FROM TINKERING TO THINKING: TINKERING AS SUPPORT FOR THE DEVELOPMENT OF CRITICAL AND CREATIVE THINKING

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Abstract

Tinkering has been recognized as an informal method to engage students with STEM disciplines. It can be defined as an open-ended process of designing and creating objects or installations, generally using both high- and low-tech tools [1]. Tinkering has been adopted not only to develop scientific knowledge but also to support thinking processes such as Critical and Creative Thinking. Indeed, participants in Tinkering activities are constantly involved in the inquiry and collaborative processes, during which scientific and aesthetic insights could be combined. Despite these theoretical assumptions, there is still a lack of empirical studies concerning the impact of Tinkering on the development of Creativity and Critical Thinking.

The Centre for Museum Studies - University of Roma Tre has been trying to fill this gap in, by investigating the impact of Tinkering activities on Critical and Creative thinking skills enhancement in museum educators and teachers involved in STEM education. The Centre for Museum Studies conducted a study with 30 participants at “Città della Scienza” - Science centre (Naples), where museum educators and STEM teachers were involved in a two-day workshop on collaborative Tinkering activities. Data about Creative [2] and Critical Thinking [3] were collected through a pre-post test methodology. In addition, different kinds of qualitative data were collected during the experience such as groups' interactions reports, presentations, and final objects' pictures.

From preliminary results, a significant correlation was detected between Critical and Creative Thinking \((r = 0.39)\). Participants showed significant higher Creative Thinking level after the Tinkering Activity \((\text{sign. } < 0.001)\). On the other hand, despite there were no statistical differences concerning Critical Thinking assessment, a slight improvement in the post-test could be quantified. In final objects and installations, it was possible to detect the process through which participants combined the scientific and the aesthetic dimension. Indeed, scientific knowledge was often explicitly connected to objects' historical, anthropological, and literary elements.

In conclusion, Tinkering seems to have a positive impact on thinking functions because it allows combining scientific and heritage knowledge through an open-ended creative process. Follow up research is required, where it will be necessary to expand the sample of the study and use different measures for Critical and Creative Thinking assessment.

Keywords: Tinkering, Museum, STEM education, Critical thinking, Creativity, Assessment and evaluation.

1 INTRODUCTION

Recently a strong concern arose among the community of researchers in education. In the last years, the scientific international education community show concerns about the growing disengagement, skepticism and disaffection with science in society [4]. In Italy students' performance in scientific literacy is lower than the OCSE average and the situation worsen for female students and students who live in the South of Italy [5]. For these reasons, a reflection upon teaching methodologies in STEM education is necessary. Educators, politicians and policy makers are recognizing the learning potentials of educational practices developed within informal communities and settings [6] such as Making and Tinkering. The Maker Movement is becoming wide-spread in science education because of its potential to involve young people with STEM [4] and to make scientific knowledge more accessible [7]. Research regarding the effect of Making strategies on learning is growing, as demonstrated by a review published in 2017 [8] where the authors found 3000 scientific papers on the learning by doing topic in formal and informal STEM education contexts. The largest number of research products on Making were aimed at enhancing 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. Scientific centers have been key players in the development of these
learning methods, in particular the Exploratorium in San Francisco opened a dedicated *Tinkering* space (*The Tinkering Studio*), described as ‘part exhibition space, part science laboratory and part atelier’ [9].

The *Tinkering* method has the potential to stimulate scientific inquiry through direct experience, sensor-motorial, and playful practices [10; 11] in a social and collaborative learning environment [12; 13] in which participants create and negotiate meaningful goals using different kinds of mediation tools. *Tinkering* can be more effective when aesthetic and creative components are emphasized [14], because participation and inclusion of all the subjects involved in the activities is promoted and facilitated.

Moreover, *Tinkering* has been recognized to be a meaningful method not only to develop scientific knowledge, but also to promote the so-called 21st century skills. Sheridan and colleagues [15] 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 [16] combining *Tinkering* with writing activities could support the process of individual empowerment. The Institute of Museum and Library Services [17] 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 included in the list of the so called the 21st Century skills. During *Tinkering* activities, participants could have the opportunity also to develop some of the *Critical Thinkers* dispositions [18], such as open-mindedness and truth-seeking.

The above-mentioned skills and dispositions are not only crucial for participants involved in *Tinkering* experiences, but also for *Tinkering* activities designers. 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.

In the present study we report about a research experience, carried out at a Science Centre in Italy and addressed to verify the impact of *Tinkering* potential to develop Critical and Creative skills.

### 1.1 *Tinkering* as a methodology for museum education

The peculiarities of museum education make related educational paths theoretically more effective to promote users’ transverse skills in lifelong learning perspective. Literature related to this field highlights how artistic and cultural heritage is perfectly suited for enhancing and exercising skills useful to adapt in an increasingly changing context, besides offering an overview on the most suitable situations for the active citizen’s development, allowing to critically acquire knowledge and promoting creativity [19]. According to Gibbs et al. [20] definition, the *active, constructivist* and *social constructionist* approaches are the most appropriate ones for developing transverse skills. On the basis of its methodological characteristics, *Tinkering* can be used as a learning methodology in a museum education context based on the *social constructionist approach*: through *Tinkering* activities, visitors should be interpreters and owners of scientific, cultural and artistic knowledge and play a main role in preparing the exhibits, in which *Tinkering* products can be shown as museum objects. Moreover, museum operators can organize *Tinkering* activity in art museum with the aim of promoting STEM education and transverse skills in visitors through an innovative learning methodology. In both these education contexts, users are involved in the construction of social, cultural, historical and political knowledge of a society, constantly changing and implementing them, and create their own identity. In addition, according to Hooper-Greenhill [21], visitors’ level of activity and liabilities towards museum experience, besides influencing the level of interaction with objects, can promote the efficacy of the exhibit itself in terms of users’ return: «Where potentially ‘active’ visitors find themselves unable to use their skills and knowledge and unable to become involved within a museum, where they are forced into a ‘passive’ model, mental discomfort, a feeling of personal inadequacy, or feelings of being out of place are likely to result. The museum becomes a place to be avoided» (p.19).

Furthermore, the close connection between *Tinkering* and *Object-based Learning* [22; 23] supports the research hypothesis by which manipulating and creating new museum objects, visitors’ critical thinking and creativity are strongly encouraged [24].

Starting from these assumptions, *Tinkering* can support the acquisition of STEM contents and the development of transverse skills especially within museum education contexts, in which critical thinking and creativity are strongly solicited.
2 HYPOTHESES AND RESEARCH ISSUES

In recent research, a relationship between Critical and Creative Thinking and some of their related sub-skills was identified [25; 26]. Based on this, our first hypothesis is that Critical Thinking and Creative Thinking are moderately correlated in the group activities devised.

Tinkering is an approach that requires educators to have good creativity levels, since they have to design activities that stimulate learners to reflect about scientific concepts (physics, mathematics etc.), starting from everyday materials such as caps, bottles and light bulbs. The second hypothesis is, therefore, that participants, involved in a co-designing tinkering activity, could improve their creativity and critical thinking skills level.

3 METHODOLOGY

The Centre for Museum Studies - University of Roma Tre designed a two-day Tinkering workshop aimed at developing museum educators and STEM teachers’ level of Critical and Creativity thinking skills.

The group of participants involved (M= 11; F= 19) was composed of STEM teachers and museum educators invited to take part at the activity developed at “Città della Scienza” Science centre, settled 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 there will be described in detail in the paragraph “Data collection and analysis”).

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 group carried out one of the four proposed activities (see the table 1). In each group, about 4-5 people 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 that they filled in and used as the starting point for the debriefing activity. One hour was dedicated to the realisation and observation and 30 minutes to reflection.

Table 1 The tinkering activities proposed in the Workshop.

<table>
<thead>
<tr>
<th>Activity name</th>
<th>Target</th>
<th>Necessary materials</th>
<th>Possible topics for reflection (non-exhaustive)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainbow</td>
<td>Primary School</td>
<td>Basins of different sizes, mirrors, water, cardboard, scissors and markers.</td>
<td>Light, Refraction, Reflection.</td>
</tr>
<tr>
<td>Card light</td>
<td>Secondary school of first / second level.</td>
<td>Led lights, cardboard, markers and coloured pencils, clips, insulating copper adhesive tape, small power generator, battery connector.</td>
<td>Electricity, circuits, electro-magnetism.</td>
</tr>
<tr>
<td>Drawing engine</td>
<td>Secondary school of first / second level.</td>
<td>Cardboard, markers, coloured pencils, clips, insulating copper adhesive tape, magnetic motor, battery connector.</td>
<td>Electricity, circuits, electro-magnetism.</td>
</tr>
<tr>
<td>Tracks for acrobatic marbles</td>
<td>For all ages, suitable for museums, large groups.</td>
<td>Pvc pipes, balls of various shapes and sizes, cardboard, rolls of kitchen papers.</td>
<td>Cinematics, different types of motion (rectilinear, uniform, acceleration) friction and gravity.</td>
</tr>
</tbody>
</table>
On the second day, participants were required to plan their own Tinkering activity. They were asked to split 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 so as to create new activities and tools. They were provided with templates to guide the design of the 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 designed 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 used was the Alternate Uses (AU) task [2]. The AU task is used to assess a specific form of creativity named “divergent thinking”. In this task, each participant is asked 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.

Participants had one minute to write on the paper all the possible uses of the three words given. When the minute expired, an alarm went on stopping the time. A thirty-second break was given between one word and another.

These activities were scored to test the following creative characteristics: Fluency (quantity of ideas), Flexibility (change of idea classification), and Elaboration (enrichment of ideas). 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.” Flexibility score was defined as the number of different categories identified by each participant across all the three words assigned. 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.

The second kind of test was meant to assess Critical Thinking skills. More specifically, participants had to write a short essay [27; 28] on a passage from Discours de La Méthode Pour Bien Conduire Sa Raison et Chercher la Vérité Dans les Sciences [29] 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 [30] model [28]. 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.

Both the tests were administered at the beginning and at the end of the activity to verify the two hypotheses.

5 RESULTS

The following table (Table 2) summarizes the correlation between Critical Thinking and Divergent Thinking. A significant correlation was detected between total score of Critical and Creative Thinking (r = 0,39). In addition, some correlations were found among sub-dimensions of the two skills. The highest correlations were found among relevance and flexibility (r = 0,452), fluency and argumentation (r = 0,407), critical evaluation and flexibility (r = 0,404).
Table 2 Correlation among Critical Thinking and Divergent Thinking sub-dimensions.

<table>
<thead>
<tr>
<th></th>
<th>Fluency</th>
<th>Flexibility</th>
<th>Elaboration</th>
<th>Divergent Thinking Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relevance</td>
<td>R Pearson</td>
<td>,312</td>
<td>,452*</td>
<td>,159</td>
</tr>
<tr>
<td></td>
<td>Sign. (two tales)</td>
<td>,093</td>
<td>,012</td>
<td>,402</td>
</tr>
<tr>
<td>Argumentation</td>
<td>R Pearson</td>
<td>,407*</td>
<td>,304</td>
<td>,021</td>
</tr>
<tr>
<td></td>
<td>Sign. (two tales)</td>
<td>,026</td>
<td>,103</td>
<td>,912</td>
</tr>
<tr>
<td>Critical Evaluation</td>
<td>R Pearson</td>
<td>,275</td>
<td>,404*</td>
<td>,041</td>
</tr>
<tr>
<td></td>
<td>Sign. (two tales)</td>
<td>,141</td>
<td>,027</td>
<td>,830</td>
</tr>
<tr>
<td>Novelty</td>
<td>R Pearson</td>
<td>,195</td>
<td>,230</td>
<td>,405*</td>
</tr>
<tr>
<td></td>
<td>Sign. (two tales)</td>
<td>,302</td>
<td>,221</td>
<td>,027</td>
</tr>
<tr>
<td>Critical Thinking Total</td>
<td>R Pearson</td>
<td>,320</td>
<td>,364*</td>
<td>,069</td>
</tr>
<tr>
<td></td>
<td>Sign. (two tales)</td>
<td>,085</td>
<td>,048</td>
<td>,719</td>
</tr>
</tbody>
</table>

Results obtained after the Tinkering Workshop show improved Divergent Thinking levels in the post-test compared to the pre-test (Figure 1). More specifically, Fluency and Flexibility obtained improved average scores.

![Figure 1 Comparison of the scores obtained (Fluency, Flexibility, Elaboration and Divergent Thinking) pre-test and post-test.](image)

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. Regarding Critical Thinking total 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).
The objects and installations produced in the end showed the kind of process through which participants combined the scientific and the aesthetic dimension (Figure 3). Indeed, scientific knowledge was often explicitly interconnected to objects’ historical, anthropological, and literary elements. For example, a kaleidoscope was created from a rain stick and the designers stated that the object decorations were inspired by Latin American aesthetics because of the cultural and historical origins of the object itself. One of the participants reported that "as the laboratory progresses, the entropy increases and this is positive because it is part of the creative process."
6 DISCUSSION AND CONCLUSIVE REMARKS

Educators, politicians and policy makers are recognizing the learning potentials of educational practices developed within informal communities and settings such as Tinkering. Tinkering has been recognized to be a meaningful method not only to develop scientific knowledge, but also to promote the so-called 21st Century skills.

Critical and creative thinking skills are not only crucial for people who participate in Tinkering activities, but also, and especially, for Tinkering activities designers themselves. 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.

In the present study we are interested to see if Tinkering could be used not only with young participants, but also with museum educators and STEM teachers to develop their Critical and Creative Thinking skills.

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 and the second hypothesis described above seems to be confirmed: Critical Thinking and Creative Thinking are moderately correlated in the group and in the post-test, participants showed significant higher Creative Thinking levels.

On the other hand, there were no statistically significant 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 Discours de La Méthode Pour Bien Conduire Sa Raison et Chercher la Vérité Dans les 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. For this reason, the experimentation is going to be repeated in other settings with larger groups. 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.

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