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Makerspaces and scientific creativity level of middle school students

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Abstract

Being creative is something natural for children. However, as human beings advance in age, the ability to express creativity often decreases or even disappears. During adolescence is when people usually leave behind the creative freedom that was enjoyed in childhood. Makerspaces are spaces that offer tools and materials that encourage students to create. The purpose of this study is to investigate the effect of Makerspaces in scientific creativity level of eight grade students, using a quasi-experimental design pretest-posttest (Cook y Campbell, 1979). The participants of the research were 200 students who attend to a private school in Madrid during 2017-2018 academic years. The experimental groups selected covered the learning standards by doing a project in the makerspace, and the control groups covered the same standards by traditional learning in the classroom. To investigate scientific creativity of secondary school students, the Hu & Adey (2002) scale test was used. Our findings showed a significant difference in scientific creativity between the groups. The experimental group (maker-centered learning) had higher scientific creativity than control group (traditional learning). Authors such as Ramirez & Fuentes (2013) have shown that activities that help students to deal with real life situations, combined with methodologies of innovation that encourage creativity and promote the involvement and motivation of students, make them feel happier and help to develop students personally and professionally, as well as to improve their academic performance. We strongly recommend the use of makerspaces in schools as learning environments that will foster scientific creativity, influencing positively in the academic performance of students.

Keywords: Makerspaces; creativity; maker-centered learning; academic performance;

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1. Introduction

Makerspaces and MakerLabs are popping up around the world. They have gathered widespread interest and support in both policy and education circles because of the ways they have been shown to link science learning to creativity and investigation. Making has been shown to support the development of an array of learning dispositions, including resourcefulness, creativity, teamwork and forms of adaptive expertise (Martin & Dixon, 2016; Peppler, 2016; Ryan, Clapp, Ross, & Tishman, 2016; quoted by Bevan, 2017).

Creativity is currently receiving increased attention in educational research studies. In China, where creativity continues to be deemed a national priority, schools are adopting a problem-based learning approach to education that allows for more innovative thinking (West-Knights, 2017). The concept of creativity has proven over the years to be an elusive one to define. Different perceptions of the meaning of creativity have led to a correspondingly wide variety of techniques to assess creativity (Hu & Adey, 2002). Scientific creativity has been identified as one of the key domains of specific creativity which has contributed to the advancement of human civilisation (Hu, Shi, Han, Wang & Adey, 2010).

The interest of makerspaces by educators is about the development of creativity. Connecting creativity with making has multiple benefits for schools. It develops the mindset, the confidence of students to trust themselves in the act of creation (Martinez, 2018) and help students to deal with real life situations (Caballero Garcia, Guillen & Jimenez, 2017). However, no findings about the connection between scientific creativity and making have been made in the middle school students. In this direction, a question is raised: can scientific creativity be fostered by maker-centred learning activities?

1.1. Scientific creativity

First scientific explanation of creativity was given by Guilford in the 50s. He explained the construct of creativity, in general, in relation to the model of the structure of intellect (SI) model. According to Guilford, creativity is mostly associated with 'divergent production' leading to a number of solutions of a particular problem, unlike 'convergent production', where information leads to one single appropriate answer (Guilford, 1956; quoted by Mukhopadhyay & Sen, 2013). The idea of Guilford on creativity has influenced the research works of other researchers like Hu and Adey, Majumdar, Singh, Misra, Shukla & Sharma, etc. (Mukhopadhyay & Sen, 2013). Different perceptions of the meaning of creativity have led to a correspondingly wide variety of techniques to assess creativity. The best-known test of general creativity is the *Torrance Test of Creative Thinking* (Torrance, 1990). This is a paper-and-pencil test which taps divergent thinking abilities. Items are scored for fluency, flexibility and original thinking (Hu & Adey, 2002).

To measure scientific creativity of secondary school students, several tests have been developed but they are somewhat dependent on science knowledge, so they cannot be used for assessing scientific creativity of secondary school students whose scientific knowledge is limited. In the light of developing a test of scientific creativity (TSC) for all secondary school students at different ages and in different cultures, Hu and Adey designed the '*TSC*', a test consisted of seven items, which were developed through three dimensions called the product (scientific knowledge, scientific phenomena and scientific problem), the process (imagination and thinking) and the feature (fluency, flexibility and originality) (Ceran, Gungoren & Boyacioglu, 2014). The questions within TSC are open-ended and thus have no accurate answers. Students' answers are scored based on creativity traits: fluidity, flexibility and originality.

1.2. Maker-centred learning

For the past decade, the maker movement—an interest in working with one's hands in interdisciplinary environments that incorporate various tools and technologies—has been on the rise. In recent years, educators, administrators, parents and policymakers have expressed a heightened interest in maker-centred learning, the incorporation of the practices of the maker movement into education (Clapp & Jimenez, 2016). The maker movement is a cultural trend that places value on an individual's ability to be a creator of things as well as a consumer of things. In this culture, individuals who create things are called 'makers'. The growth of the maker movement is often attributed to the rise of makerspaces (Rouse, 2014).

A makerspace is a collaborative workspace inside a school, library or separate public/private facility for making, learning, exploring and sharing that uses high tech to no tech tools. These spaces are open to kids, adults and entrepreneurs and have a variety of maker equipment including 3D printers, laser cutters, CNC machines, soldering irons and even sewing machines. A makerspace, however, doesn't need to include all of these machines or even any of them to be considered a makerspace. It's more of the maker mindset of creating something out of nothing and exploring their own interests that's at the core of a makerspace. These spaces are also helping to prepare those who need the critical 21st century skills in the fields of science, technology, engineering and math. They provide hands-on learning, help with critical thinking skills and even boost self-confidence (makerspace.com, n.d.).

Since the maker movement's entry into popular culture, maker education programmes and makerspaces have sprung up in K-12 schools across the world. The maker education approach aligns with aspects of the pedagogical theory that have been developing for many years. Numerous researchers have traced modern maker education ideas to John Dewey (and others, including Friedrich Froebel and Maria Montessori), who maintained that education should be based on experiences that are connected to real-world objects and events. Add to this heritage, Jean Piaget's emphasis on the importance of play, individual learning and learning through discovery and the foundations of emerging maker education are evident. A significant precursor to modern maker education is constructionism, a concept advanced by Seymour Papert, who has been called the 'father of maker education'. Papert argued that knowledge is constructed very effectively when young learners are creating and building objects they can share with others. This type of playful, independent, hands-on/minds-on, discovery-based learning—sometimes called 'active learning'—is considered important for developing problem-solving skills, as these cannot be taught but must be discovered. The difference is in the approach: in a traditional classroom setting, students learn about circuitry and electricity; in a makerspace, students use circuitry and electricity to create objects they want to make (Lindsey & DeCillis, 2017).

Maker-centred learning helps students to acquire the 21st century skills and build their character while making, supporting a development of a resilient disposition, a foundation for a wide variety of valuable thinking dispositions, that include problem solving, critical thinking, inquiry, a growth mindset, collaboration, curiosity, playfulness, resourcefulness, responsibility and optimism. Also, Lindsey and DeCillis explain that through maker activities, students make things that are meaningful to themselves or others, taking ownership of the making process, developing their 'agency', fostering important skills such as leadership (through setting expectations of the process, presentation and difficulty of work performed), collaboration through constructive criticism and ideas sharing, practicing the ability to defend an argument or describe a problem, and self-awareness as a learner, practicing informed iteration while working towards a solution or improvement.

2. Method

In this study, the purpose is to investigate the effect of maker-centred learning in scientific creativity level of 8th grade students compared with traditional learning, using a quasi-experimental design pre-test–post-test (Cook & Campbell, 1979).

2.1. Participants

The sample was selected on a non-random and intentional way. The final group involved in this study was composed of 200 middle school students in the 8th grade, aged between 13 and 15 years old, from two private schools in Madrid, Spain. Respecting the system of intact classrooms, 100 students were randomly assigned to each group. The experimental group was comprised of 48 girls and 52 boys, and the control group contained 42 girls and 58 boys. All 200 students, 110 boys and 90 girls, participated in the experimental research over a period of 8 weeks (Table 1).

Table 1. Distributions belonging to students' gender for experimental and control group

Gender	*N*	Experimental group	Control group
Female	90	48	42
Male	110	52	58
Total	200		

2.2. Measures

The data of the study have been collected using the 'Scientific Creativity Test' (SCT) which was developed by Hu and Adey (2002) for the purpose of determining secondary school students' level of scientific creativity. Two equivalent tests were used as pre-test and post-test. The SCT consists of seven open-ended questions and each question was scored using the scoring criteria of Hu and Adey for the test. The first question in the test has been designed to use an object for a scientific purpose, the second question is to test the sensitivity level of a scientific problem, the third question is to test students' ability of designing a technical product, the fourth question is to test students' scientific imagination, the fifth question is to test the ability of creating a scientific solution, the sixth question is to detect the creative experimental ability and the seventh question is to test the ability of designing creative scientific product (Ceran, Gungoren & Boyacioglu, 2014). In the research conducted by the authors, the test obtained a satisfactory reliability index ($\alpha = 0.893$) and an adequate inter-judge reliability, with Pearson correlation coefficients between 0.793 and 0.913. Regarding the validity of the test, all the items charged in a single factor that explained 63% of the variance. The Cronbach Alpha coefficient of internal consistency of this test was 0.893.

2.3. Data collection procedure

Students were informed of the purpose of the research. When they agreed to voluntarily participate in the experiment, and with centre and families permission, they performed SCT tests (pre-test). Data collection was carried out in one session of 40 minutes of duration approximately. After that, the experimental group developed their classes with a maker methodology, while the control group worked their science lessons with a traditional methodology. At the end of the semester, scientific creativity level (post-test) was evaluated again. Once all this information was collected, the different tests were corrected and it was possible to start with the statistical data analysis.

2.4. Data analysis

The data of the study have been analysed using two different tools. In the first place, the analysis of the SCT was made using the guidelines given by Hu and Adey to score the test. Students' expressions in each question were coded and their frequencies were determined using Atlas Ti (version 7.1). In the result of the point scoring analysis, SPSS for Windows (version 24) was used to test inferential statistics analyses to test whether there were significant statistical differences between the two samples. Alpha value was set at 0.05, level of significance.

3. Results

Points that experimental group and control group have got from the SCT have been calculated. For each item of the test, the mean and standard deviation have been calculated and the results are summarised in Table 2.

Table 2. Descriptive statistics of each item taken from SCT scores

Questions	*N*	Experimental group				Control group			
		Mean pre-test	SD	Mean post-test	SD	Mean pre-test	SD	Mean post-test	SD
Item 1	200	6.01	4.800	9.38	6.612	8.19	7.739	9.38	5.345
Item 2	200	10.36	5.462	9.57	6.285	10.05	5.953	9.49	5.423
Item 3	200	7.44	3.715	6.85	4.585	6.33	3.091	5.94	3.604
Item 4	200	6.05	3.514	5.14	3.361	5.18	3.935	4.35	3.810
Item 5	200	4.34	3.294	8.61	6.944	5.58	5.386	7.87	7.977
Item 6	200	5.28	4.461	16.04	11.217	5.50	4.616	11.44	9.411
Item 7	200	10.52	5.597	14.70	5.651	10.92	6.169	10.66	5.584

When Table 2 is examined, it is seen that the average for experimental and control groups, when comparing pre-test and post-test, in both decreases in items 2, 3 and 4 but increases in items 1, 5 and 6. Average of Item 7 doesn't follow the same tendency in both, since it increases in the experimental group but decreases in the control group. When looking at the standard deviation, it is seen that for the experimental group the value for each item increases in post-test, except for item 4. Whereas, in the control group, the value of standard deviation increases only in items 3, 5 and 6. This indicates that the experimental group experiences a variation in the post-test as a result of the intervention made through maker-centred learning, resulting in a greater standard deviation for almost every item. This is probably a consequence of a bigger difference between the students with standard performance and students with outstanding performance (Ruiz, Bermejo, Prieto, Ferrandiz & Almeida, 2013).

The findings belonging to students' *t*-test for the comparison of two means in the experimental group are represented in Table 3.

Table 3. Summary of *t*-student analysis for experimental groups with $\alpha = 0.05$

	N	Minimum	Maximum	Mean	SD	*F*	Sig.	*P*
Pre-test	100	11	109	50.00	17.285	2.452	0.000	0.000(*)
Post-test	100	11	192	70.29	27.065			

(*) Meaningful difference at a 95% level of significance

According to *t*-student analysis, it is seen that in the experimental group there is a meaningful difference ($p = 0.000 < 0.05$) among students' total points of the scientific creativity when comparing the pre-test and post-test, with a level of significance of 95%. The average of students' total points of SCT in pre-test is 50.00 and the average in post-test is 70.29. Both datasets have high homogeneity, since standard deviation values, 17.285 for pre-test and 27.065 for post-test, are below the 25% of the interval represented by the maximum and minimum values that have been calculated for each test, represented in Table 3.

Students' *t*-test has been used also to compare the two means in the control group and the results are represented in Table 4.

Table 4. Summary of *t*-student analysis for control groups with $\alpha = 0.05$

	N	Minimum	Maximum	Mean	SD	*F*	Sig.	*p*
Pre-test	100	15	109	51.75	19.457	1.676	0.0052	0.077
Post-test	100	0	192	57.41	25.188			

(*)Meaningful difference at a 95% level of significance

Looking at the *t*-student analysis, it is seen that in the control group there is not a meaningful difference ($p = 0.077 > 0.05$). The average of students' total points of SCT in pre-test is 51.75 and the average in post-test is 57.41. Standard deviation values are 19.457 for pre-test and 25.188 for post-test. So, taking into account what was said before about homogeneity for the experimental group and looking to the maximum and minimum values of pre-test and post-test, it is seen that both datasets have high homogeneity.

Further analysis has been carried out in order to test whether there is a difference among groups in terms of students' scientific creativity. Descriptive statistics among groups in the pre-test and post-test are represented in Table 5.

Table 5. *t*-student analysis among groups in pre-test and post-test scientific creativity, with $\alpha = 0.05$

	N	Mean	SD	*F*	Sig.	*t*	*p*
Pre-test experimental group	100	50.00	17.285	1.267	0.1191	−0.672	0.502
Pre-test control group	100	51.75	19.457				
Post-test experimental group	100	70.29	27.065	1.155	0.2368	3.484	0.001(*)
Post-test control group	100	57.41	25.188				

(*)Meaningful difference at a 95% level of significance

When Table 5 is analysed, it is seen that there is not a meaningful difference in terms of students' scientific creativity among groups in the pre-test ($p = 0.502 > 0.05$) but there is a meaningful difference among experimental and control group in the post-test ($p = 0.001 < 0.05$). The mean of scientific creativity is bigger in the experimental group than the control group.

4. Conclusion

The present research does indicate that maker-centred learning has a positive effect in middle school students' scientific creativity. The experimental group showed a greater scientific creativity level than the control group, improving their creativity ability in 20.29 points when implementing science lessons in a maker-centred learning environment. This study is parallel with the results of the study carried out by Saorin et al. (2017). In their research, an educational activity with 44 engineering students from La Laguna University was designed in a maker environment. The results showed that participants who performed the activity improved their creativity ability in 24.04 points, representing a meaningful difference at a significance level above 99.9%. Labangon and Mariano (2017) conducted other research to reveal and evaluate the perspective of participants joining the Upcycling makerspace programme implemented in a library in Filipinas. A survey was conducted and participants stated that since they were able to create new material out of something, they were able to harness their creative skills.

Our research shows as Siew, Chin and Sombuling (2017) claimed, that emphasis on carefully structured maker activities in the teaching and learning of middle school science lessons foster originality, elaboration of ideas and imaginative and abstract thinking. But learning in a maker environment is not a sufficient condition to effectively promote scientific creativity. It is important to clearly articulate learning outcomes of maker activities and set out to document 'what learning looks like' in different maker settings (Lindsey & DeCillis, 2017).

Many researchers and practitioners acknowledge a lack of obvious paths forward or right answers when it comes to how to best assess learning while making. There is ongoing work on developing documentation and assessment tools designed with maker-centred environments in mind, such as the Agency by Design research initiative at the Harvard Graduate School of Education, which sets the key characteristics that support maker-centred learning (Figure 1).

Who (and What) Are the Teachers in the Maker-Centered Classroom?	
Students as Teachers	Students function as teachers in a variety of ways, including teaching one another, teaching the teacher, and teaching others in the school community and beyond.
Teachers in the Community	Community members often serve as resources for students in the maker-centered classroom, offering onsite and offsite expertise and mentorship.
Online Knowledge-Sourcing	Students access the Internet to find information and instruction.
Tools and Materials as Teachers	Students are encouraged to learn from the their physical interactions with tools and materials.
What Does Teaching Look Like in the Maker-Centered Classroom?	
Facilitating Student Collaboration	Teachers structure assignments and projects to encourage students to work together in a variety of formal and informal ways, and provide ongoing support for them to do so.
Encouraging Co-inspiration	Teachers design instruction so that students are encouraged to engage with and derive inspiration from one another's work.
Encouraging Co-critique	Teachers provide strategies and support for students to give each other informative, useful, and generous feedback.
Redirecting Authority	Teachers actively redirect students away from the fallback of "teacher as the authoritative dispenser of knowledge" and toward other authorities, especially other students and online resources.

Who (and What) Are the Teachers in the Maker-Centered Classroom?	
Promoting an Ethics of Knowledge Sharing	Teachers take a "learn something, teach something" approach to encourage students to feel a sense of responsibility to share their newly developing skills and knowledge with others, especially other students in the maker-centered classroom.
What Does Learning Look Like in the Maker-Centered Classroom?	
All of the Above	Students learn by engaging in the various activities teachers encourage, including collaboration, co-inspiration, co-critique, seeking skills and knowledge on their own, and sharing skills and knowledge with others.
Figuring It Out	The most pervasively visible sign of student learning in the maker-centered classroom is students trying to figure things out on their own, especially through tinkering and iterative processes.
What Does the Maker-Centered Classroom Look Like?	
Tools and Materials	Maker-centered classrooms incorporate tools and materials from multiple disciplines.
Storage and Visibility	Tools, materials, and student work need to be stored within the maker-centered classroom. The more visible tools, materials, and student work are, the more likely it is that students will make new connections.
Specific and Flexible Spaces	Maker-centered classrooms tend to be either activity specific, or flexibly designed for engagement in a variety of maker-centered activities.

Figure 1. Overview of strategies for designing maker-centred learning experiences and environments (Clapp, Ross, Ryan & Tishman, 2016)

However, developing such tools is challenging. Some see the intrinsic differences between makerspaces and traditional classroom environments as an opportunity to freely shift the focus from quantitative summative assessments (i.e., grades) to more qualitative feedback and formative assessment. Indeed, some researchers view makerspaces as inviting a revolution in assessments in the K-12 school system (Lindsey & DeCillis, 2017).

This research has contributed substantive proof that middle school science teachers need to integrate maker activities in their science lessons to inculcate scientific creativity among students, encouraging them to make not only things but also themselves—into better problem solvers and self-directed learners of meaningful content. Fostering students' agency will result in a better academic performance in science.

Nevertheless, the research findings do have some limitations. The 200 middle school students that were involved in this study may not be representative of the whole population of Spanish middle schoolers. A larger sample size with students from different schools around the country randomly chosen is required to have a representative sample of the whole population in Spain for future research. Another future research would consist on applying maker-centred learning during three or five consecutive school years, from 6th to 8th or 10th grade middle school courses, to study the impact of makerspaces in students' scientific creativity levels.

We recommend the implementation of emotional educational programmes like makerspaces in schools that improve the professional skills of our students and contribute to their personal and social development (Caballero Garcia & Carretero, 2014; Caballero Garcia, Carretero & Fernandez, 2015; Caballero Garcia, Carretero, Sanchez & Ruano, 2018). Considering that education in the 21st century seeks for innovation, in order to adapt schools to the modern world that is progressing so fast, it is essential to start educating students from creativity and optimism, to get awakening and happy minds capable of giving quick solutions to problems and create with originality and fluidity. These minds will make their own way into the real world and, what is more important, will guide us to the future (Caballero Garcia, Ruano & Sanchez, 2018).

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