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The Use of 3D Printing and ICT in the Designing of Didactic Strategies to Foster Creative Thinking

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Abstract: The use of iteration is fundamental in the field of design, as it allows for the exploration of multiple options and the development of innovative solutions. This research analyzes how iteration, combined with Information and Communications Technology (ICT), especially 3D printing, facilitates the development of creativity in higher-level students, specifically Industrial Designers. A qualitative approach was employed, using an action-research methodological strategy with a field journal to document student activities during the iterative process. The results indicate that group dynamics enhance iteration by facilitating the exchange of ideas; therefore, the incorporation of activities that adopt constant feedback is necessary to refine initial concepts and integrate new perspectives. Additionally, the use of technology, such as 3D printing, drives the creative process by encouraging students to continue developing their ideas through physical iteration, allowing them to materialize and improve their concepts. The creative process only needs to be stimulated through different methodological strategies, both analog and digital, in and outside the classroom, with the use of technologies as essential learning tools.

Keywords: iteration; design; creative thinking; 3D printing; educational technology

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1. Introduction

Creative thinking refers to the ability to generate new and effective ideas, as well as to approach problems from innovative perspectives. This type of thinking involves various cognitive processes that interact in complex ways, including imagination, cognitive flexibility, and memory [1]. From the perspective of Khalil et al. [2], thinking should be fostered through the creation of learning environments that expand and diversify students' experiences, thereby promoting their cognitive and innovative development.

The development of creative thinking is crucial for problem-solving, innovation, and adaptation to new scenarios. The ability to combine isolated concepts into novel ideas is an indicator of creativity, suggesting that enhancing an individual's semantic memory enables them to navigate and associate ideas effectively, thus generating more creative proposals.

Designing a competency-based training model focused on creativity is essential to demonstrate how this skill drives the teaching–learning process, becoming a key aspect for both students and educators in a university context [3]. Creative experiences are generally more engaging for students, which can lead to increased motivation and more active participation in their own learning. For educators, the use of ICT in the educational process fosters innovation in their teaching practices [4]. However, one of the main barriers educational institutions face when incorporating creativity into the classroom is the lack of knowledge among educators about methodologies that support teaching of creative thinking, as well as the absence of digital resources that facilitate this process [5].

To foster the development of creative thinking, iteration plays a crucial role, as it allows for the refinement and continuous improvement of ideas through a cyclical process. According to Kenett [1], the influence of iteration on creative thinking can be observed in the following aspects:

- Trial-and-error approach: Initial ideas can be evaluated, adjusted, and improved based on the results obtained. This process allows students to explore various perspectives and alternatives without fear of making mistakes, which is fundamental for creativity.
- Constant feedback: Through iteration, it is possible to receive feedback on ideas, enabling students to identify areas for improvement and consider new concept combinations. This feedback cycle can inspire new connections and foster deeper and more divergent thinking.
- The exploration of innovative combinations: Iteration allows for experimentation with different combinations of ideas and concepts, which is essential for creativity. By repeating and refining their approach, students can discover new ways to merge ideas that initially seemed unrelated.
- The enhancement of cognitive flexibility: The iterative process helps develop cognitive flexibility, which is fundamental for generating innovative ideas in changing contexts.
- The development of an open mindset: Iteration encourages an open mindset toward change and the evolution of ideas. By accepting that initial solutions are not definitive and that there is always room for adjustment and refinement, students can unlock their creativity and feel more motivated to experiment.

Iteration enables continuous improvement of ideas in the creative process while creating a favorable environment for exploration, adaptation, and concept integration, key elements for the development of creative thinking.

According to Jalolov [6], creative thinking can be enhanced through Information and Communications Technology (ICT) using the following strategies:

- Incorporating multimedia elements: Using videos, animations, and audio in instructional sequences can make learning more engaging and help stimulate students' imagination.
- Interactive activities: Implementing hands-on activities involving multimedia platforms allows students to actively participate in the learning process, fostering collaboration and creative expression.
- Active learning: Applying active learning methodologies such as project-based or problem-based learning enables students to research and apply their creative thinking skills in practical contexts [7,8].
- Collaboration: Encouraging group work using multimedia tools helps students exchange ideas, reflect on different perspectives, and collectively develop innovative solutions.

By integrating these ICT tools into the curriculum, educators can create meaningful learning experiences that enhance students' creative thinking.

This article presents the development of a didactic strategy based on iteration to foster creative thinking through the use of Information and Communications Technology (ICT). Section 2 provides a description of related works to contextualize the study topic, Section 3 explains the research design, Section 4 presents the main results obtained, Section 5 includes a discussion of the study, and finally, Section 6 outlines the conclusions.

2. Related Work

2.1. The Development of Creative Thinking

According to Valverde et al. [9], in various fields, there is a need for profound educational reform that addresses contemporary demands. Proposals for modernization and the incorporation of new content are added to existing subjects, overloading curricula with minimal and barely noticeable changes due to a school culture deeply rooted in traditions and practices that hinder transformation. However, the creative process is characterized by a series of interrelated phases whose primary objective is the generation of new ideas, as well as their development and evaluation of effectiveness. In an educational setting, this process is essential for enhancing investigative capacity and activating problem-solving skills. It is approached with the goal of being strengthened within the teaching–learning process, playing a leading role linked to the ability to consciously present a situation in a novel way. According to [10], creativity has not always been studied with the intention of being strengthened and optimized. Instead, its analysis has often focused on tangible aspects, neglecting the study of creative thinking.

In the field of design, creative processes should be oriented toward exploring non-linear methodologies characterized by iterative execution, which promotes innovation and the progressive evolution of ideas. Therefore, educators must recognize creativity as an inherent potential that can be developed throughout the teaching–learning process by implementing activities that foster curiosity, improvisation, and the generation of innovative ideas [11].

Wu et al. [12] emphasize that artists need flexible and dynamic thinking that allows them to integrate diverse resources, fostering innovation and creativity. This approach involves the interaction of multiple factors that stimulate reflection and continuous refinement of the creative process, adapting to the diversity and complexity of artistic creation. In education, this perspective contributes to improving students' ability to face challenges by promoting advanced problem-solving skills.

Grimaldo-Salazar et al. [13] state that, based on Torrance's conceptualization of creativity, specific tests were designed to evaluate it through various activities such as music, drawing, and writing. These tests provide fundamental elements for analyzing the multiple dimensions of creative thinking. Creativity manifests in different fields, and its assessment requires differentiated tasks. The Torrance Test of Creative Thinking is an evaluation instrument consisting of two scales, one verbal and one figurative. Each subtest is presented in two forms: Form A, used as a pre-test, and Form B, applied as a post-test. The data obtained from both tests can be analyzed individually and/or collectively.

According to Humble et al. [14], the Torrance Tests of Creative Thinking demonstrate a degree of transferability, evidenced by the creativity construct measured by the Figural Form, which could be multidimensional by incorporating both innovative and adaptive factors across different cultural contexts, depending on the study's objective. Their findings highlighted sociocultural homogeneity, showing significant positive and negative associations between context, education, and self-perceptions with the innovative and adaptive factors of creativity.

For this study, the objective is to identify the extent to which iteration facilitates the development of creativity through the use of technological tools in university students. As Rúa et al. [15] state, the goal is to achieve significant improvements in student performance and creativity by motivating their imagination and fostering greater innovation. Therefore, the figurative subtest was specifically selected as the measurement tool for this construct, as it evaluates creative thinking through visual representations in the form of sketches. From Cuervo-Pulido et al.'s perspective [16], the use of sketches is an essential component of the design process, as it not only pertains to the final product but also to the creative path that generates it. Thus, teaching and learning design focuses more on strengthening the creative thinking skills inherent in the design process than on achieving specific outcomes.

2.2. Managing Creativity and Iteration

Creativity in the university context is considered an essential component in the comprehensive training of future professionals, as it is associated with progress, innovation, and improvement. However, there is an insufficient promotion of creativity among students, whose potential is not fully reflected in the classroom. Strengthening creativity is crucial for enhancing the competencies necessary for their professional performance. In this regard, the role of educators becomes particularly significant, as they have the opportunity to design and foster educational environments that stimulate creative thinking. This is achieved through the implementation of technological tools and pedagogical strategies aimed at encouraging and consolidating this potential.

As noted by Martínez and González [17], creativity is not a new concept, but it is essential for students to possess the theoretical and technical knowledge, as well as the skills, competencies, and strategies that enable them to effectively tackle the professional challenges they will face. The iterative process allows for the identification of improvement opportunities in intermediate stages, the development of independent components, and their integration in subsequent iterations [18]. However, Hincapié-Atehortúa [19] argues that project delays often result from poor planning in the design phase, which can be mitigated by developing structured iterative methods that optimize productivity.

Thus, iterative work within the creative process is recognized as a fundamental element, as it enables the progressive generation and integration of necessary changes. Creativity is not merely a matter of inspiration, as it would not be possible to create consistently over time and produce work regularly. Since the process is not linear, changes in direction are unpredictable, giving each student the opportunity to solve their own problem while working within a trial-and-error technique [20].

According to Wynn and Eckert [21], many early design representations inspire designers themselves to seek alternative solutions because they are often poorly structured from the outset. This necessitates an iterative process influenced by both the designer's level of experience and imagination, with the goal of creating new pathways and evaluating more viable proposals as more information about the problem becomes available. In other words, this process allows each individual to select a method that enables them to transform their experience into learning.

2.3. Three-Dimensional Printing as Support for the Iterative Process

It is essential to explore learning strategies that combine theory and practice, traditional work and technological application, as teaching and learning must be adapted to different levels of experience to develop more educational resources. In other words, there is a recognized need to integrate design and production simultaneously into the curriculum to enhance training in creative fields [22].

From Mata-Abdelnour's perspective [23], this integration led to increased student participation, accompanied by greater discipline and organization, even among those who were initially less collaborative. This dynamic aimed to foster an active student role, encouraging the resolution of complex problems and the use of new technologies by promoting deeper student engagement. Thus, the iterative process becomes a fundamental part of 3D printing education, and vice versa, as some students tend to accept their first model without assessing its deficiencies or fully committing to the learning process.

2.4. Research Question

For this study, the research question is: how do iteration and the use of 3D printing stimulate the development of creative thinking in Industrial Designers?

3. Materials and Methods

This study is based on a qualitative methodological approach, which, as argued by Flick [24], "stems from the notion of the social construction of the realities under study and focuses on the participants' perspectives, everyday practices, and common knowledge related to the subject of inquiry". The primary objective is to explore students' activities, processes, and work experiences concerning the development of creative thinking. This study follows an action-research methodological strategy, as described by Peralta-Castro et al. [25], where the participants' voices highlight key aspects such as observation, analysis, and reflection from both students and educators. This facilitates learning and overcoming challenges while bridging theory and practice.

For data collection, various qualitative research techniques were used, including a field journal as an observation method to characterize activities, understand dynamics, and identify challenges [26]. This journal provided a detailed record of activities carried out during each of the seven scheduled sessions across two participating groups, documenting in-class tasks and the strategies students employed in designing objects.

Additionally, at the end of the intervention, a questionnaire was administered to gather students' perceptions and opinions about their experience throughout the process. The questionnaire also assessed their evaluation of weekly activities, the daily evidence generated in each session, and the use of the digital platform Discord as a learning support tool. Discord was selected for its ability to integrate with various tools, facilitating a more flexible, efficient, and accessible learning process for all users. It promoted interaction beyond academic hours, allowing information exchange, messaging, and the completion of complementary activities [27].

3.1. Participants

The study was conducted at the Universidad Autónoma de Querétaro, specifically at the Faculty of Engineering's Center for Design and Technological Innovation (CEDIT), involving students who integrate 3D printing as an innovative tool in their design development to enhance creative development and materialize their ideas. The educational strategy was implemented in three stages: (1) population analysis, (2) pilot study, and (3) didactic intervention. In all three stages, students from the sixth semester of the Industrial Design program participated in the Computer-Aided Manufacturing (CAM) course, as shown in Figure 1. Before participation, the objective of the research was explained to the students to obtain their informed consent.

For the third stage, corresponding to the didactic intervention, students signed a commitment letter for the submission of exercises and provided authorization for their personal data to be treated anonymously and exclusively for research purposes. A database was used to track and monitor the activity submissions of all 21 students, including their names, identification codes, email addresses, results from the Honey and Alonso Learning Styles Questionnaire, pre-test and post-test scores from the Torrance Test, attendance, and assignments submitted via the platform.

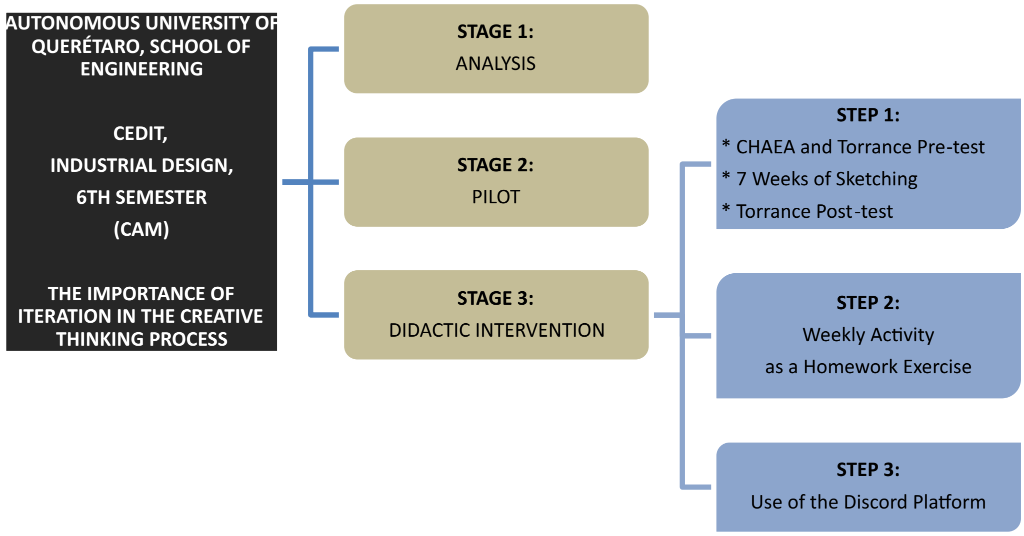

Figure 1. An overview of the three-stage intervention process (population analysis, pilot, and didactic intervention) and its main steps (CHAEA/Torrance tests, weekly sketching, and Discord use).

3.2. Procedure

From Villarreal-Fernández's perspective [28], knowledge is based on the dynamic interaction between the individual and their environment, contributing to the development of their cognitive structure. This interactive process enables individuals to assign meaning to their perceptions and construct representations that provide context to their experiences. Learning, in turn, is part of an active cycle in which action is the primary resource, and reflection on that action generates the learning process.

Following a thorough analysis of the population, the next step involved studying class dynamics and the methodology used in implementation to identify relevant activities and determine the most suitable strategies for the second stage—the pilot study. Understanding students' learning styles was identified as crucial. According to Costa et al. [29], it is essential for educators to understand both their students and themselves, as this self-awareness and comprehension of the student body enable them to diversify and adapt their teaching strategies to effectively meet the needs of the classroom.

To identify the optimal characteristics of individual learning, students completed the Honey and Alonso Learning Styles Questionnaire via Google Forms, which consists of 80 items, divided into twenty per category—active, reflective, theoretical, or pragmatic—with dichotomous responses (+ or −), where students had to express their level of agreement or disagreement with the presented statements. This information was used to plan activities that foster creative thinking by enabling students to make connections and formulate original or functional ideas, design strategies, structures, or products that had not been previously considered [30], while also defining the predominant learning style within the classroom.

During the semesters in which stages 1 (population analysis) and 2 (pilot study) were carried out, students participated in three sessions dedicated to the creative process—one per evaluation period within the CAM course. However, for stage 3, corresponding to the didactic intervention, it was determined—based on the institutional academic calendar—that nine consecutive classes were necessary. This schedule avoided holidays and vacation periods to ensure an uninterrupted workflow, allowing the iterative process within creative development to proceed without disruption, as outlined in Table 1.

Table 1. Summary of each methodological stage (population analysis, pilot, and didactic intervention), showing the number of students, main steps, duration, and location.

Stage	No. of Students	Steps	Duration	Location
Population Analysis	30	Observation	3 creativity sessions	Classroom
Pilot	7	Creation of CHAEA via Google Forms	N/A	Online
		Design of the Discord platform server	N/A	N/A
		1st sketching exercise per session	3 creativity sessions	Classroom
Didactic Intervention	21	CHAEA application	N/A	Online
		Pre-Test Torrance application	Session A	Classroom
		Sketches	7 weeks	Classroom
		Weekly activity	7 weeks	ICT
		Use of platforms for evidence	7 weeks	Classroom/ICT
		Post-Test Torrance application	Session B	Classroom

At the beginning of the semester, during the didactic intervention, students were given a detailed explanation of the class schedule and the methodology that would be followed throughout the process. The intervention plan consisted of three main steps.

As shown in Table 2, the first step, carried out in Week A, involved the online development and application of the CHAEA test, while in the classroom, the Torrance pre-test was administered. Subsequently, students created sketches based on basic shapes inspired by the Torrance Test of Creative Thinking (TTCT). These exercises were designed to gradually increase in complexity as the weeks progressed, along with the time allocated for their completion. Initially, in Week 1, students had five minutes to create four sketches. Over time, this increased incrementally until they were required to complete ten sketches within ten minutes. This structured timing aimed to facilitate the cognitive and creative iteration process among participants over seven weeks.

The second step involved a weekly take-home activity where students worked on class-generated references, modifying them based on specific instructions aligned with the competencies targeted in each session. This led to the third step, which was the use of the Discord platform.

Table 2. Timeline of the didactic intervention from January to April 2024, showing the scheduling of key activities (CHAEA, Torrance pre- and post-tests, weekly exercises, and the use of Discord).

2024 Month	January				February				March					April			
Week	1	2	3	4	1	2	3	4	1	2	3	4	5	1	2	3	4
Torrance Test Submission		✓															
CHAEA Application				✓													
Torrance Test (PRE) Application				✓													
Torrance Exercise Application					✓	✓	✓	✓	✓	✓	✓						
Weekly Activities					✓	✓	✓	✓	✓	✓	✓						
Use of Discord for Evidence and Feedback					✓	✓	✓	✓	✓	✓	✓						
Torrance Test (POST) Application												✓					
Submission and Receipt of TTCT Analysis Results							✓	✓				✓				✓	

Hernández-Jaime et al. [31] point out that creative thinking does not follow a logical or systematic process but rather progresses through an initially chaotic and uncertain path, characterized by the generation of ideas that may seem unconventional at first. Consequently, the competencies targeted for development, as outlined in the TTCT, reflected key aspects of the creative process, including originality, flexibility, fluency, elaboration, problem solving, openness to experience, collaboration, creative communication, curiosity, and automatization. The objective was to identify progress in these areas.

A field journal was used to record each session, as illustrated in Figure 2. This journal included sections to document general and specific class objectives, session activities, attendance, materials used, tools, student comments, instructor observations, and researcher notes, along with instructions for the next session. This allowed for the systematic tracking of competency development across sessions and the integration of the platform into the learning process.

<table>
<tr><td colspan="2">Field
Journal</td><td colspan="2" rowspan="2">Place

Autonomous University of Querétaro, School of Engineering, Industrial Design,
6th Semester</td><td>Work Area

CEDIT Meeting Room
Laboratory
Classroom
Virtual</td></tr>
<tr><td colspan="2">Date: ___ /2023</td><td>Group</td></tr>
<tr><td>Session number</td><td></td><td colspan="3">General objetive:</td></tr>
<tr><td>Number of Activities</td><td></td><td colspan="3">Class Duration:</td></tr>
<tr><td>Number of Students</td><td></td><td>Materials:</td><td>Tools:</td><td>Equipment:</td></tr>
<tr><td colspan="5">Specific objectives:</td></tr>
</table>

Figure 2. The template for the field journal used to record session details, objectives, materials, and reflections throughout the intervention.

3.2.1. Stage 1: Before the Didactic Intervention (January 2023–December 2023)

A year before implementation, a population analysis was conducted to understand how classes were structured, the general characteristics of the students, the available materials, and the workspace (see Figure 1). The following semester, after identifying these aspects, a pilot study was conducted to test the Honey and Alonso Questionnaire via an online format, ensuring that it worked properly and could be completed by each student to determine their learning style.

Angulo-Valenzuela and Ascuntar-Rivera [32] argue that sketching aligns with students' divergent and exploratory thinking processes. At the same time, technological integration in classrooms has transformed design education, incorporating it into the digital learning phenomenon and promoting autonomous learning. Based on this, sketching exercises were carried out to allow students to demonstrate competencies assigned in activities while also providing an initial introduction to Discord as a knowledge management platform. This stage enabled an analysis and risk assessment of potential implementation challenges, such as session interruptions due to holidays or an excessive workload preventing students from completing exercises on time.

A key takeaway was how students adapted to the platform, which helped structure and organize activities for implementation. It also allowed for estimating the time required to provide peer feedback effectively.

3.2.2. Stage 2: During the Intervention (January 2024–March 2024)

After completing the pilot study and analyzing the collected data, activities were planned to foster creative thinking through iteration among Industrial Design students. This process began with refining and redesigning the application of the Honey and Alonso

Questionnaire (CHAEA) via Google Forms to determine the predominant learning style in the classroom. This information was then used to develop activities focused on creative thinking development.

As part of the intervention, students signed a commitment letter outlining the weekly sketching exercises, emphasizing that they would be completed at the beginning of each session. Students were required to register on the platform using their institutional email to ensure proper identification when uploading their work for peer and instructor evaluation.

At the start of the semester, Session A was conducted, focusing on the Torrance Test, which evaluates creative capacity through engaging and stimulating activities. These tasks were selected based on factorial analyses conducted on a wide range of activities designed by Coronado-Hijón [33]. The test consists of two forms—verbal and figurative—each with two subtests, A and B. The Figure A pre-test comprised three exercises, each with a completion time of 10 min.

The first section of the test started with a central base figure for students to create a general sketch. The second section required them to create ten sketches based on a base figure, and the final section involved producing 30 sketches with different interpretations of a base figure. For the pre-test, students were given creative freedom, with instructions to think of and draw objects or parts that they could potentially 3D print. As emphasized by Candia [34], institutions should promote an integrated learning approach that connects knowledge, action, and execution, bridging the gap between theory and practice in technological contexts.

Once completed, the test was sent to the Torrance Academic Evaluation Service for review by specialists.

For Weeks 1 to 7, students received a worksheet similar to the pre-test of the Torrance tests with fewer sketches to complete, as shown in Figure 3. Each week, they were given specific instructions on the types of objects to design, always envisioning them for 3D printing. These included motor components, backpack racks, tool racks, modified parts, and credenzas. The number of required sketches increased progressively, as did the time allocated for their completion. Students took photos of their work and uploaded them to a designated Discord channel as evidence, allowing for peer feedback.

Based on the established structure, the competencies necessary to achieve the weekly objective and carry out the iterative process were selected. Consequently, two strategies were implemented, as shown in Table 3. The iteration strategy aimed to measure originality, flexibility, fluency, and openness to experience, while problem solving was assessed through the use of ICT with Discord. The latter strategy aimed to measure elaboration, collaborative work, creative communication, curiosity, and automation, fostering interaction and dynamic learning while promoting reflection and deeper cognitive engagement in idea exchange [35].

Each weekly activity included both in-person classroom work and remote tasks via the Discord platform. Weekly evidence of the iterative process was recorded, along with adjustments based on targeted competencies.

The first two weeks were a challenging adaptation period for students as they learned to share their work on Discord. While they were familiar with the platform, they were not accustomed to its potential applications. However, as the weeks progressed, their sketches became more fluid and natural.

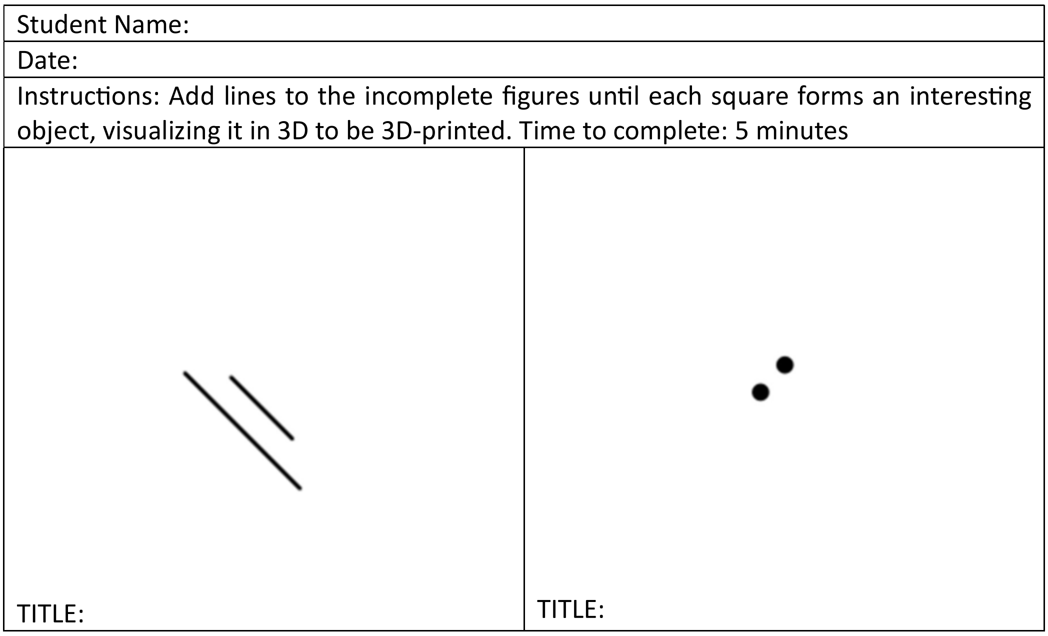
Student Name:
Date:
Instructions: Add lines to the incomplete figures until each square forms an interesting object, visualizing it in 3D to be 3D-printed. Time to complete: 5 minutes
TITLE:
TITLE:

Figure 3. Sample weekly sketching worksheet, where students transform basic shapes into 3D-printable objects within a set time.

Table 3. Weekly quick-sketch and ICT-based activities, detailing each strategy, its description, and the competencies reinforced.

Week	Strategy	Activity	Description	Competency
1	Iteration	Quick Sketching Use of ICT	Develop unique ideas with concrete and executable details	Fluency, Elaboration, Originality
2	Iteration Use of ICT	Quick Sketching	Work on the ability to consider different perspectives and approaches	Fluency, Flexibility, Openness to experience
3	Iteration	Quick Sketching	Suggest design options based on a real need	Fluency, Originality, Problem solving
4	Iteration Use of ICT	Quick Sketching	Clearly interpret proposed requirements	Fluency, Collaboration, Creative communication
5	Iteration	Quick Sketching	Consider innovative questions to seek creative answers	Fluency, Curiosity, Openness to experience
6	Iteration Use of ICT	Quick Sketching	Adjust and improve based on received feedback	Fluency, Curiosity, Automation
7	Iteration	Quick Sketching	Deepen planning and execution while adapting to changes	Fluency, Flexibility, Elaboration, Automation

Each week, students were given a specific theme, which helped structure their work and streamline the iterative process. By this point, they no longer felt anxious about the time constraints, understood the strategy, and had no doubts about the sketching process. This resulted in better time management, more detailed sketches, more complete figures, and greater confidence in their work.

By the end of Week 5, students began providing peer feedback in real time. They examined each other's sketches, realizing the different possibilities for utilizing the base figure. Although they sometimes finished early, they used the extra time to add more elements and refine line quality. However, they had not yet considered positioning their objects within a physical space.

Finally, Session B was conducted, in which the Torrance Figures Post-Test was administered. Students were again instructed to envision objects for 3D printing. Unlike the pre-test, they demonstrated improved time management, greater focus, and more fluid idea generation. Their work speed increased, and their exercises were better structured. The completed post-tests were sent to the Torrance Academic Evaluation Service for specialist analysis and evaluation.

3.2.3. Stage 3: After the Intervention (April 2024–June 2024)

The process of data collection and systematization went beyond mere record-keeping, becoming an analytical and dialogical space for the knowledge gained from practice. This collaborative process fosters critical understanding, questioning, and concrete actions within a specific context [36]. All evidence from the field journal and physical documents generated during each in-person session was verified and duly recorded on the digital platform Discord. A thorough review was conducted to ensure that each student had uploaded all weekly activity evidence to the designated channel and that the provided and received peer feedback on submitted work was properly documented. Consent forms and individual student assignments were organized into personal folders, allowing for quick and structured access to track each participant's progress.

At the end of the last intervention week, students were given a link to a Google Forms survey to provide feedback on their experience during the execution of exercises designed to foster creative thinking development.

3.3. Data Collection and Analysis

The collected data included observations recorded in the field journal, documented for each classroom and each session, resulting in a total of 14 entries—seven sessions per classroom. This served as the primary qualitative data source. Additionally, the Torrance pre-test and post-test were considered, along with the evidence generated during in-class activities. Weekly activities were uploaded to the digital platform Discord, enabling the continuous tracking of student progress. The comments and feedback exchanged among peers also served as secondary information, supporting and affirming the work completed.

Furthermore, a survey consisting of 24 items was administered via Google Forms to gather information on students' experiences throughout the three implementation phases. The survey covered daily evidence, weekly activities, and platform usage to assess the progress achieved in developing creative thinking among Industrial Design students through the application of iteration in their weekly work.

4. Results

The evaluation of the results consisted of analyzing the comparison between the Torrance pre-test and post-test results, along with the data collected for each student and the creative strengths selected as competencies to be developed. Additionally, responses from the Google Forms questionnaire, administered to all 21 students at the end of the intervention, were examined. The analysis identified an increase in originality within the classroom, as students moved away from conventional and repetitive responses, offering innovative and unconventional solutions as shown in Table 4, which suggests that originality scores identified in the post-test (Originality B) are more consistent compared to the extreme values observed in the pre-test (Originality A). At the same time, there was notable progress in the formulation, as students responded to the stimulus figure with unique and detailed solutions.

Table 4. Descriptive statistics comparing originality scores before (pre-test) and after (post-test) the intervention, highlighting improvements in students' creative responses.

	N	Mean	Median	SD	Minimum	Maximum	Percentiles		
							25th	50th	75th
Originality A (pre-test)	18	17.1	16.0	7.75	7	33	13.0	16.0	21.0
Originality B (post-test)	19	17.9	18.0	5.70	6	35	16.0	18.0	20.0

Activities and Participation in the Classroom

Students, based on the predominant reflective learning style identified in the classroom, had the opportunity to work from theory to practice, better conceptualizing their sketching ideas through the visualization of 3D printing.

To document students' perceptions regarding iterative work and the development of creative thinking, a 24-item questionnaire was divided into three sections. A manual coding process was applied to their responses, identifying the most frequently mentioned constructs, which were categorized according to the three initial activities and the four final activities conducted during the intervention. Table 5 presents the intervention sections and the most frequently mentioned codes, based on the responses of the 21 participants. This grouping resulted in three main categories: creativity, sketching, and iteration.

Table 5. Categories and most frequent codes derived from students' perceptions of intervention activities, grouped by early (Sessions 1–3) and later stages (Sessions 4–7).

Intervention	Categories	Section	Code	Mentions
Session 1 to 3	Creativity	Daily evidence	Repetitive exercises	13
	Sketching	Weekly activities	Develop detailed ideas	8
	Iteration	ICT for creative thinking	Express ideas effectively	4
Session 4 to 7	Creativity	Daily evidence	Interesting exercises	11
	Sketching	Weekly activities	Ability to express ideas	10
	Iteration	ICT for creative thinking	Developing different perspectives/approaches	10

Table 6 presents these categories across the 24 items distributed within the three divisions of the questionnaire, recorded as follows:

Table 6. Distribution of mentions across questionnaire sections, highlighting student perceptions of iterative practices, sketching activities, and creative resource use.

Section	Categories	Mentions
Daily Evidence	Iteration/Activities	13
Weekly Activities	Sketching/Ideas	11
Creative Thinking	Creativity/Resources	10

Figure 4 provides a general overview of the frequency with which these constructs were mentioned, confirming that the highest number of citations correspond to the categories of greatest interest to students.

Figure 4. Word cloud showing the most frequently mentioned terms and categories derived from participant feedback.

It was identified that iterative work over the seven sessions evolved the creative process from an approach based on quantity (generation of many ideas) to one focused on quality (improving and refining ideas); thus, 3D printing, when combined with iteration, enhances this process by visualizing and testing ideas in physical versions, modifying models based on real tests, and enabling creativity development through continuous improvement, as noted by Tena-Parera [37] when conducting critical reflection, thorough analysis, and informed determination, all conceived as reference points within the creative process for structuring and developing a new cycle.

5. Discussion

5.1. Three-Dimensional Printing and Iteration

Students engaged in an iterative process for developing creative thinking through weekly sketching exercises. The findings indicate that while most students can solve problems individually, they often hesitate at first. However, upon observing their peers' work, they become more proactive in designing their sketches, submitting materials, and providing peer feedback. According to Canabal and Margalef [38], this stems from motivation and action, which foster sustainable learning by encouraging dialogue rather than mere corrections. This approach helps identify areas for improvement and raises expectations, motivating students to continue progressing.

This iterative process took place both in-person and online, bridging theory and practice. Weekly sketching exercises in class helped students recognize the skills they were developing—originality, flexibility, fluency, elaboration, problem-solving, openness to experience, collaboration, creative communication, curiosity, and automation. Initially, these skills were not easily identifiable, but as they were practiced, students applied them more naturally. As Suardíaz et al. [39] suggest, future experiences should further enhance motivation and engagement during sessions.

Santander-Salmon and Schreiber-Parra [40] emphasize that a positive emotional attitude strengthens educational practice and fosters deeper learning, allowing students to achieve their goals and enhance their competitiveness. Thinking in 3D from the conceptualization phase enabled students to visualize multiple possibilities—not just a complete object, but also its individual components. Iteration was found to facilitate creative development in parameters such as originality and design elaboration. López-Chao and Meira-Rodríguez [41] support this view, stating that iteration drives innovation by allowing students to discuss proposals and refine their adaptation to visual communication.

Vicente [42] notes that additive manufacturing is rapidly growing, exceeding expectations and solidifying itself as an accessible and cost-effective technology. However, this study revealed that despite encouraging students to think in 3D and create objects for printing, they lacked direct access to the 3D printer. Limited semester schedules and the large number of students prevented continuous use of the equipment, restricting the iterative redesign process. This posed a challenge, as students could not observe changes in their designs as they were made. Even though the study included 21 students who had already used 3D printing in their education, Mejía Salazar [43] emphasizes the importance of incorporating activities and workshops in the classroom to strengthen the use of technology as an essential learning tool.

A key finding of this research is that 3D printing combined with iteration fosters the development of more flexible and less linear creative thinking; this process does not follow a fixed trajectory but adapts to new ideas and discoveries. This aligns with an increased independence among variables. Such a combination enables transitioning from generating new ideas to refining existing ones. Designers were able to adjust their approach based on the results obtained in each iteration, accelerating the innovation process by allowing rapid modifications and promoting experimental exploration and testing of ideas in physical formats.

5.2. Future Projects for Developing Creative Skills with 3D Printing

Some students lacked confidence in using 3D printing, while others were eager to apply it. Therefore, it is suggested to design projects that integrate 3D printing directly and individually, ensuring that students can address real-world challenges with greater confidence. Such projects would allow them to see how additive manufacturing strengthens their learning process, while also supporting continuous teacher training.

Incorporating additive manufacturing into teaching helps shape a new mindset, enabling students to envision their designs for 3D construction from the outset. It also allows for continued iterative work in a tangible, physical manner. The object itself becomes a facilitator for dialogue and discussion, making its use a valuable addition to the classroom. While images can serve as substitutes, their integration enhances the effectiveness of learning [44]. This ensures that the iterative process is maintained, allowing ideas to be refined continuously in a hands-on manner.

5.3. Relevance, Limitations, and Future Directions

This study highlights the relevance of integrating technological tools, particularly 3D printing, into educational settings to support creative processes. Direct access to these tools enables students to engage in ongoing iteration, a key element of creativity not only in Industrial Design but across disciplines that value innovation. As Ortiz-Gil [45] notes, additive manufacturing offers precision, speed, and sustainability, making it a transformative force in both education and research. For students, having hands-on access to such technology facilitates a cycle of experimentation, feedback, and refinement, which is critical to developing adaptable and innovative thinkers.

Although the focus here was Industrial Design, the pedagogical benefits of 3D printing and iterative methodologies extend beyond this field. Creativity thrives when students are equipped with tools and goals that encourage exploration. Peramás and Escurra-Mayaute [46] highlight that creative individuals use cognitive flexibility to apply knowledge across contexts, skills that are increasingly vital in today's complex world. When supported by analog and digital methods, the creative process becomes more accessible, and cross-disciplinary collaboration further enhances reflective and critical thinking.

However, the study has several limitations. In particular, the small sample size of 21 students restricts the generalizability of the findings. Although the results offer valuable information, a broader participant base is needed to validate these outcomes in different disciplines and educational contexts. Additionally, conducting the intervention with two classrooms from the same class introduces possible bias, mainly due to inconsistent attendance. Future research should control for variations in student engagement and explicitly examine how participation levels influence creative development.

Another limitation is the disciplinary focus of the study. Restricting the sample to Industrial Design students raises questions about applicability to other domains such as engineering, architecture, or visual arts. Investigating how iterative design and 3D printing influence creativity in these fields could yield richer comparative insights.

Future work should explore interdisciplinary approaches that bring students from different academic backgrounds to solve real-world problems. This could clarify how iterative design practices and technological tools function in collaborative environments and whether such settings promote deeper creativity and innovation than discipline-specific interventions.

From a practical point of view, the findings suggest that integrating iterative design and 3D printing into curricula can significantly enrich collaborative learning environments. These tools not only support faster development and refinement of ideas, but also help students visualize and test concepts more effectively. Immersion time and hands-on interaction remain essential: students benefit most when they can continuously design, prototype, reflect, and iterate. However, limited access to equipment constrained this potential, as not all students were able to materialize each improvement during the intervention.

Looking ahead, developing environments that guarantee access to advanced technological tools and promote sustained iteration will enhance the capacity of students to innovate. By cultivating collaboration and supporting iterative thinking, educational institutions can better prepare learners to apply their skills for societal benefit, ultimately transforming classroom practices into dynamic, community-oriented learning experiences.

6. Conclusions

Iteration is essential as part of the creative process and is fundamental to refining ideas. Activities that incorporate feedback to enhance initial concepts while integrating new perspectives create an academic experience that balances structure with creative freedom. By implementing suggestions derived from structured activities, students can improve their ability to express and generate original ideas.

Students do not always perceive iteration as necessary; however, they notice differences in their work when they engage in it. This highlights the need for exercises that do not feel repetitive, while allowing greater flexibility in activities to explore multiple approaches effectively.

Group dynamics facilitate the iterative process by encouraging the exchange of ideas and exploring different ways to work with the same base figure while pursuing a shared goal. Peer interaction and feedback are perceived as valuable, enriching students' ideas and enabling them to observe and learn from the creative solutions of others.

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References

1. Kenett, Y.N. The role of knowledge in creative thinking. *Creat. Res. J.* **2024**, 1–8. [CrossRef]
2. Khalil, R.Y.; Tairab, H.; Qablan, A.; Alarabi, K.; Mansour, Y. STEM-based curriculum and creative thinking in high school students. *Educ. Sci.* **2023**, *13*, 1195. [CrossRef]
3. Arias Arciniegas, C.M.; Giraldo Bedoya, D.P.; Anaya Urbina, L.M. Competencia Creatividad e Innovación: Conceptualización y Abordaje en la Educación. *Katharsis* **2013**, *15*, 195–214. [CrossRef]
4. Aguiar, B.O.; Velázquez, R.M.; Aguiar, J.L. Innovación docente y empleo de las TIC en la Educación Superior. *Rev. Espac.* **2019**, *40*, 8.
5. de Carvalho, T.d.C.M.; de Souza Fleith, D.; da Silva Almeida, L. Desarrollo del pensamiento creativo en el ámbito educativo. *Rev. Latinoam. Estud. Educ.* **2021**, *17*, 164–187.
6. Jalolov, T.S. Enhancing Creative Thinking in Elementary School Students Through Multimedia Technologies. *World Sci.* **2024**, *7*, 114–120.
7. Almutairi, H.; Delaney, P. Exploring Student Usage of ICT Tools in Project-based Learning. *IEEE Intell. Inf. Bull.* **2023**, *23*, 10–17.
8. Rizal, R.; Surahman, E.; Aripin, H.; Maulidah, R. Problem-Based Learning Management System (PBLMS): A Mobile Learning Application to Facilitate Creative Thinking Skills (CTS) of Prospective Physics Teachers. *Int. J. Interact. Mob. Technol.* **2024**, *18*, 97–109.
9. Valverde Berrocoso, J.; Fernández Sánchez, M.R.; Garrido Arroyo, M.d.C. El pensamiento computacional y las nuevas ecologías del aprendizaje. *Rev. Educ. Distancia* **2015**, *46*, 1–18. [CrossRef]
10. Silva Mantilla, E.L. La creatividad: Un momento de inspiración o una búsqueda rigurosa. *Actas Diseño* **2024**, *45*, 263–267.
11. Carranza, M. Pensamiento creativo: Un estudio holístico en la educación. *Rev. Innova Educ.* **2021**, *3*, 123–132.
12. Wu, R.; Fan, J.; Tang, C.; Yang, X. Interaction-based creative thinking research and its application in artistic creation. *Think. Ski. Creat.* **2025**, *56*, 101750. [CrossRef]
13. Grimaldo Salazar, E.; Chávez Soto, B.I. Prueba de creatividad verbal de Torrance: Evidencias de validez psicométrica en estudiantado mexicano de educación primaria. *Actual. Investig. Educ.* **2023**, *23*, 70–93. [CrossRef]
14. Humble, S.; Dixon, P.; Mpofu, E. Factor structure of the Torrance Tests of Creative Thinking Figural Form A in Kiswahili speaking children: Multidimensionality and influences on creative behavior. *Think. Ski. Creat.* **2018**, *27*, 33–44. [CrossRef]
15. Rúa, E.B.; Jiménez, F.; Gutiérrez, G.A.; Villamizar, N.I. Impresión 3D como herramienta didáctica para la enseñanza de algunos conceptos de ingeniería y diseño. *Ingeniería* **2018**, *23*, 70–83.
16. Cuervo Pulido, R.; Hernández Mihajlovic, E. Cómo evaluar la cognición creativa al enseñar diseño industrial? Un insumo para su aprendizaje. *BitÁCora Urbano Territ.* **2020**, *30*, 163–176. [CrossRef]

17. Martínez Suárez, E.M.; González, M.d.P. La creatividad como competencia universitaria? La visión de los docentes. *Rev. Form. Innov. Educ. Univ.* **2009**, *2*, 101–114.
18. Solano Fernández, E.; Porras Alfaro, D. El modelo iterativo e incremental para el desarrollo de la aplicación de realidad aumentada Amón_RA. *Tecnol. Marcha* **2020**, *33*, 165–177. [CrossRef]
19. Hincapié Atehortúa, E.A. La Iteración Como Herramienta de Gestión y Planificación en el Diseño de Ejecución en Proyectos de Construcción. Master's Thesis, Universidad Nacional de Colombia, Medellín, Colombia, 2022. Available online: https://repositorio.unal.edu.co/bitstream/handle/unal/83923/71790225.2022.pdf?sequence=4&isAllowed=y (accessed on 1 February 2025).
20. Sawyer, R.K. The iterative and improvisational nature of the creative process. *J. Creat.* **2021**, *31*, 100002. [CrossRef]
21. Wynn, D.C.; Eckert, C.M. Perspectives on iteration in design and development. *Res. Eng. Des.* **2017**, *28*, 153–184. [CrossRef]
22. Žujović, M.; Obradović, R.; Rakonjac, I.; Milošević, J. 3D printing technologies in architectural design and construction: A systematic literature review. *Buildings* **2022**, *12*, 1319. [CrossRef]
23. Mata Abdelnour, E. Propuesta para la incorporación del modelado e impresión 3D para la enseñanza de Ingeniería Civil de la Universidad de Costa Rica. *Rev. Educ.* **2023**, *47*, 460–478. [CrossRef]
24. Flick, U. *El Diseño de la Investigación Cualitativa*; Ediciones Morata: Madrid, Spain, 2015; ISBN 978-84-7112-806-5.
25. Peralta-Castro, F.; Mayoral-Valdivia, P.J. La investigación acción como estrategia de reflexión, mejora y cambio en la práctica docente de la enseñanza de lenguas. *RIDE Rev. Iberoam. Para Investig. Desarro. Educ.* **2022**, *12*, 1–25.
26. Piza Burgos, N.D.; Amaiquema Márquez, F.A.; Beltrán Baquerizo, G.E. Métodos y técnicas en la investigación cualitativa. Algunas precisiones necesarias. *Conrado* **2019**, *15*, 455–459.
27. Contreras-Espinosa, R.S.; Eguia-Gomez, J.L. Discord como herramienta de enseñanza en línea durante la pandemia de COVID-19. *Rev. FAEEBA Educ. Contemp.* **2022**, *31*, 106–120.
28. Villarreal-Fernández, J.E. Cuestionario Honey-Alonso de estilos de aprendizaje (CHAEA). Propiedades psicométricas en estudiantes universitarios colombianos. *Psicogente* **2023**, *26*, 46–69.
29. Costa, R.D.; Souza, G.F.; Valentim, R.A.; Castro, T.B. The theory of learning styles applied to distance learning. *Cogn. Syst. Res.* **2020**, *64*, 134–145.
30. Fernández Iglesias, M.J. *Introducción al Pensamiento Creativo*; AtlanTTic, Universidad de Vigo: Vigo, Spain, 2024. [CrossRef]
31. Hernández Jaime, J.; Jiménez Galán, Y.I.; Rodríguez Flores, E. Desarrollo de competencias de pensamiento creativo y práctico para iniciar un plan de negocio: Diseño de evidencias de aprendizaje. *RIDE Rev. Iberoam. Para Investig. Desarro. Educ.* **2018**, *9*, 314–342.
32. Angulo-Valenzuela, C.; Ascuntar-Rivera, M.C. La enseñanza y aprendizaje del boceto de diseño a través de mediadores tecnológicos. *Rev. Latinoam. Estud. Educ.* **2020**, *16*, 137–158.
33. Coronado-Hijón, A. Aplicación Contextualizada Del Test De Pensamiento Creativo De Tor Rance (TTCT). *Rev. Española Orientac. Psicopedag.* **2015**, *26*, 70–82.
34. Candia García, F. Integración de la impresión 3D en la educación tecnológica. *RIDE Rev. Iberoam. Para Investig. Desarro. Educ.* **2022**, *12*, 1–31. [CrossRef]
35. Granda Asencio, L.Y.; Espinoza Freire, E.E.; Mayon Espinoza, S.E. Las TICs como herramientas didácticas del proceso de enseñanza-aprendizaje. *Conrado* **2019**, *15*, 104–110.
36. Villa-Holguín, E. La sistematización de experiencias, una estrategia de la investigación anti-hegemónica. *El Ágora USB* **2019**, *19*, 547–557. [CrossRef]
37. Tena Parera, D. Diseño como proceso iterativo. *Grafica* **2015**, *3*, 5–11. [CrossRef]
38. Canabal, C.; Margalef, L. La retroalimentación: La clave para una evaluación orientada al aprendizaje. *Profr. Rev. Curric. Form. Profr.* **2017**, *21*, 149–170. [CrossRef]
39. Suardíaz Muro, J.; Pérez Gomáriz, M.; Cabrera Lozoya, A.; Do Carmo Trolle, R.O. Combinando Impresión 3D y electrónica como estrategia para mejorar la experiencia de aprendizaje. *Ried Rev. Iberoam. Educ. Distancia* **2021**, *24*, 115–135. [CrossRef]
40. Santander Salmon, E.S.; Schreiber Parra, M.J. Importancia de la motivación en el proceso de aprendizaje. *Cienc. Lat. Rev. Cient. Multidiscip.* **2022**, *6*, 4095–4106. [CrossRef]
41. López-Chao, V.; Meira-Rodríguez, P. Composición e iteración de color para desarrollar arte de concepto de entornos. Exploración de un procedimiento de análisis visual en el desarrollo creativo. *Revista* **2023**, *180*, 75–86. [CrossRef]
42. Vicente Oliva, S. La Impresión 3D Como Tecnología de Uso General en el Futuro. Technical Report. 2018. Available online: https://dialnet.unirioja.es/servlet/articulo?codigo=6535713 (accessed on 1 February 2025).
43. Mejía Salazar, G. La aplicación de las TIC en los procesos de enseñanza-aprendizaje en estudiantes de nivel medio superior en Tepic, Nayarit. *RIDE Rev. Iberoam. Para Investig. Desarro. Educ.* **2020**, *11*, 1–20. [CrossRef]
44. Tapia Espinosa, F.; Arias Ferrer, L. El aprendizaje basado en objetos como estrategia para la enseñanza de la historia en Educación Primaria: Un estudio cuasi-experimental. *Espiral. Cuad. Profr.* **2021**, *14*, 44–56.
45. Ortiz Gil, A. Las impresoras 3D como herramientas científicas. *Obs. Astron. Univ. Val.* **2019**, *61*, 1–8.

46. Peramás De La Fuente, T.D.C. El Pensamiento Creativo y el Rendimiento Escolar en Niños de Segundo Grado de Primaria de una Institución Educativa Privada del Distrito de La Molina. Master's Thesis, Universidad Ricardo Palma, Lima, Peru, 2017. Available online: https://repositorio.urp.edu.pe/entities/publication/ae15ed28-67f7-4f48-a670-be237f528b84 (accessed on 1 February 2025).