Building Learning Experiences

The Transformative Power of Constructionist Makerspaces in Holistic Child Development

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Abstract

This case study explores the educational potential of a constructivist makerspace, analyzing its impact on a child's development across multiple dimensions: cognitive, creative, and intrapersonal competencies. Through engaging with analog and digital tools, the child advanced from basic problem-solving tasks to complex projects requiring conceptual understanding and technological integration. The findings highlight how iterative design processes, guided by constructivist principles, foster critical thinking, creativity, and learning autonomy. Although the single-case design limits more general applications, the study offers practical insights into strategies that enhance engagement and holistic skill development in student-centered learning environments like educational makerspaces.

Keywords and Phrases: Educational makerspace, Constructionism, Creativity, Computational fluency.

1. Introduction

Makerspaces, designed originally with adults in mind, are collaborative environments where highly creative people can work with others who share their interests and explore innovative ideas, developing projects with analog and digital tools (Dougherty, 2012; Sheridan, 2014). "Makers" as Dougherty calls those who use makerspaces, are characterized by their curiosity, resilience, and willingness to learn through experimentation, to overcome challenges, and solve problems independently and collaboratively. Recently, this concept has expanded to include educational environments designed for children, offering an alternative to the more formal approach to learning seen in school. Despite visions of schools transformed into constructionist learning spaces, as posited by Papert (1980, 1995), these institutions have been unable to adopt an approach to learning based on exploration and construction. This has resulted in a proliferation of independent educational makerspaces, some of which have

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adopted a technocentric approach, featuring digital tools. In contrast, others, like Patagonia Lab Makerspace[1], situated in Costa Rica, have prioritized learning with technology, through the creation of "objects-to-think-with" (Papert, 1980) that use a range of materials, from cardboard to micro:bits[2] microcontrollers.

Learning in a constructionist makerspace is dynamic, disorganized, and frequently incidental, with unexpected insights emerging through exploration, as learners externalize ideas and discover new connections. According to Ackermann (2001), this type of learning exercises superior cognitive functions employs diverse media, and empowers the learner to take the initiative. In contrast to traditional, linear learning, children learning in more dynamic spaces follow multiple creative channels, integrating concepts and abilities in a fluid and natural manner. However, learning in a makerspace still requires guidance: the role of the teacher is crucial. The teacher acts as a guide and facilitator, provoking learning through carefully curated challenges, materials, or situations selected and designed to spark a child's curiosity and strengthen commitment to conclude. These provocations do not rigidly direct learning; rather, they create a space where children can follow diverse trains of thought, fostering critical thinking, creativity, and the integration of knowledge from different disciplines. This focus is closely aligned with the concept of *engagement*, defined as the sustained willingness to actively participate in the learning process (Lee et al., 2021). Engagement is essential in makerspaces, as it facilitates metacognitive strategies like active attention, deliberate effort, and connecting prior knowledge and new information (Fredricks et al., 2004). This high level of commitment to explore and discover, combined with the type of pleasure that Papert termed "hard fun" enables profound and significant learning.

Morado, Melo, and Jarman (2021) introduce a framework for analyzing learning in makerspaces across several key areas. Cognitive development is explored through skills like problem-solving and critical thinking. Intrapersonal development encompasses traits like autonomy, resilience, and self-confidence. Additionally, creativity is highlighted as the ability to generate original ideas and adapt solutions to new challenges. The framework emphasizes the significance of interdisciplinary learning, allowing children to apply concepts from diverse fields such as science and technology in practical, meaningful ways.

This case study follows a constructionist makerspace over seven years and considers how the experience of constructing "objects-to-think-with" contributes to the holistic development of a child, not only stimulating advanced cognitive abilities, like computational fluency and problem-solving, but also honing intrapersonal skills, and creativity. The case study also examines how engagement and the opportunity to integrate knowledge from different disciplines can facilitate deeper understanding.

The case study seeks to answer the following investigation question: How does the experience of constructing *objects-to-think-with* in a constructionist makerspace contribute to the holistic development of a child over seven years? In particular, is there evidence that this experience fosters cognitive development, specifically in computational fluency and problem-solving, or in greater intrapersonal skills and more creativity?

1 www.patagonialab.net
2 www.microbit.org

2. Theoretical framework

Constructionism has its early roots in the first half of the 20th Century when John Dewey published his findings in 1938 that learning occurs when a person interacts with his or her surroundings. He asserted that profound and lasting learning required both action and reflection. Later, Jean Piaget advanced his theory, *constructivism*, positing that concrete experiences permit children to construct their learning. Piaget argued that as children explore, interact with, and think about objects and situations, they develop skills like problem-solving, logical reasoning, and conceptual understanding. Building on Dewey and Piaget's ideas, Seymour Papert proposed that cognitive artifacts – what he termed "objects-to-think-with" – are created from the interaction between ideas, materials, and the environment (Papert, 1980), and permit the construction of new understanding.

Learning, making, and reflecting are integrally part of an educational makerspace. To be clear, making is more than following instructions as set forth by a kit, while technology is not an end in itself, but a means to prompt cognitive learning of a higher order. In a constructionist makerspace, children use a range of tools, both analog and digital, to construct projects that stimulate their creativity through cognitive challenges that require both reflection and problem-solving. Teachers are vitally important in makerspaces, since they carefully design provocations, then accompany learners through the learning process, instead of providing them with answers that must be copied and memorized. This process reflects Piaget's insights that learning should emerge as learners interact with their surroundings, as well as Papert's view that learning occurs where an environment invites – in fact, incites – discoveries. In this way, makerspaces become dynamic environments where action, reflection, and technology are integrated, allowing learners to construct new knowledge and develop stronger skills in ways that are authentic and creative.

The *"objectives-to-think-with"* possess three essential characteristics:(1) they form part of the child's social-material environment; (2) they are used in specific fields of learning; and (3) they permit the exploration of complex ideas through physical manipulation (Papert, 1980). In the context of making, these objects permit students to access more abstract concepts and apply more formal thinking routines. Papert showed how construction using digital tools can also support students in their learning. When programming was required to solve a particular problem, students had to employ more abstraction, even thinking about their thinking process (Paper, 1980). This metacognition puts students in the role of the programmer, connecting algorithms and code with concepts from science, math, and the art of making.

Programming, for example, is more than a theoretical exercise; it is a form of communication between humans and computers using a shared language. When children learn this language in a self-directed manner to program solutions to concrete problems, we can see the power and potential of learning based on doing. In this autonomous, self-directed path to learning, the child has become a tinkerer or *bricoleur* of code.

In makerspaces, children develop a profound sense of ownership over their projects since they have been actively involved in every step of the creative process. The open-ended, collaborative atmosphere fosters a sense of agency, empowering learners to make decisions about what to construct, how to resolve problems, and what tools

to use. According to Sheridan et al. (2014), a makerspace permits the child to become a self-directed learner, able to identify learning goals and assume responsibility for the results.

Engagement, or commitment, plays a fundamental role in makerspaces, since it relates to the learner's willingness to actively participate in problem-solving and the learning that results. In these spaces, personalized, self-directed projects foster a stronger emotional connection between learners and their creations, due to the time, effort, and focus that is invested. According to Lee et al. (2021), a high level of engagement prompts self-regulated learning, which includes the use of important metacognitive strategies like sustained, focused attention, and self-monitoring. Fredericks et al. (2004) underline the importance of cognitive engagement which requires learners to connect new information to previous learning, enhancing learning outcomes while developing more advanced learning skills.

Finally, when children participate in makerspaces over a prolonged period, they develop what Resnick (2020) describes as digital fluency, which permits them to use technology as a tool that serves their creativity, curiosity, and desire to solve problems. At this level of mastery, students can use technology to innovate and create without feeling limited by tools or mechanics.

Morado, Melo, and Jarman (2021) developed a framework to analyze how the practices followed in a constructionist makerspace develop knowledge and abilities across diverse dimensions, permitting key competencies to be identified, such as cognitive development, critical thinking, problem-solving, the use of tools and materials, psychomotor growth and proficiency, creativity, and intrapersonal awareness. Applying this framework, makerspaces not only nurture learning but also support students' active engagement, stimulating holistic development across multiple dimensions.

3. Methodology

This article follows the learning experience of a child over seven years in a constructionist makerspace, focusing on how the creation of "objects-to-think-with" supports cognitive development, problem-solving, psychomotor growth and proficiency, creativity, intrapersonal development, interdisciplinary integration, and computational fluency.

The participant began attending the makerspace at the age of three, while enrolled in an alternative kindergarten and later transitioned to a bilingual international school in Costa Rica at age six. He comes from a U.S. family residing in Costa Rica with a strong academic background. Although his parents are not technologically inclined themselves, they have consistently encouraged his interest in creative, hands-on technological learning. From an early age, the child showed intellectual development above the average for his age, which led to the need for highly personalized instruction.

He attended the makerspace once a week as an extracurricular activity, outside the formal school setting. Instruction was provided in Spanish, though the child is fully bilingual in English and Spanish. Depending on his needs and interests, he participated in both group and one-on-one sessions. His projects evolved from early

explorations with tools such as Little Bits, Scratch Jr., and squishy circuits to more complex work with soldered circuits, 3D design, laser cutting, and eventually programming with Arduino in C++.

The teaching approach was grounded in constructionism, guided by project-based learning and design thinking methodologies. The educator's role was key: listening attentively, offering just-in-time support, and helping the child realize his ideas without doing the work for him. A central challenge was balancing the child's ambitious ideas with what was developmentally appropriate. For example, some projects (like making a drone or submarine) had to be adapted or reimagined.

Case study analysis involved iterative cycles of reflection between the educators and the child, capturing both explicit insights and implicit learning processes. The team collected and analyzed 482 images and videos from these seven years, each image was accompanied by a detailed description from the teacher field notes, categorizing them according to the framework by Morado, Melo & Jarman (2021) and applying Saldaña's coding method (2009). Systematic field observations and reflective sessions complemented this process, and triangulation across sources (visual data, teacher notes, child perspectives) was employed to ensure the reliability of findings.

Dimensions	Description
Resolution of Problems	Refers to when the child faces challenges, analyzes options, and generates effective solutions. It includes identifying problems, designing strategies to address them, and evaluating outcomes.
Intrapersonal Development	Relates to moments when the child shows emotional regulation, intrinsic motivation, greater understanding of oneself, and confidence in his or her abilities to face challenges in the makerspace.
Creativity	Describes when a child generates original ideas, combines elements in a novel way, explores unconventional solutions, or shows an awareness of aesthetics.
Cognitive Development	Encompasses a wider range of cognitive functions, such as planning, sustained attention, language acquisition, logical reasoning, and working memory, and how they evolve over time.
Use of digital tools	Encompasses the competent use of digital tools (design programs, 3D printers, coding platforms) to build projects. It also includes the ability to select appropriate tools for a specific task.

Table 1: Interpretative framework for photos and videos. Source: Morado, Melo & Jarman, 2025.

4. Results

Problem Solving: Over the time spent in the makerspace, the child faced problems of increasing complexity, from simple tasks to more complicated challenges. Initially, the teacher demonstrated practical solutions; later, orientation was provided verbally. Finally, the child was permitted time and space to identify challenges and generate his solutions in a self-directed manner. As he mastered different technological tools, he strategically integrated them to solve problems, which showed a significant

advance in his technical competence, his critical thinking, and his capacity to solve problems. This process highlighted his progress toward becoming an autonomous learner and his overall development in a constructionist context.

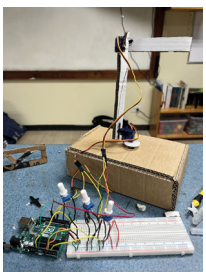
2018	2021	2024
Problem :Attaching different parts of the project. **Solution** :Use masking tape to attach the parts. In the early stages ,the child successfully attached the parts of the project using tape .However ,he did not consider the implications of the excessive use of tape, which led to obstructions in essential components .For example ,at times ,the tape covered important access points like the power port or interfered with the movement of a rotation servo. These types of situations provided opportunities to reflect on the proper use of materials and adjust strategies ,demonstrating progressive learning and development in problem-solving.	Problem: Maintaining a boat's balance in the water when installing the motor and batteries. When testing the first prototype, the boat tilted to one side due to uneven weight distribution. Solution: Center the battery holder and motor on the hull of the boat to balance the weight. The child used the alignment feature in the Tinkercad 3D design app to correct this issue. He redesigned the space to better accommodate the motor and batteries, using the alignment tool to ensure that both components were equidistant from the central axis of the hull. This allowed for an even weight distribution, eliminating the tilt and ensuring the boat remained stable in the water.	Problem: Using five servos to achieve movement of a robotic arm in all possible directions. Solution: Incorporate and adjust the servos progressively, evaluating the movement angle of each one. The child used C++ programming for Arduino, creating five dials that allowed for independent control of each servo. During the process, he tested each servo individually on different parts of the arm, which allowed him to determine its optimal position to achieve the desired range of motion. This iterative approach demonstrated his ability to integrate programming, analysis, and functional design skills, to ensure smooth and precise movement of the robotic arm. The process not only reflected his technical skills but also his critical thinking and ability to solve complex problems through trial and error.
		

Table 2: Development in Problem-Solving. Source: Morado, Melo & Jarman, 2025.

Intrapersonal Development: Over his time at the makerspace, the child advanced through different stages in his intrapersonal development. At the start, his primary motivation was curiosity. His projects, which tended to be simple tasks, did not generate a deep connection. Later, he began to connect projects to his personal experiences, showing increased creativity through his ability to connect his learning to events and situations that had impacted him. Finally, his projects began to increase in complexity as he gained confidence in his thinking and planning, and his ability

to use tools and software. When he wasn't able to reach his project's main objective, he faced frustration but was able to manage his emotions and still find value in the learning process, which showed a marked increase in his intrapersonal development through greater resilience and self-acceptance.

2018	2020	2022
At the beginning of his experience in the makerspace, the child was not yet familiar with the available tools and technologies, or their potential. His primary motivation was curiosity. In this initial phase, his interest was sparked by the teacher's suggestions, and the challenges were not complex. For example, building a 3D doll was an easy task for him, but important, as it allowed him to start becoming familiar with the technological tools and the creative process.	As time went on, the child began to connect his projects with his own life and experiences. A significant example was how a family trip to Japan inspired him to build a Samurai that saluted. This moment reflects progress in his intrapersonal development, as he was not only applying what he had learned in the makerspace but also channeling his creativity and personal experiences into his projects, shaping ideas that transcended the educational sphere and became more meaningful to him.	At this more advanced stage, the child had gained confidence in his abilities, and his projects became more complex. One example of this was when he attempted to create an electric generator to charge a mobile phone using kinetic energy. Although he did not achieve the goal of charging the phone, he faced the challenge of managing frustration when he didn't get the expected result. Instead of feeling defeated, he was content with the fact that he had powered a Makey Makey board, recognizing the partial success and valuing the learning process. This moment is key in his intrapersonal development, as it shows growth in resilience, the ability to accept limitations, and satisfaction with the achievements made, regardless of not reaching the initial goal.
		

Table 3: Intrapersonal Development. Source: Morado, Melo & Jarman, 2025

Creativity: The child showed a greater ability to generate new and more effective ideas. He was able to innovate, adapting the available tools and materials to meet his objectives. After mastering technologies and tools over time, he showed he could combine different elements in new ways to solve problems. He was also able to

personalize his designs according to his interests and needs. His creativity made his learning process take on greater personal significance, as he addressed each challenge as an opportunity to exercise his unique perspective and flexible, adaptable approach.

2018	2023	2024
The child's creativity is shown when he begins to apply his knowledge of tools and technologies in an original way that is functional. As he masters his application of the available resources and tools, he starts to come up with innovative solutions to practical problems. In this case, the design of an amphibious vehicle, with a rudder and a seat strategically placed at the tip of a mast to improve visibility, is a clear example of how his creativity not only addresses technical needs but also enhances the user experience. The integration of a fan at the base of the seat demonstrates an approach that not only solves mechanical problems but also addresses comfort and usability, reflecting an increasing ability to create solutions that go beyond the conventional.	As the child grows, his approach to design becomes more sophisticated, without losing his ability to experiment with innovative and alternative proposals. In this case, he presents a vehicle with an unconventional design, featuring a rounded front, which reflects his willingness to incorporate shapes different from standard models. Additionally, the decision to embed the wheels in the body demonstrates a more streamlined approach, where each component is part of a cohesive design. This ability to create practical solutions not only shows his mastery of technology but also the development of his creative thinking as he faces design challenges.	When faced with the need to position an LCD screen to display text, the child initially proposes a functional but aesthetically unpleasing solution: a box that will hold the screen. However, he quickly realizes that this design is clunky, prompting him to rethink his proposal. Instead of settling for a simple solution, he decides to redesign the screen holder by placing it on an inclined plane, which not only enhances its aesthetics but also optimizes its visibility. This change reflects the child's ability to combine practical considerations with a growing sensitivity to form and design, balance and proportion, and visual appeal, showing progress in his creative thinking and his ability to make more refined design decisions.
		

Table 4: Creativity. Source: Morado, Melo & Jarman, 2025.

Cognitive Development: This was shown in the child's growing ability to solve more complex problems through different projects. At first, his designs in 3D were simple, as he was limited to selecting figures and adjusting their size and position using the keyboard. However, over time, his vision and planning process improved, and he began to create basic prototypes on cardboard before making precise digital versions, all the while respecting the specific measurements and proportions demanded by his project. He gained the ability to design more complex systems, involving pincers that were operated by servomotors, where the precision in the placement of the gears and the correct alignment of each component was crucial. Over time, his progress became

evident in logical reasoning, planning, sustained attention, and working memory, as he successfully integrated technical concepts, improved his precision, and employed knowledge and skills autonomously.

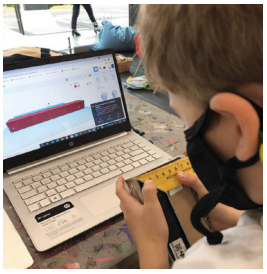
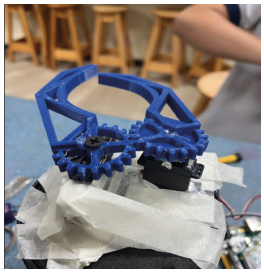
2018	2023	2024
The child's cognitive development is reflected in his progress as he learns to design in 3D. At first, his interaction with the design tools was basic, limited to moving shapes with the keyboard arrows to assemble his designs.	As the child progressed in his design process, he began to apply a more structured and reflective approach, developing the following strategy: he would first think through his ideas, then prototype them in cardboard, and finally create a 3D final version, always respecting the dimensions and proportions of his project.	Finally, he designs very complex elements, such as gear-driven pincers that must be attached to servomotors, where a perfect connection is required, both in securing the servomotors and in meshing the gears. The precision he achieved in creating these components reflects his cognitive development, as he had to integrate technical concepts and apply planning skills. Focused attention can be observed in the detailed work required to secure the gears and ensure the servomotors are perfectly aligned, highlighting his cognitive ability to tackle increasingly advanced technical problems.
		

Table 5: Cognitive Development. Source: Morado, Melo & Jarman, 2025.

Use of Digital Tools: As the child advanced in his different projects over the years, he explored diverse digital tools that allowed him to express his creativity and technical abilities. He began with Scratch Jr., a coding platform for children, where he used visual coding blocks to interact with and animate visual elements called Sprites. As he gained computational fluency, he began to use Micro Bit, which allowed him to program sequences, apply conditions, and incorporate sensors. Later he worked with Arduino to collect the readings gathered by external sensors and show them on an LCD panel; this required him to program in an abstract language. The child's use of a wider range of digital tools not only improved his programming skills, but also allowed him to explore more deeply how hardware and software can be integrated to achieve more sophisticated solutions.

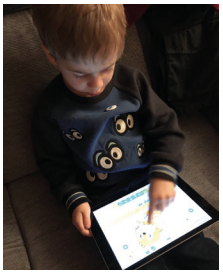
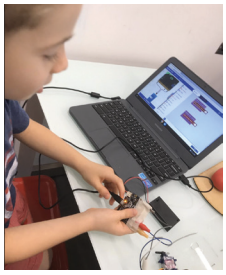
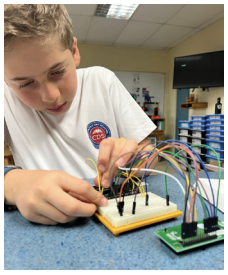
2018	2022	2024
In this image, the child is shown interacting with programming software on his tablet. He is working on creating a project in Scratch Jr., a visual programming environment designed to introduce children to basic coded blocks. With a simple and engaging interface, the child drags and connects these blocks of code to make his characters move and interact. This helps him learn how to use digital tools while developing the computational logic necessary to carry out his project.	As his learning progressed, the child began working with more complex tools, such as the Micro:bit board, expanding his understanding of programming and robotics. He uses the board to develop projects involving more advanced concepts such as sequences, conditionals, loops, inputs and outputs, and sensors. Through the use of block-based programming languages, he is able to program more precisely and with greater sophistication,, using the pins on the board to connect components that can interact with the physical environment. This demonstrates his growing ability to employ digital tools in increasingly complex projects, highlighting his creativity as well as his logical and computational thinking.	Over time, the child begins programming in more complex, abstract languages, using the Arduino board for more advanced projects. In one of these projects, he integrated an LCD screen that displayed the temperature detected by a sensor, allowing him to experiment with the interaction between hardware and software. This advance reflects his ability to incorporate prior knowledge in new solutions, expanding his understanding of both programming and technology, and providing him with greater autonomy in creating more sophisticated projects.
		

Table 6: Use of Digital Tools. Source: Morado, Melo & Jarman, 2025.

5. Discussion

The analysis of this individual case study reveals how constructionist makerspaces can be potent environments for holistic learning. The results demonstrate that engaging students in the design and programming of projects leads not only to greater technical competence but also to meaningful growth in cognitive, emotional, interpersonal, and creative dimensions. These findings align with Papert's constructionism (1980), which argues that learners build knowledge through the creation of "objects-to-think-with," and with the active learning theories of Dewey and Piaget, who emphasized the value of concrete experiences and reflective interaction with the environment.

A particularly significant finding relates to the evolution of the child's problem-solving capacity: over time, he progressed from a more assisted stage – where he relied more on teacher demonstrations – to an autonomous phase, where he independently addressed technical and conceptual challenges. This transformation reflects the impact of a well-designed environment, but even more importantly, the value of a pedagogical approach grounded in active listening, personalized scaffolding, and respect for the learner's agency. This process echoes previous studies by Resnick (2020) and Sheridan et al. (2014), which show how makerspaces support both computational fluency and meaningful, learner-centered experiences.

The child's projects consistently integrated concepts from multiple disciplines – mathematics, physics, engineering, and design – demonstrating the interdisciplinary potential of makerspaces. By translating abstract ideas into real-world applications, the child embodied the kind of cognitive engagement described by Lee et al. (2021) and Resnick (2020), in which learners move fluidly between domains and apply knowledge creatively and contextually. Makerspaces, in this sense, offer an antidote to fragmented curricula by fostering environments where knowledge is built through iteration, experimentation, and connection.

In terms of intrapersonal development, the study illustrates how long-term participation in complex projects can foster skills such as emotional regulation, resilience, and self-confidence. For instance, when a project failed due to a mechanical limitation that exceeded his developmental capabilities, the child accepted the outcome and was able to reflect on the experience constructively. His ability to persist through frustration, maintain motivation, and take pride in his process – even requesting online sessions when unable to attend in person – demonstrates a strong sense of engagement and personal investment. This finding reinforces Fredricks et al. (2004), who argue that emotional engagement plays a key role in fostering metacognitive strategies, sustained attention, and deeper learning.

A notable development was also observed in the child's emotional and cognitive resilience. For instance, when an automated irrigation system failed due to a mechanical issue he was not yet able to solve, he did not become discouraged. On the contrary, he accepted his limitations and reflected constructively on what he had learned. His curiosity remained steady throughout the seven years – to the extent that, when he was unable to attend the makerspace due to illness or traffic, he would request to have the session virtually.

Beyond individual progress, the case suggests broader implications for learning design. Makerspaces must offer more than tools and materials – they must provide open-ended, exploratory spaces where children are encouraged to imagine, prototype, and build on their ideas. The educator's role is not to direct learning, but to guide, challenge, and co-construct meaning. In this case, the child benefited from continuous, personalized support that respected his ambitions while gently negotiating the boundaries of his developmental stage – particularly when he brought project ideas too difficult for his age, such as building drones or submarines.

While the insights from this case are compelling, the study's single-case nature and the unique characteristics of the child and his environment limit the generalizability of the findings. The child's intellectual profile, sustained interest, and strong academic support from his family created ideal conditions for the observed outcomes.

Nevertheless, the depth of this portrait provides valuable indications for future research. Questions worth exploring include whether similar trajectories can be supported in children with less familial stimulation or group settings within formal educational contexts.

Constructionist makerspaces emerge as transformative educational environments that combine action, reflection, technology, and iteration – offering opportunities for deep, meaningful, and personalized learning. They reveal what becomes possible when we trust children to lead, explore, and create – within a framework of intentional guidance and support.

6. Conclusion

This case study offers an in-depth portrait of how constructionist principles can be applied to personalized and sustained learning experiences. Through a wide variety of technologies, the child developed not only technical and cognitive abilities but also intrapersonal skills and growing creative confidence. His milestones – such as programming input/output functions at age 7, mastering unit conversion for 3D design at age 8, and building functional robotic arms – demonstrate the transformative potential of long-term engagement in a makerspace.

While the findings are not generalizable, they provide valuable insights for educators and learning designers: the importance of time, autonomy, the use of open-ended technologies, and pedagogical guidance that adapts to the learner's pace. Future research could explore how similar outcomes might be fostered in more diverse student populations and within formal school contexts. Constructionist makerspaces emerge as fertile environments not only for skill development but also for nurturing meaningful, interest-driven growth guided by the learner's intrinsic motivation.

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