ACTIO: Docência em Ciências
ISSN: 2525-8923

http://periodicos.utfpr.edu.br/actio

Maker training for teachers: competencies developed through didactical engineering

Luiz Paulo Fernandes Lima
Universidade Federal do Ceará (UFC), Fortaleza, Ceará, Brasil.
luiz.lima@ifce.edu.br
orcid.org/0000-0002-5250-7669

Daniel Brandão Menezes
Universidade Estadual do Ceará (UECE), Fortaleza, Ceará, Brasil.
brandao.menezes@uece.br
orcid.org/0000-0002-5930-7969

Francisco Herbert Lima Vasconcelos
Universidade Federal do Ceará (UFC), Fortaleza, Ceará, Brasil.
herbert@virtual.ufc.br
orcid.org/0000-0003-4896-9024

ABSTRACT

The article addresses the training of basic education teachers in maker activities, a requirement of the Ministry of Education according to legislation, specifically Resolution CNE/CP Nº. 1, dated October 27, 2020, which deals with the National Curriculum Guidelines for the Continuing Education of Basic Education Teachers and establishes the Common National Base for the Continuing Education of Basic Education Teachers (BNC – Formação Continuada). The study aims to analyze the maker competencies and skills developed in physics and mathematics teachers through training based on Didactic Engineering. This is an action research conducted with seven teachers at the Center for Excellence in Educational Policies (CEnPE) at the Federal University of Ceará (UFC) at the end of 2023, using the four steps of Didactic Engineering as the research methodology, guiding the training process, and data collection and analysis. Among the results, we highlight the development of competencies and skills acquired in the modeling processes, which integrate digital culture through the use of FabLab tools, where teachers demonstrated scientific, critical, and creative thinking during the development and fabrication of educational products. Additionally, they exhibited good communication, empathy, and cooperation, which were essential in the creative processes, contributing relevant considerations to the success of maker activities.

KEYWORDS: Didactic Engineering of Training. Maker Culture. Computational Modeling. Digital Fabrication.

Formação maker de professores: competências desenvolvidas via engenharia didática

RESUMO

O artigo aborda a formação de professores da educação básica em atividades makers, uma exigência do Ministério da Educação, conforme legislação, especialmente a resolução CNE/CP Nº 1, de 27 de outubro de 2020, que dispõe sobre as Diretrizes Curriculares Nacionais para a Formação Continuada de Professores da Educação Básica e institui a Base Nacional Comum para a Formação Continuada de Professores da Educação Básica (BNC – Formação Continuada). O estudo objetiva analisar as competências e habilidades makers desenvolvidas em professores de física e matemática através de uma formação embasada na Engenharia Didática. Trata-se de uma pesquisa-ação que foi conduzida com sete professores no Centro de Excelência em Políticas Educacionais (CEnPE) da Universidade Federal do Ceará (UFC), no final de 2023, tendo como metodologia de pesquisa os quatro passos da Engenharia Didática, orientando o processo formativo, a coleta e a análise de dados. Dentre os resultados, destacamos o desenvolvimento das competências e habilidades adquiridas nos processos de modelagem, que integra a cultura digital através do uso das ferramentas do FabLab, em que os professores demonstraram pensamento científico, crítico e criativo durante o desenvolvimento e a fabricação de produtos educacionais, além de apresentaram boa comunicação, empatia e cooperação, que foram essenciais nos processos criativos, contribuindo com considerações relevantes para o sucesso das atividades makers.

PALAVRAS-CHAVE: Engenharia Didática de Formação. Cultura Maker. Modelagem Computacional. Fabricação Digital.

INTRODUCTION

A very important aspect of the need for continuing education concerns improving teaching quality, as stated in Article 7 of CNE/CP of 2020 (Brasil, 2020). There is a need for teachers to constantly update their knowledge of new pedagogical practices, differentiated teaching methodologies, new educational technologies, and specific content areas. In addition, continuing education allows adaptation to ongoing changes in society and education, promoting innovation and the efficient use of digital tools.

One of the changes that Brazilian education has experienced in recent years is the maker culture implementation in basic education schools. These activities are designed to stimulate creativity through the creation and implementation of projects and products using digital technologies, promoting the development of essential skills and competencies to teachers´ and students´ lives. (Bremgartner, Fernandes, Sousa & Souza, 2022).

The environments in which these maker projects are conducted tipically feature a diverse array of specialized tools and equipament, generally found in digital fabrication labs known as FabLabs. These spaces may include laser cutters, CNC routers, vinyl cutters, 3D printers, portable scanners, Arduino kits, and other resources. It is important to highlight that handling this equipment requires specialized skills, emphasizing the importance of comprehensive and collaborative training that integrates computational modeling and digital fabrication concepts. This educational approach must align with the demands and legislative regulations of Brazilian education (Frosch & Alves, 2017), covering all necessary aspects for learning these new educational technologies.

Thus, this research is justified by the need to train teachers in handling maker tools, equipping them in computational modeling and digital fabrication processes, enabling them to design and create educational products autonomously. This poses a guiding research question: How can teacher training in the maker culture promote the development of essential 21st-century skills and improve teaching quality in basic education?

Therefore, this study seeks to analyze which maker skills and competencies are developed in physics and mathematics teachers through a training program based on Didactic Engineering.

This was an action research conducted at the Center for Excellence in Educational Policies (CEnPE) at the Federal University of Ceará (UFC), organized and conducted by students and researchers in the Science and Mathematics Teaching Ph.D. program of the Northeast Teaching Network (Renoen). The training followed the four stages of Didactic Engineering (Artigue, 1998), with data collected throughout these stages, which provided important information for concluding this study.

In the following sections, we review the Brazilian guidelines governing teachers' continuing education, the key aspects of training according to Perrenoud, the explanation of the four phases of Didactic Engineering for teacher training, and the skills and competencies a maker teacher should possess. Then, we present the research methodology, results, and discussions.

CONTINUING TEACHER EDUCATION

The training of basic education teachers is governed by Resolution CNE/CP No. 1, dated October 27, 2020, issued by the Ministry of Education (Brazil, 2020), which outlines the National Curriculum Guidelines for the Continuing Education of Basic Education Teachers and establishes the National Common Core for Continuing Education of Basic Education Teachers (BNC–Continuing Education).

By addressing classroom diversity, continuing education empowers teachers to meet the specific needs of each student, promoting critical thinking among in educators and students, and strengthens the teaching profession by recognizing it as essential to societal progress. Article 3 of CNE/CP of 2020 (Brazil, 2020) describes three interdependent dimensions fundamental to teaching practice in Basic Education: I – professional knowledge; II – professional practice; and III – professional engagement, which aim to foster the full development of students.

When analyzing the general teaching competencies in the BNC – Continuing Education, we identify Competency 5, which emphasizes the need to "Understand, use, and create digital information and communication technologies in a critical, significant, reflective, and ethical way in various teaching practices, as a pedagogical resource and as a tool for teacher development, to communicate, access and disseminate information, produce knowledge, solve problems, and enhance learning."

MAKER CULTURE COMPETENCIES AND SKILLS

The maker culture is a contemporary movement that promotes a hands-on, problem-solving approach. At its core, it values creativity, experimentation, and collaboration, encouraging individuals to become active participants in producing physical objects and addressing real-world challenges. It embraces a "do-it-yourself" (DIY) mindset, motivating individuals to learn new skills and use accessible tools, such as 3D printers, laser cutters, and prototyping platforms, to bring their ideas to life (Silveira, 2016).

Maker culture emphasizes a sharing community, where makers often openly and freely share their projects, plans, and knowledge, promoting a collaborative learning and innovation environment (Bandoni, 2016). Through maker education, it is possible to cultivate the competencies and skills proposed by the BNCC, namely: knowledge; scientific, critical, and creative thinking; cultural repertoire; communication; digital culture; work and life projects; argumentation; self-knowledge and self-care; empathy and cooperation; responsibility and citizenship (Brazil, 2017b). It goes beyond technology and engineering, incorporating arts and crafts, which play fundamental roles, allowing students to express creativity and refine their manual skills. Integrating activities such as drawing, painting, sculpture, collage, sewing, and other artistic techniques into the maker curriculum is essential (Hatch, 2013).

FabLabs contribute significantly to the developing of these competencies, as they are environments equipped with machines and tools that allow students and teachers to design, prototype, and manufacture both physical and digital objects. Equipment includes 3D printers, laser cutters, CNC routers, electronics kits, woodworking tools, and design and creation software. In these spaces, students have the opportunity to develop projects and learn through hands-on practice, experimentation, and creating tangible products using computational modeling, which are then fabricated by machines.

Through computational modeling with specialized software, teachers and students can create virtual models of objects, systems, or phenomena, while digital fabrication involves producing these models using the technologies mentioned above. By exploring computational modeling and digital fabrication, teachers and students are encouraged to think creatively and innovatively, developing essential skills such as problem-solving and critical thinking using a methodology known as Design Thinking (DT). These technologies also foster interdisciplinary approach, being applicable across a wide range of subjects, from mathematics and sciences to arts and humanities.

By incorporating these state-of-the-art tools into education, schools provide students access to advanced technology, offering a science and technology literacy framed by in the Science, Technology, and Society (STS) movement. As Oliveira (2019) states in his study on the teleology of STS science education, computational modeling and digital fabrication can be adapted to meet educational needs for different learning styles, skills, and interests, promoting an inclusive approach and valuing diversity.

TEACHER TRAINING DIDACTIC ENGINEERING

Didactic Engineering is a research methodology that centers on the triad of teacher, student, and knowledge, and intends to analyze didactic situations within the scope of Mathematics Didactics (Bianchini & Machado, 2019). It emerged from the studies and discussions of authors notably Yves Chevallard and Guy Brousseau on French Mathematics Didactics in the 1980s, with later contributions from the French researcher Michèle Artigue.

According to Artigue (1998), the researcher or teacher plays a role similar to that of an engineer in designing and executing architectural projects. Artigue describes Didactic Engineering as a methodological approach focused on developing and analyzing innovative educational practices, emphasizing problem-solving in teaching and learning. It can be considered a theory that encompasses both theoretical and experimental dimensions (Gomes, Menezes & Almeida, 2019).

This methodology is structured around experimentation, based on implementing didactic sequences in the classroom, and is divided into four phases: 1st Phase: Preliminary Analysis; 2nd Phase: Design and A Priori Analysis; 3rd Phase: Experimentation; and 4th Phase: A Posteriori Analysis and Validation (Artigue, 1998).

Complementing traditional Didactic Engineering (DE), Teacher Training Didactic Engineering (TTDE) is a pedagogical approach that focuses on creating specific didactic sequences for teacher training. Unlike traditional DE, which is dedicated to teaching content to students, TTDE directs its efforts toward developing teaching strategies that equip educators with the practical skills and pedagogical competencies needed to succeed in the classroom.

This approach aims to offer contextualized didactic situations, providing teachers with more organized and effective training (Alves, 2018). TTDE uses pedagogical tools from the perspective of Didactic Engineering, adapting them to create specific learning resources for teacher education. In doing so, it aims to contribute to the improvement of teacher training quality, aligning with the demands and challenges of teaching practice.

METHODOLOGY

This research methodology is configured through experimentation based on the implementation of didactic sequences (DS) in the classroom, divided into four phases: 1st Phase: Preliminary Analysis; 2nd Phase: Design and A Priori Analysis; 3rd Phase: Experimentation; and 4th Phase: A Posteriori Analysis and Validation (Artigue, 1998; Perrin-Glorian & Bellemain, 2019).

The Preliminary Analyses encompass essential epistemological, cognitive, and institutional studies for developing a series of situations to be tested in the classroom.

In Brazil, epistemological challenges in science and mathematics education include the continuous training of teachers in scientific and pedagogical knowledge, pedagogical innovation with active methodologies that encourage inquiry and problem-solving, and the effective integration of technology into teaching (Nascimento, Fernandes & Mendonça, 2012). Additional issues include the excess content in textbooks and curricula without clear objectives, the need to contextualize content for students' everyday lives, and assessment methods that emphasize conceptual understanding and critical thinking (Millar, 2003). Cognitive challenges involve the complexity of scientific concepts, the need to identify and correct students' alternative conceptions, and the integration of different scientific knowledge areas (Seixas, Calabró & Sousa, 2017). Institutionally, challenges include poor infrastructure, deficiency of teaching resources, low investment in teacher training, high teaching loads, insufficient planning time, bureaucracy, lack of autonomy, and insufficient institutional support, all of which require a comprehensive approach considering educational policies and socioeconomic contexts (Silva, Ferreira & Vieira, 2017).

The Design and A Priori Analysis phase was structured to allow data collection and reflection on maker activities and the use of FabLab tools, enabling a comparison with experimental data in the A Posteriori Analysis. Global variables included the introduction of maker culture and its implementation, the operation of maker tools in FabLabs, and the various possibilities of the maker approach to enrich teaching, computational modeling, digital fabrication, and the development of educational products applicable in the classroom. Based on these global choices, an action plan was developed with local choices, implemented in five in-person sessions, where we applied Didactic Sequences related to this study's theme, in addition to pre-organized online training activities. We anticipated that questions would arise regarding the use of design and creation tools and difficulties with digital fabrication due to handling both virtual and physical FabLab tools. Despite being immersed in the digital age, we expected that teachers might be unfamiliar with maker activities and, consequently, digital fabrication. Finally, we imagined that teachers would be able to design and fabricate their educational products at the end of the training sessions, reflecting on their classroom experiences.

In the Experimentation phase, the application of the Didactic Sequences was conducted by researchers who observed and collected data. Observations and data collection were guided by the research question and the engineering dimension, allowing analysis of teachers' interactions with the FabLab environment, the effects on knowledge, and the actions of teachers and researchers regarding FabLab organization. The experimentation took place over five in-person sessions, supplemented by synchronous and asynchronous online activities. The topics covered in the in-person sessions were:

1. Integration of Maker Culture in Basic Education;
2. 3D Computational Modeling;
3. 3D Digital Fabrication;
4. 2D Computational Modeling;
5. 2D Digital Fabrication.

During these sessions, data were collected through questionnaires on the participants' personal and professional characteristics, as shown in Table 1, and on their knowledge and use of tools necessary for maker activities, as seen in Table 2, with responses based on the Likert scale (1932).

Table 1

Personal and Professional Identification Survey

1 – Full Name ________________________________	2 – Gender a) Male b) Female c) Other
3 – Age a) Up to 24 years b) 25-29 years c) 30-39 years d) 40-49 years e) 50 years or older	4 – What is your highest level of education completed? a) Bachelor's degree b) Specialist c) Master's degree d) Doctoral degree e) Postdoctoral
5 – What is your field of study? a) Physics b) Chemistry c) Biology d) Mathematics e) Other (please specify)	6 – How many schools do you work at? a) Only 1 b) 2 c) 3 d) 4 or more
7 – What is your weekly workload (in hours)? a) Up to 20 hours/week b) 20-30 hours/week c) 30-40 hours/week d) 40-50 hours/week e) Over 50 hours/week	8 – How long have you been teaching? a) Less than 5 years b) 5-10 years c) 10-15 years d) 15-20 years e) Over 20 years

Source: Original authorship (2024).

Table 2

Maker Tool Awareness and Utilization

Q1 – I use computers, laptops, tablets, or smartphones in my professional activities. 1. I don't use because the school doesn't have them. 2. I don't use, but the school has them. 3. I'm unsure. 4. I use, but the school doesn't have them. 5. I use and the school has them.	Q2 – I use the internet during my classes. 1. I don't use because the school doesn't have it. 2. I don't use, but the school has it. 3. I'm unsure. 4. I use, but the school doesn't have it. 5. I use and the school has it.
Q3 – I use virtual simulation software in my classes. 1. I don't use because the school doesn't have them. 2. I don't use, but the school has them. 3. I'm unsure. 4. I use, but the school doesn't have them.	Q4 – I use programming and robotics materials in my experimental activities. 1. I don't use because the school doesn't have them. 2. I don't use, but the school has them. 3. I'm unsure. 4. I use, but the school doesn't have them.

5. I use and the school has them.	5. I use and the school has them.
Q5 – I use electronics kits in my experimental activities. 1. I don't use because the school doesn't have them. 2. I don't use, but the school has them. 3. I'm unsure. 4. I use, but the school doesn't have them. 5. I use and the school has them.	Q6 – I use board or electronic games in some classes. 1. I don't use because the school doesn't have them. 2. I don't use, but the school has them. 3. I'm unsure. 4. I use, but the school doesn't have them. 5. I use and the school has them.
Q7 – I use the maker space or FabLab. 1. I don't use because the school doesn't have them. 2. I don't use, but the school has them. 3. I'm unsure. 4. I use, but the school doesn't have them. 5. I use and the school has them.	Q8 – I use computer modeling in creating my experiments. 1. I don't use because the school doesn't have them. 2. I don't use, but the school has them. 3. I'm unsure. 4. I use, but the school doesn't have them. 5. I use and the school has them.
Q9 – I use laser cutting machines to produce educational materials. 1. I don't use because the school doesn't have them. 2. I don't use, but the school has them. 3. I'm unsure. 4. I use, but the school doesn't have them. 5. I use and the school has them.	Q10 – I use 3D printing to produce educational materials. 1. I don't use because the school doesn't have them. 2. I don't use, but the school has them. 3. I'm unsure. 4. I use, but the school doesn't have them. 5. I use and the school has them.
Q11 – I use low-cost materials (wood, cardboard, plastics, etc.) to produce educational materials. 1. I don't use because the school doesn't have them. 2. I don't use, but the school has them. 3. I'm unsure. 4. I use, but the school doesn't have them. 5. I use and the school has them.	Q12 – I use general tools (hammer, pliers, screwdriver, etc.) to produce educational materials. 1. I don't use because the school doesn't have them. 2. I don't use, but the school has them. 3. I'm unsure. 4. I use, but the school doesn't have them. 5. I use and the school has them..
Q13 – I use other materials (glue, scissors, adhesive tape, etc.) to produce educational materials. 1. I don't use because the school doesn't have them. 2. I don't use, but the school has them. 3. I'm unsure. 4. I use, but the school doesn't have them. 5. I use and the school has them.	

Source: Original authorship (2024).

We recorded, through photographs, the moments of modeling and digital fabrication, and collected written reports on the teachers' impressions regarding the training and proposed Didactic Sequences. Important notes were taken throughout the formative moments in field diaries, crucial for the subsequent Post-Hoc Analysis. Each meeting lasted five hours and took place on Saturdays at CEnPE, with seven teachers participating, spanning two and a half months to acquire basic competencies for developing maker activities, as stated by Lima et al. (2024) regarding the suitable training time for maker education.

In the Post-Hoc Analysis, distinguishing between contingent and necessary events was crucial, differentiating what resulted from specific circumstances and what was intrinsic to the situation. This analysis evaluated whether the environment fulfilled its expected role, identified discrepancies between observations and expectations, and attempted to explain them. Some indicated that the Prior Analysis was insufficient and needed completion, while others may have resulted from environmental limitations or students' lack of knowledge to interpret feedback.

Comparing Prior and Post-Hoc Analyses allowed adjusting both the situation (modifying the environment or interaction conditions) and the theory (reviewing hypotheses and refining theoretical concepts).

FINDINGS AND DISCUSSION

To perform a more adequate analysis of the questionnaire results, we utilized the Jamovi statistical software (2023) in two distinct functions. For the description of the personal and professional identification of participating teachers, we employed Gtsummary: summary of presentation-ready data and analytical result tables (Sjoberg, Hannum, Whiting, & Zabor, 2020), available within the ClinicoPath module (Balci, 2022) in Jamovi's exploration analysis function, as shown in Table 3.

Table 3

Personal and Professional Identification Survey Results

Participant Characteristics – n = 7				
2. Gender	F 2 (29%)		M 5 (71%)	
3. Ager (years)	20 – 24 1 (14%)	25 – 29 2 (29%)	30 – 39 1 (14%)	40 – 49 3 (43%)
4. Academic Level	Bachelor´s 2 (29%)		Master´s 5 (71%)	
5. Area of Expertise	Pedagogy 1 (14%)	Mathematics 1 (14%)	Physics 5 (71%)	
6. Number of Schools Taught	1 3 (43%)	2 3 (43%)	3 1 (14%)	
7. Weekly Workload (hours/week)	10 – 20 1 (14%)	30 – 40 3 (43%)	40 – 50 3 (43%)	
8. Years of Teaching Experience	0 – 5 1 (14%)	5 – 10 2 (29%)	15 – 20 3 (43%)	20 – 30 1 (14%)

Source: The authors, generated via Jamovi (2024).

The results show that the predominant age range of teachers was over 30 years, with most holding a master's degree, and Physics being the dominant subject area. One teacher with a degree in Pedagogy reported teaching Mathematics to elementary school students.

Further results indicate that most teachers worked in one or two schools, with a workload exceeding 30 hours/week and over ten years of teaching experience. One Physics teacher with less than five years of experience reported a workload under 20 hours/week.

Based on these results, we conclude that this group consisted of experienced teachers with a substantial teaching workload, consistent with the average 40 hours/week for teachers in Ceará.

For the analysis of the questionnaire on knowledge and use of maker culture tools, we employed the R package (R Core Team, 2022), a language and environment for statistical computing, using descriptive statistics in Jamovi's exploration analysis.

We aligned the variables, using the mean and median as measures of central tendency, the standard deviation as a measure of dispersion, the 95% confidence interval for the mean as an indicator of variability, and the Shapiro-Wilk normality test.

We included all 13 questions with responses based on the Likert scale (1932), ranging from 1 (most negative) to 5 (most positive). Table 4 presents the results of this descriptive statistics analysis

Table 4

Descriptive Statistics of the Maker Culture Survey

			Confidence Interval (CI) 95%					Shapiro-Wilk	
	N	Mean	Standard Error (SE)	Lower Limit (LL)	Upper Limit (UL)	Median	Standard Deviation (SD)	W	p
Q1	7	4.71	0.184	4.263	5.17	5	0.488	0.600	< .001
Q2	7	4.86	0.143	4.508	5.21	5	0.378	0.453	< .001
Q3	7	2.71	0.606	1.231	4.20	4	1.604	0.664	0.001
Q4	7	1.71	0.421	0.685	2.74	1	1.113	0.720	0.006
Q5	7	2.57	0.649	0.982	4.16	2	1.718	0.826	0.073
Q6	7	2.43	0.571	1.030	3.83	2	1.512	0.747	0.012
Q7	7	1.86	0.459	0.733	2.98	1	1.215	0.773	0.022
Q8	7	1.86	0.459	0.733	2.98	1	1.215	0.773	0.022
Q9	7	1.57	0.429	0.523	2.62	1	1.134	0.612	< .001
Q10	7	1.14	0.143	0.793	1.49	1	0.378	0.453	< .001
Q11	7	3.29	0.474	2.126	4.45	4	1.254	0.650	0.001
Q12	7	3.57	0.571	2.173	4.97	4	1.512	0.844	0.107
Q13	7	4.14	0.404	3.154	5.13	4	1.069	0.781	0.026

Source: The authors, generated via Jamovi (2024).

The results of Q1 indicate that most teachers use computers, notebooks, tablets, or smartphones in their professional activities, and most schools have these resources (Mean = 4.71; Median = 5). However, there is some variability in usage levels among teachers, and the data does not follow a normal distribution ($p < 0.001$), giving statistical significance.

Attached to this, it can be concluded in Q2 that most teachers use the internet during classes and the school also has internet access (Mean = 4.86; Median = 5).

The Q3 data suggests significant variation in teachers' responses regarding the use of virtual simulation software, whose availability at school seems to influence this decision (Mean = 2.71; Median = 4). However, the lack of normality in the data indicates caution when interpreting the mean and standard deviation (SD = 1.604), as they may not be fully representative of the actual data distribution.

The results for Q4 suggest that most teachers do not use programming and robotics materials in their experimental activities (Mean = 1.71; Median = 1). Although the mean and median indicate a consistent trend, the data dispersion (SD = 1.113) and lack of normality ($p = 0.006$) indicate variation in teachers' responses.

Similar results were found for Q5 (Mean = 2.57; Median = 2) and Q6 (Mean = 2.43; Median = 2), suggesting diversity in practices among teachers regarding the use of electronics kits and board or electronic games in their classes.

For questions Q7 and Q8, the identical results (Mean = 1.86; Median = 1) suggest that most teachers do not use maker spaces or FabLabs in their classes or computational modeling in creating experiments. Although the means and medians indicate a trend towards non-use, the high data dispersion (SD = 1.215) indicates variability in teachers' practices. These results are significant for this research.

The Q9 results suggest that most teachers do not use laser cutting machines in producing educational materials (Mean = 1.57; Median = 1). The normality test ($p < 0.001$) indicates non-normal data distribution, trending towards non-use due to lack of school resources, similarly for Q10.

The Q10 results strongly suggest most teachers do not use 3D printers in producing educational materials (Mean = 1.14; Median = 1). Both mean and median indicate this trend, and the relatively low standard deviation (SD = 0.378) suggests responses are close to the mean with minimal variation.

The Q11 results indicate most teachers use low-cost materials in producing educational materials (Mean = 3.29; Median = 4). Both mean and median suggest a trend towards using these materials, despite considerable variability in teachers' responses (SD = 1.254).

The Q12 results suggest most teachers use general tools in producing educational materials (Mean = 3.57; Median = 4). Both mean and median indicate a trend towards using these tools; however, data dispersion suggests variation in usage frequency among teachers (SD = 1.512).

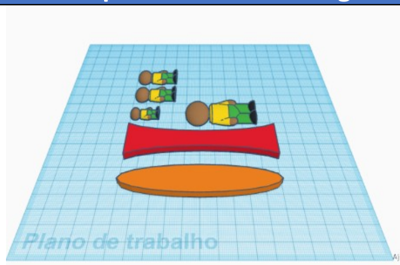
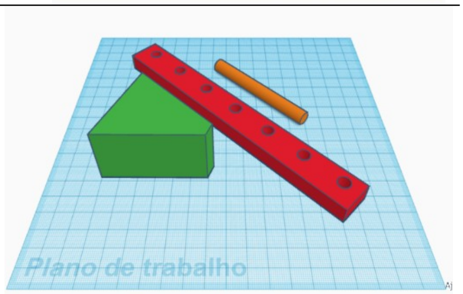
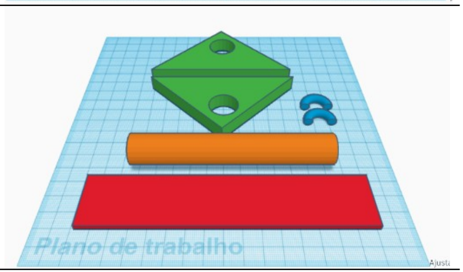
The Q13 results indicate most teachers use other materials in creating educational materials (Mean = 4.14; Median = 4). Both mean and median suggest a trend towards using these materials, with moderate standard deviation (SD = 1.069) indicating some variation in usage frequency.

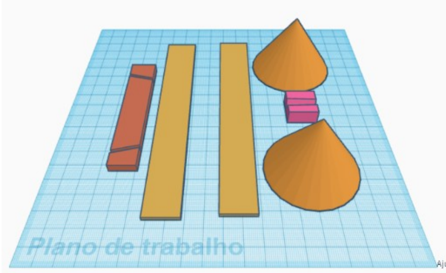
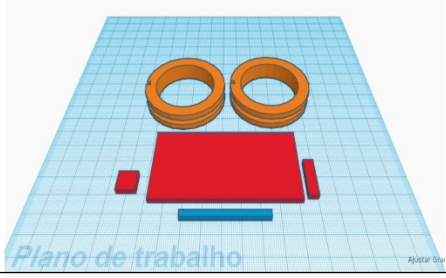
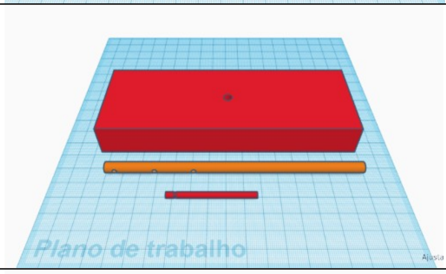
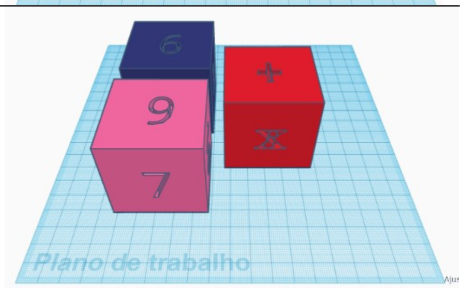
Conclusively, questions 7-10 show this group of teachers were unfamiliar with and did not use computational modeling, digital fabrication, or any FabLab tools. Following questionnaire analysis, we proceeded to formative activities where we explained computational modeling and digital fabrication concepts through Didactic Sequences. Our objective was for teachers to develop their educational products within the training period.

For computational modeling activities, we used Tinkercad, UltimakerCura, and DueStudio4 software, based on Design Thinking methodology with idea generation, prototyping, and fabrication stages (Luiz *et al.*, 2024). This occurred over 30 hours of training, with 15 hours online software training and 15 hours in-person product development and fabrication. Table 5 shows the results of teachers' modeling and project objectives.

Tabela 5

Computational Design with Tinkercad.

Teacher	Project Objective	3D Computational Modeling
JE	Lenses and objects of different sizes for teaching geometric optics to low-vision students.	
LM	Lever arm for teaching topics on force balance and torque.	
JR	Geometric shapes found on a seesaw in children's playgrounds for plane and spatial geometry lessons.	

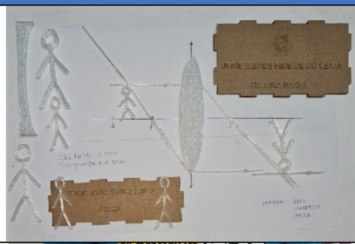
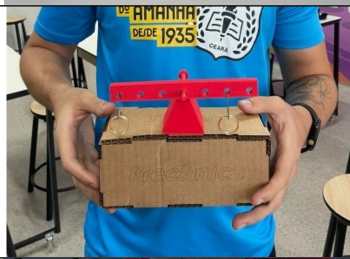
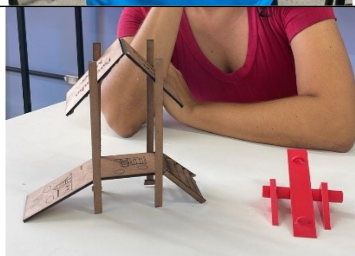
Teacher	Project Objective	3D Computational Modeling
AS	Double cone experiment for classes on center of mass, dynamics, and kinematics.	
MF	Helmholtz coil for electromagnetism lessons.	
JC	Simple pendulum for harmonic systems classes.	
DM	Mathematical data for basic math operations lessons.	

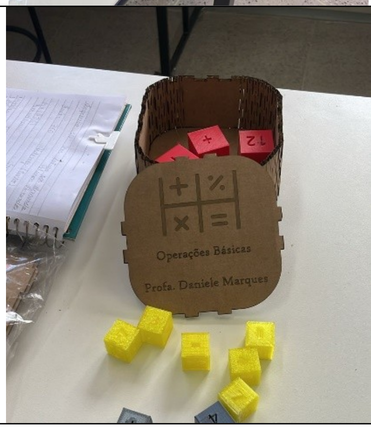
Source: Original authorship (2024).

Following the modeling phase, we proceeded to 3D printing on Ender 3 printers and laser cutting on the DUE machine. Ten hours were allocated for project fabrication, and after overcoming various operational hurdles, the results can be seen in Table 6 below, which also includes a description of the educational product.

Table 6

Digital Fabrication of Educational Products.

Teacher	Description of Educational Product	Digital Fabrication
JE	3D-printed lenses and objects of varying sizes, and partially completed cardboard box cut on the laser cutter.	
LM	3D-printed lever arm e supports, reusable laser-cut cardboard box, additional items like nuts e clips for extra weights.	
JR	3D-printed geometric shapes for seesaw e laser-cut MDF playhouse com slide e stairs.	
AS	3D-printed double cone e laser-cut reusable cardboard box.	
MF	"3D-printed Helmholtz coil, laser-cut reusable cardboard box, and additional items including copper wire, 9.0V power source, and adhesive for coil assembly.	

Teacher	Description of Educational Product	Digital Fabrication
JC	3D-printed simple pendulum, laser-cut reusable cardboard box, and additional items including sewing thread, screws and nuts for extra weights.	
DM	3D-printed mathematical models, laser-cut MDF box, and additional items including pencils and paper for calculation notes.	

Source: Original authorship (2024).

Once the development activities and manufacturing of the projects were completed, we asked the participants two questions: the first about the main challenges encountered in the computational modeling and digital manufacturing processes; and the second about how digital manufacturing could be used effectively in the creation of educational products. Table 7 shows the full answers from each participant.

Table 7

Participant Feedback Following Digital Fabrication Activities

Teacher	P1 – What were the primary challenges encountered in computational modeling and digital fabrication?	P2 – How can digital fabrication be effectively utilized in creating educational products?
JE	*Having the availability to dedicate oneself to digital tools, software being a new environment requires this extra dedication. Knowing suppliers of good quality products for using the tools. And having the creative skills, creativity and imagination to make it work.*	*Making abstract things from the natural sciences or even mathematics material, physical, and tangible, enriches the learning process. Having a student develop these materials from scratch edifies even more, as the student becomes the protagonist of the learning process.*
LM	*I believe that the main challenges are related to the handling of*	*Mainly in the production of low-cost materials and experiments,*

Teacher	P1 – What were the primary challenges encountered in computational modeling and digital fabrication?	P2 – How can digital fabrication be effectively utilized in creating educational products?
	modeling platforms and printing machines. Once these platforms are mastered, digital manufacturing becomes elementary, depending only on the teacher's creativity.	*effectively contributing to meaningful learning.*
JR	*Software manipulation.*	*Based on the experience of the teacher who is in the classroom and understands the need related to the content that requires other means for its effective understanding.*
AS	*I believe that the biggest challenges are related to mastering the tools (modeling, rendering and production), the time required to design and manufacture products (especially 3D printers) and the high cost of the machines.*	*Their efficiency is related to the teacher's sensitivity to identify learning problems, the creativity of designing a product and their ability to model, produce and apply in the search for more meaningful learning.*
MF	*The main challenges are fine-tuning the material, something that can only be learned by testing and verifying that the part is as expected.*	*Digital manufacturing can enable the creation of innovative materials or materials that would require large resources to acquire on the market, creating endless possibilities.*
JC	*My main challenge was the difficulty in operating the programs and all their functions, something that becomes normal at the beginning of any new process, and the difficulty in visualizing the objects when making the planned objects.*	*Digital manufacturing can be used as an alternative for creating new items that will generate new forms of learning. It is clear that students develop better when they see and touch the objects, which are sometimes illustrative. Creating objects so that students can effectively participate in the process is essential for the development of the teaching and learning process.*
DM	*Internet and computer with slow processor.*	*Starting from the teacher's need to teach, and the student's right to learn. Within the lesson planning.*

Source: Original authorship (2024).

We can conclude that the challenges faced and mentioned by the teachers revolve around the use of modeling software, the proper handling of 3D printers and laser cutting machines, selecting appropriate materials for digital fabrication, and critical factors like having a reliable internet connection and a good computer to carry out the activities. Two teachers took longer than expected to complete their fabrications, requiring an additional session. One teacher was unable to print correctly on the 3D printer, necessitating the researchers' assistance to complete the activity.

Regarding the creation of educational products through the maker culture, we identified important aspects such as the connection between ideation and fabrication in the stages of Design Thinking, the reuse of materials like cardboard for making boxes, the potential for creating products that fit teachers' classroom realities, the various ways students can engage in the creation and use of educational products, and the opportunities for innovation, whether by fabricating something already available on the market or creating a solution for a societal problem.

Our a posteriori analysis suggests that, despite the emergence of questions about the use of design and creation tools and the challenges encountered during digital modeling and fabrication, the teachers managed to overcome these difficulties and developed educational products focused on their classroom needs. Another anticipated point, as shown by statistical results, is that teachers frequently use computers, tablets, and mobile phones, as well as the internet provided by schools; however, as described in the A Priori Analysis, few if any of them used a FabLab or any of the tools available within it.

We consider that this training, based on the stages of Didactic Engineering, was relevant to the pedagogical practice of these teachers, involving moments of innovation, problem-solving, and effective integration of technologies focused on teaching, as highlighted in the epistemological challenges based on Nascimento et al. (2012). We also observed that the complexities of maker activities were understood and assimilated, allowing for the integration of different areas of knowledge, as anticipated in the cognitive challenges cited by Seixas et al. (2017). Finally, we believe that the digital fabrication of educational products can help mitigate the lack of didactic resources in schools, as noted by Silva et al. (2017). Although other issues were mentioned in our Preliminary Analysis, these stood out in our observations and perceptions throughout this research.

Regarding the competencies and skills observed during the training, which was the goal of this study, we highlight the knowledge developed throughout the modeling processes, encompassing digital culture, as participants successfully used the FabLab's virtual and physical tools. Scientific, critical, and creative thinking was demonstrated in the development and digital fabrication of educational products based on the teachers' own experiences. Communication, empathy, and cooperation were essential in the creative processes, as each participant assisted others and contributed relevant insights to their projects and the success of their maker activities.

We conclude that the design of this Didactic Engineering for Teacher Training contributed to achieving the objectives set out in this research, given that the training group had no prior maker knowledge or competencies, as anticipated in the A Priori Analysis and confirmed by the questionnaires in the Experimentation phase. After applying the Didactic Sequences, the group was able to ideate, model, and fabricate their educational products, demonstrating the development of various competencies and skills outlined in the BNC and validated in the A Posteriori Analysis and Validation phase

FINAL REMARKS

This research highlighted the importance of maker culture in education, demonstrating how the creation of educational products can be adapted to teachers' realities and how these activities can engage students in practical and meaningful ways. The training showed that it is possible to implement innovative solutions that enrich the teaching-learning process.

The training positively impacted teachers' pedagogical practices, encouraging innovation and the integration of teaching-oriented technologies. Digital fabrication proved to be a powerful tool to address the lack of teaching resources in schools, aligning with the goals of developing essential 21st-century competencies and skills. The experience underscored the need for ongoing support and training for teachers to fully adopt these technologies, ensuring more dynamic and effective teaching.

The main challenges reported by teachers included using modeling software, operating digital fabrication machines, and logistical issues such as the need for reliable technological infrastructure. The lack of adequate school infrastructure can be a significant limiting factor in executing maker activities, as indicated by the questionnaire on maker culture.

The Didactic Sequences focusing on computational modeling and digital fabrication had a substantial impact, as teachers overcame technical and operational challenges to develop innovative educational products that align with classroom needs. The Design Thinking methodology used during the training effectively promoted creativity and problem-solving.

The objective of this research was achieved by highlighting the competencies and skills acquired in the modeling processes, which integrate digital culture through the use of FabLab tools. Teachers demonstrated scientific, critical, and creative thinking during the development and fabrication of educational products, as well as strong communication, empathy, and cooperation. These qualities were essential in the creative processes, with each participant contributing relevant insights to the success of maker activities.

Based on the results obtained, we consider that this Didactic Engineering approach excelled in structuring a training that effectively integrated theory and practice, using Design Thinking to guide teachers through ideation, prototyping, and fabrication stages. We observed its relevance in planning and implementing Didactic Sequences that enabled an effective training and allowed us to design an engineering approach from theoretical research, through experimentation, and into a posteriori analyses. This approach moved from an initial knowledge deficiency about maker culture to the successful development of educational products through it.

ADDITIONAL INFORMATION

This research was authorized by the Ethics and Research Committee of the Federal University of Ceará (UFC), with opinion number 6.652.098. No financial support was received for the execution of this research, and all material expenses were covered by the authors. No potential conflict of interest was reported by the authors. All data reported in this research were authorized by the participants, and their names were kept confidential.

The original text was written in Portuguese (Brazil) and translated into English (USA) by Adriano de Sousa Santiago, Licensed in Portuguese-English Letters by the State University of Ceará (UECE) and text reviewer at the Federal University of Ceará (UFC)

REFERENCES

Alves, F. R. V. (2018). Engenharia Didática de Formação (EDF): Sobre o ensino dos números (generalizados) de Catalan (NGC). *Educação Matemática Pesquisa*, 20(2), 47-83. https://doi.org/10.23925/1983-3156.2018v20i2p47-83

Artigue, M. (1998). Ingénierie didactique. *Recherches en Didactique des Mathématiques*, 9(3), 281-308. http://kleio.ch/HEP_VS/hepvsvideo/8_INGENIERIE_DIDACTIQUE_ARTIGUE.pdf

Balci, S. (2022). *ClinicoPath jamovi Module* [R package]. Zenodo. https://doi.org/10.5281/zenodo.3997188

Bandoni, A. (2016). Já não se fazem objetos como antigamente. In V. F. Megido (Org.), *A revolução do design: Conexões para o século XXI* (pp. 50-61). Editora Gente.

Bianchini, B. L., & Machado, S. D. A. (2019). A engenharia didática em pesquisas publicadas nos últimos dez anos da revista Educação Matemática Pesquisa. *Educação Matemática Pesquisa*, 21(5), 618-635. https://revistas.pucsp.br/index.php/emp/article/view/45520

Brasil. (2020). *Resolução CNE/CP nº 1, de 27 de outubro de 2020: Estabelece as Diretrizes Curriculares Nacionais para a Formação Continuada de Professores da Educação Básica e institui a Base Nacional Comum para a Formação Continuada de Professores da Educação Básica (BNC – Formação Continuada).* Diário Oficial da União, Seção 1, 43-46.

Bremgartner, V., Fernandes, P., Sousa, J., & Souza, J. C. (2022). Aprendizagem baseada em projetos aplicada a cursos de formação inicial e continuada em Cultura Maker. *Revista Ibero-Americana de Estudos em Educação*, 17(3), 1943-1957. https://doi.org/10.21723/riaee.v17i3.16409

Frosch, R., & Alves, A. F. G. (2017). Perspectivas para a formação docente universitária com aspectos makers. *Revista de Estudos Aplicados em Educação*, 2(4), 109-126. https://doi.org/10.13037/rea-e.vol2n4.4997

Gomes, M. J. S., Menezes, M. B., Almeida, F. E. L. (2019). O contrato didático e as expectativas do professor e alunos frente ao conteúdo figuras planas. *ACTIO*, 4(2), 48-70. https://periodicos.utfpr.edu.br/actio

Hatch, M. (2013). *The maker movement manifesto: Rules for innovation in the new world of crafters, hackers, and tinkerers.* McGraw-Hill Education.

Likert, R. (1932). A technique for the measurement of attitudes. *Archives of Psychology*, 22(140), 1-55. https://archive.org/details/likert-1932/page/8/mode/2up

Lima, L. P. F., Lima, G. P. F., Braga, F. L. P., Menezes, D. B., & Vasconcelos, F. H. L. (2024). O design thinking e a fabricação em 3D de experimentos físicos. *Revista Foco*, 17(2), e4489. https://doi.org/10.54751/revistafoco.v17n2-104

Lima, L. P. F., Abreu, F. G. S., Menezes, D. B., & Vasconcelos, F. H. L. (2024). Time of basic education teachers training in maker activities: A meta-analysis. *Global Journal of Human-Social Science*, 24(G2), 93-106. https://socialscienceresearch.org/index.php/GJHSS/article/view/104019

Millar, R. (2003). Towards a science curriculum for public understanding. *Ensino Pesquisa Educação Ciência*, 5(2), 139-154. https://doi.org/10.1590/1983-21172003050206

Nascimento, F., Fernandes, H. L., & Mendonça, V. M. (2012). O ensino de ciências no Brasil: História, formação de professores e desafios atuais. *Revista HISTEDBR On-line*, 10(39), 225-249. https://doi.org/10.20396/rho.v10i39.8639728

Oliveira, L. V. (2019). Em busca de uma teleologia para a educação científica CTS: da consolidação do campo às unidades de ensino. *ACTIO*, 4(2), 87-108. https://periodicos.utfpr.edu.br/actio/article/view/9034

Perrin-Glorian, M. J., & Bellemain, P. M. B. L. (2019). L’ingenierie didactique entre recherche et ressource pour l’enseignement et la formation des maitres. *Caminhos da Educação Matemática em*

Revista/Online, 9(1). https://periodicos.ifs.edu.br/periodicos/caminhos_da_educacao_matematica/article/view/298

R Core Team. (2023). *R: A language and environment for statistical computing* (Version 4.1) [Computer software]. CRAN. https://cran.r-project.org

Seixas, R. H. M., Calabró, L., & Sousa, D. O. (2017). A formação de professores e os desafios de ensinar ciências. *Revista Thema*, 14(1), 289-303. https://doi.org/10.15536/thema.14.2017.289-303.413

Silva, A. F., Ferreira, J. H., & Vieira, C. A. (2017). O ensino de ciências no ensino fundamental e médio: Reflexões e perspectivas sobre a educação transformadora. *Revista Exitus*, 7(2), 283-304. https://doi.org/10.2237-94602017000200283

Silveira, F. (2016). Design & educação: Novas abordagens. In V. F. Megido (Org.), *A revolução do design: Conexões para o século XXI*. Editora Gente.

Sjoberg, D. D., Hannum, M., Whiting, K., & Zabor, E. C. (2023). *gtsummary: Presentation-ready data summary and analytic result tables* [R package]. CRAN. https://CRAN.R-project.org/package=gts

The jamovi project. (2023). *jamovi* (Version 2.4) [Computer software]. https://www.jamovi.org

Received: Sep. 24st. 2024
Approved: Oct 30st. 2024
DOI: https://doi.org/10.3895/actio.v9n3.19194

How to Cite:
Lima, Luiz Paulo Fernandes, Menezes, Daniel Brandão, & Vasconcelos, Francisco Herbert Lima. (2024). Maker training for teachers: competencies developed through didactical engineering. ***ACTIO***, 9(3), 1-24. https://doi.org/10.3895/actio.v9n3.19194

Correspondence:
LUIZ PAULO FERNANDES LIMA
Rua Tianguá 13, Bairro Parreão, Fortaleza, Ceará, Brasil.