# FROM TINKERING TO THINKERING. TINKERING AS CRITICAL AND CREATIVE THINKING ENHANCER.

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Education research interest in Tinkering, as an informal method to engage students with STEM subjects, has been growing and growing in the last few years. Recent research has highlighted that Tinkering could be adopted not only to develop students' scientific knowledge but also to support thinking processes such as Critical Thinking and Creative Problem Solving. Despite these assumptions, there is still limited empirical research evidence concerning the impact of Tinkering on the development of the 21st Century skills. That is why the Centre for Museum Studies - University of Roma Tre investigated the influence of Tinkering activities on Critical and Creative thinking skills enhancement in museum educators and teachers involved in STEM education. To fill in the above gap of empirical evidence, the Centre for Museum Studies carried out a pilot study at "Città della Scienza" Science centre (Naples), where 30 participants (museum educators and STEM teachers) were involved in a two-day workshop on collaborative Tinkering

activities. During the workshop, participants were required to take two kinds of pre and post-tests with the aim of assessing Critical and Creative thinking skills development. On one hand, in the Creative Thinking post-test participants showed significant improvement. On the other hand, despite there were no statistical differences concerning Critical Thinking assessment, a slight improvement in the post-test could be quantified. The data collected support follow up research, where the sample of the study could be enlarged and further measures for Critical and Creative Thinking assessment employed.

## 1 Introduction

More than ever, the education scientific community is interested in developing methods that can engage students with STEM subjects, promoting, at the same time, 21st Century skills. Not only formal, but especially informal education methods are catching the attention of the scientific community, taking into consideration a lifelong learning approach. Among informal education methods, the *Maker Movement* is becoming wide-spread in science education because of its potential to involve young people with STEM (Rocard *et al.*, 2007) and to make scientific knowledge more accessible (Martin, 2015). Research regarding the effect of *Making strategies* on learning is growing, as demonstrated by a review published in 2017 (Papavlasopoulou, Giannakos, & Jaccheri, 2017) where the authors found 3000 scientific papers on the *learning by doing* topic in formal and informal STEM education contexts. It was shown that the largest number of research products on *Making* was aimed to enhance programming skills and computational thinking. Other studies suggested that the current trends of learning through *Making* in art, design, and technology practice can provide fertile ground for developing STEM education. The *Tinkering Movement* emerged in the wider context of the *Making Movement*: despite the common features between them, Tinkering is considered more as a personal disposition towards problem solving, curiosity, scientific investigation, direct experience and experimentation. *Tinkering* can be defined as «a branch of making that emphasizes creative, improvisational problem solving. It centres on the open-ended design and construction of objects or installations, generally using both high- and low-tech tools. At the heart of tinkering is the generative process of developing a personally meaningful idea, becoming stuck in some aspects of physically realizing the idea, persisting through the process, and experiencing breakthroughs as one finds solutions to problems» (Bevan *et al.*, 2015, p. 99).

*Tinkering* was adopted by science educators not only in formal learning contexts such as schools and universities, but also in scientific centres. Indeed, since 2008 the *Exploratorium* in San Francisco has been developing, testing and refining *tinkering* activities for museum visitors, opening a dedicated *Tinkering* space (The *Tinkering Studio*) that is described as «part exhibition space, part

science laboratory and part atelier» (Petrich & Wilkinson, 2013).

The *Tinkering* method is rooted in theoretical frameworks that emphasize scientific inquiry through direct experience, sensor-motorial, and playful practices (Dewey, 1938; Montessori & Holmes, 1912). In addition, *Tinkering* stimulates forms of social and collaborative learning (Vygotsky, 1980; Wenger, 2010) in which participants create and negotiate meaningful goals with their communities using different kinds of mediation tools.

In a recent review (Vossoughi & Bevan, 2014), the authors underlined that *Tinkering* can be effective when inquiry-based learning is combined with aesthetic and creative components; in this way, it is possible to promote participation and inclusion of all the students involved in the *Tinkering* activities. This is an important innovation for STEM education, that has been traditionally based only on written texts (Windschitl, Thompson, & Braaten, 2008). *Tinkering* often incorporate different kinds of "languages", from painting to coding.

From our perspective, *Tinkering* could be a meaningful method not only to develop scientific knowledge, but also to promote 21st century skills. Sheridan and colleagues (2014) reported that after *Tinkering* activities students changed their disposition towards scientific discoveries trying to solve problems with methods never thought before. According to other authors (Vanderslice, 2008), combining *Tinkering* with writing activities could support the process of individual empowerment. The Institute of Museum and Library Services (2009) explained that *Tinkering* makes people more flexible, resilient and creative and helps them to develop critical thinking, problem solving and entrepreneurship skills, that are often defined as the 21st Century skills (see the table 1). In addition, the above-mentioned dispositions of the *Tinkerer* seem to partially overlap with *Critical Thinkers* dispositions (Facione, 1990), such as open-mindedness, scepticism, and truth-seeking. In addition, all the *Tinkering* practises can be defined as "creative problem solving" because they cross the boundaries among science, engineer and art (Vossoughi & Bevan, 2014).

Although many authors reported that Tinkering could support the development of the 21st Century Skills (Kafai & Peppler, 2010; Harris *et al.*, 2017), there are a few empirical studies that verify such a hypothesis (see Husin *et al.*, 2016). Kafai and Peppler asserted that tinkering methodologies could improve both: 1. critical thinking through observing and deconstructing media, evaluating and reflecting, and referencing, reworking and remixing and 2. creative thinking by making artistic choices and connecting multimodal sign systems. Anyway, the authors do not present any evidence which could prove the above statements. The present paper is, instead, aimed to test empirically the above-mentioned theoretical statements in a 'pre and post-test' design research

experience (Marsden, & Torgerson, 2012). In particular, the research group investigated the impact of a two-day *Tinkering* workshop on museum operators and STEM teachers' level of Critical and Creativity thinking skills.

Table 1
OPPORTUNITIES THAT TINKERING EXPERIENCES PROVIDE FOR DEVELOPING THE 21ST CENTURY SKILLS. ADAPTED FROM HARRIS ET AL., 2017

| 21ST CENTURY SKILLS | OPPORTUNITIES THAT TINKERING EXPERIENCES PROVIDE FOR DEVELOPING SUCH SKILLS |
|---|---|
| Creativity and divergent thinking | Using a wide range of idea creation techniques e.g. planning, sketching, brainstorming; developing unique strategies, tools, objects or outcomes; creating new ways to use materials or tools; setting personal long and short-term goals and planning ways to achieve these. |
| Communication and collaboration | Incorporating input and feedback from other people (e.g. peers or a facilitator) into their work; developing, implementing and communicating new ideas to others effectively; being open and responsive to new and diverse ideas |
| Problem solving, Critical Thinking and Strategic Thinking | Posing problems to solve<br>Identifying emerging problems<br>Coming up with solutions or methods to try to find solutions<br>Elaborating, refining, analysing, testing and evaluating ideas<br>Planning steps for future action |

Critical and creative thinking skills are not only crucial for people who participate in Tinkering activities, but also, and especially, for designers of *Tinkering* activities. Indeed, museum educators and teachers interested in adopting a *Tinkering* approach need to have a good level of creativity and critical thinking skills to generate, analyse and evaluate the ideas according to the learning objectives (*Tinkering: Contemporary Education for Innovators of Tomorrow*, 2014). In the present study the research group investigates if *Tinkering* could be used with museum educators and STEM teachers to develop some soft skills. In the following paragraphs the results of the experience are described and discussed.

## 2 Hypotheses and research issues

The efficiency of the training course was assessed in a pilot study with 30 participants (M= 11; F= 19). The group was composed of teachers and museum operators involved in STEM education and invited to take part at the activity developed at "Città della Scienza" Science centre.

Our first assumption is that *Tinkering* is an approach that requires participants to have good creativity levels, since they, starting from everyday materials such as caps, bottles and light bulbs, have to design activities that stimulate learners to reflect about scientific concepts (physics, mathematics etc.). So, the *first hypothesis* is that participants, involved in a co-design activity of *tinkering*, could improve their creativity levels.

Previous studies have also observed a relation between Creativity and Critical thinking (Chan, 2013), and they confirmed that to be good critical thinkers some specific domain knowledge is needed, as in the case of STEM teaching and learning. The *second hypothesis* investigated is that improving teaching methods (through face to face teaching) and creativity skills in the participants, also their critical thinking might increase.

## 3 Methodology

A professional who wants to adopt a *Tinkering* approach in school and museum contexts needs not only to know the main principles of the approach, but also to have a good level of creativity, in order to design the education activities starting from the available materials and to develop critical thinking skills in participants, allowing them to generate, analyse and self-assess their own ideas according to the teaching objectives.

The Centre for Museum Studies - University of Roma Tre designed a two-day *Tinkering* workshop aimed to fulfil the training needs of museum educators and teachers working within STEM education. These subjects require not only knowledge about scientific contents but also about the teaching and learning approaches to be used in museum and classroom contexts. The workshop was carried out at "Città della Scienza" Science Centre in Naples in February 2019. The objectives of the training activity were the following:

1. to design *Tinkering* learning activities aimed at promoting 21st Century skills;
2. to develop participants' Creativity skills;
3. to develop participants' Critical thinking skills.

The workshop was characterized by face-to-face classes and co-design activities in small groups. On the first day, participants were required to take two kinds of pre-test (that will be described in detail in the next paragraph).

After the pre-tests, the *Tinkering* methodology theoretical principals were illustrated to the museum operators and STEM teacher participating in the workshop. Afterwards, the 30 participants were divided into 4 groups, of about 7-8 members each. Each group carried out one of the four proposed activities (see the table 2). About 4-5 people (per group) were involved in realising

the objects related to the activity proposed, whereas the other members of the group played the role of observers and/or facilitators. The observers had an observation grid to fill in and used as the starting point for the debriefing subsequent activity. One hour was devoted to work and observation and 30 minutes to reflection.

Table 2
THE TINKERING ACTIVITIES PROPOSED IN THE WORKSHOP

| Activity name | Target | Necessary Materials | Possible topics for reflection (non-exhaustive) |
|---|---|---|---|
| Rainbow | Primary School | Basins of different sizes, mirrors, water, cardboard, scissors and markers | Light, Refraction, Reflection. |
| Card light | Secondary school of first / second level | Led lights, cardboard, markers and coloured pencils, clips, insulating copper adhesive tape, small power generator, battery connector | Electricity, circuits, electro-magnetism |
| Drawing engine | econdary school of first / second level | Cardboard, markers, coloured pencils, clips, insulating copper adhesive tape, magnetic motor, battery connector | Electricity, circuits, electro-magnetism. |
| Tracks for acrobatic marbles | For all ages, suitable for museums, large groups | Pvc pipes, balls of various shapes and sizes, cardboard, rolls of kitchen papers | Cinematics, different types of motion (rectilinear, uniform, acceleration) friction and gravity. |

On the first day, the workshop ended with a dynamic activity, the "Drawings of light", where all the participants were able to paint using lights in a dark room. The goal of this activity was to explore the properties of light by combining the artistic and aesthetic attitude of the participants.

On the second day, participants were required to plan their own *Tinkering* activity. They were asked to split themselves into groups based on 4 different targets of interest. 1. Primary school, 2. Middle school 3. Secondary school 4. Science centre Users.

Participants were able to use the same materials made available during the first day in order to design new activities and tools. They were provided with templates to guide the further *Tinkering* activity. Participants were also invited to move freely in the room and exchange materials.

During the afternoon session, they took the post-test and presented the project realised by each group in a plenary session.

## 4 Data collection and analysis

To test our hypotheses, the data were collected in two different moments, at the beginning and at the end of the training session. Assessment sessions were administered through pre and post-tests. Each time, participants had to take two different tests, one aimed at identifying Creativity and the other Critical Thinking levels. The first kind of test we used was the Alternate Uses (AU) task (Guilford *et al.*, 1978). The AU task is used to assess a specific form of creativity named "divergent thinking". In this task, the participant is required to indicate how many different ways a particular object can be used: for example, a shoe can be used to walk with or it can be used, in a creative way, as a drum. During the present research activity, participants were given 4 different sheets of paper: on the first sheet, they should indicate a code number, which was used to compare the results between the pre-test and the post-test. In the second, third and fourth sheets, on the top left one word was printed (e.g. "key", "pencil" or "boot" - all the words used were taken from handbook provided). Participants had one minute to write on the paper all the possible uses of each word given on each single sheet. When the minute expires, an alarm went on telling them to stop writing. They had a thirty-second break between one word and another. Three main indicators were computed from the AU task: *Ideational Fluency*, *Ideational flexibility* and *Elaboration*. The *Ideational Fluency* score was defined as the number of different uses given by the participant for the three items. On the basis of all the uses identified by the participants, 24 independent categories were defined across all the items. These included broad categories of usage such as "as a weapon" or "to make a dress." The *Ideational flexibility* score was defined as the number of different categories identified by the participant across all three words presented. Hence, in order to calculate the flexibility score, all responses of a given item were divided into different independent categories. For example, using an item both as a musical instrument and as a weapon was considered as two independent categories; while using it as a drum and as a trumpet was regarded as the same category. The *Elaboration* score was defined as the average number of words used to describe a specific use. This test was administered at the beginning and at the end of the activity to verify the first hypothesis.

The second kind of test used to assess Critical Thinking skills was a short essay. More specifically, participants had to write a short essay (Poce, Corcione & Iovine, 2012; Poce, 2015) on a passage from *Discours de La Méthode Pour Bien Conduire Sa Raison et Chercher la Vérité Dans les Sciences* (1637) by René Descartes. In order to assess Critical Thinking skills, participants' written productions were evaluated using a Short Essay Assessment Grid, adapted from the Newman, Webb and Cochrane (1997) model (Poce, 2017). The main

categories of the analysis include *Communication skills*, *Argumentation*, *Relevance*, *Importance*, *Critical evaluation* and *Novelty*. Three independent evaluators scored the test independently and then the average score was calculated.

This test was administered at the beginning and at the end of the activity to verify the second hypothesis.

## 5 Results and findings

Results obtained after the *Tinkering* Workshop show improved *Divergent Thinking* levels in the post-test compared to the pre-test (Figure 2). More specifically, Fluency and Flexibility obtained higher average scores.
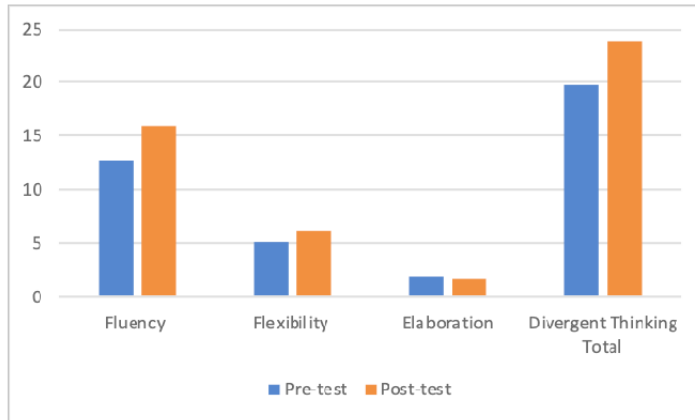


Fig. 1 - Comparison of the scores obtained (Fluency, Flexibility, Elaboration and Divergent Thinking) pre-test and post-test

The non-parametric test of Wilcoxon was conducted in order to know whether the differences were significant or not. The difference for the Fluency and Divergent Thinking Total was significant for sign. < 0,001 whilst for the Flexibility sign. < 0,05. The differences on Elaboration were not significant.

Table 3
COMPARISON PRE-POST TEST ON DIVERGENT THINKING. * Significance is lower than 0,05, ** significance is lower than 0,001

|  | Fluency | Flexibility | Elaboration | Divergent Thinking total |
|---|---|---|---|---|
| Z | -3,685 | -2,102 | -,387 | -3,815 |
| Sign. asint. (two tales) | ,000** | ,036* | ,699 | ,000** |

Regarding Critical Thinking scores, any significant difference between the pre and the post-test was found, in general terms. However, it is possible to see a slight improvement on Relevance, Importance, Argumentation, Critical evaluation and Novelty indicators (Figure 2).
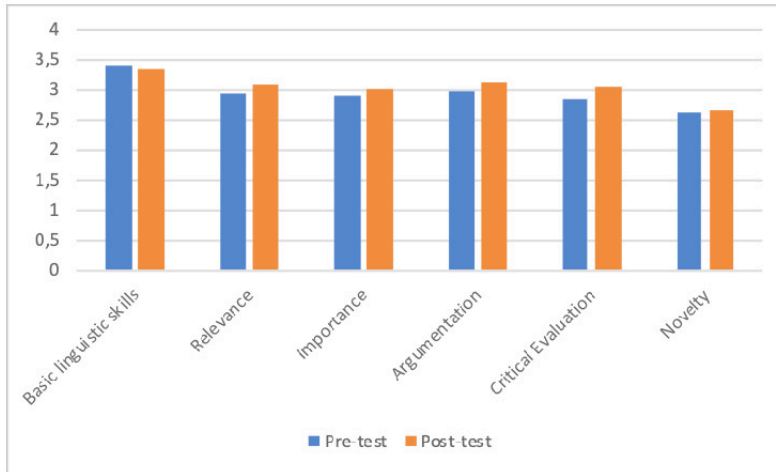


Fig. 2 - Comparison of the scores obtained in Basic linguistic skills, Relevance, Importance, argumentation, Critical evaluation and Novelty between the pre-test and the post-test

## Discussion and conclusive remarks

The interest about *Tinkering* as a learning method to engage students with STEM subjects has been growing and growing among educators and scholars. Recent research supports the hypothesis that *Tinkering* could be adopted not only to develop students' scientific knowledge but also to support thinking processes, enhancing Critical Thinking skills and dispositions and Creative problem solving, in an inclusive and cooperative learning environment. Despite these assumptions, there is still limited empirical research evidence concerning the impact and evaluation of *Tinkering* on the development of the 21st Century skills.

This study has tried to start fill this gap in the literature by investigating, in a pilot study, how *Tinkering* could influence Creative and Critical Thinking levels of a group of museum educators and teachers involved in STEM education, who took part in the workshop considered.

Though no generalisation is possible, due to the small group of analysis available and the short time of intervention (just one pilot over a two-day workshop), the first hypothesis described above seems to be confirmed: in the

post-test, participants showed significant higher Creative Thinking levels. On the other hand, there were no statistical differences concerning Critical Thinking development and this could be explained with the choice of the assessment tool. The feedback received from participants on the Critical Thinking essay, on the passage from "*Discourse on the Method of Rightly Conducting One's Reason and of Seeking Truth in the Sciences*" (1637) by René Descartes, proved to be too much engaging and demanding, especially if performed over two days in a row. This could be one of the reasons why the test did not catch any difference between the pre and post-test.

Data collected showed some limitations of the study carried out but at the same time support follow up activities. Firstly, the pre and post-test design used may be subject to a number of confounding variables, such as history, maturation, test effects and the regression to the mean effect (Marsden & Torgerson, 2012). For this reason, the experimentation is going to be repeated in other settings with larger groups and with a control group. In addition, different assessment procedures to identify Critical Thinking levels would be adopted in order to keep acceptable and stable affective validity levels during performance activities. Correlation tests will be then carried out on the values obtained.

## Acknowledgments

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