

In conclusion, we started from a basic problem: how to integrate the use of technologies with Montessori pedagogy? If one thinks about it, one could say that technology is not a problem for the Montessori school, but rather that Montessori is a solution to the problem of technology in the school.

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