

Integración de la impresión 3D en la educación tecnológica

Integration of 3D Printing in Technology Education

Integração da impressão 3D na educação tecnológica

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Resumen

El presente trabajo describe una experiencia académica que permite alinear la educación basada en competencias con las metas del cuarto indicador de los Objetivos de Desarrollo Sostenible. El propósito principal es integrar la impresión 3D a la educación técnica y tecnológica para acceder al empleo, al trabajo decente y al emprendimiento. Desde la teoría del constructivismo cognitivo, emplea la gamificación para la enseñanza de las matemáticas. El diseño metodológico tiende un puente entre la exposición de conocimientos analíticos (fórmulas y ecuaciones) y la apropiación cognitiva a través de material impreso en 3D. Así, mediante la observación directa a través de una lista de cotejo, se documentó la experiencia de un grupo de estudiantes. Los resultados encontrados proporcionan evidencia de que el diseño y fabricación de material didáctico impreso en 3D permite la integración sistemática de contenidos matemáticos que los estudiantes, ya sean niños, jóvenes o adultos, utilizan en actividades cotidianas o laborales, tal y como el análisis y cálculo de áreas, volúmenes, razones y proporciones, así como de los ajustes y tolerancias.

Palabras clave: didáctica, evaluación por competencias, material didáctico, secuencia didáctica.

Abstract

This paper describes an academic experience that allows aligning competency-based education with the goals of the fourth indicator of the Sustainable Development Goals. The main purpose is to integrate 3D printing into technical and technological education to access employment, decent work and entrepreneurship. From the theory of cognitive constructivism, it uses gamification for the teaching of mathematics. The methodological design builds a bridge between the presentation of analytical knowledge (formulas and equations) and cognitive appropriation through 3D printed material. Thus, through direct observation through a checklist, the experience of a group of students was documented. The results provide evidence that the design and manufacture of 3D printed didactic material allows the systematic integration of mathematical content that students, whether they are children, young people or adults, use in daily or work activities, such as analysis and calculation. areas, volumes, ratios and proportions, as well as adjustments and tolerances.

Keywords: didactics, evaluation by competencies, didactic material, didactic sequence.

Resumo

Este artigo descreve uma experiência acadêmica que permite alinhar a educação por competências com as metas do quarto indicador dos Objetivos de Desenvolvimento Sustentável. O objetivo principal é integrar a impressão 3D na educação técnica e tecnológica para acessar o emprego, o trabalho decente e o empreendedorismo. A partir da teoria do construtivismo cognitivo, utiliza a gamificação para o ensino da matemática. O desenho metodológico constrói uma ponte entre a apresentação do conhecimento analítico (fórmulas e equações) e a apropriação cognitiva através de material impresso em 3D. Assim, por meio da observação direta por meio de um checklist, foi documentada a experiência de um grupo de alunos. Os resultados encontrados evidenciam que a concepção e fabricação de material didático impresso em 3D permite a integração sistemática de conteúdos matemáticos que os alunos, sejam crianças, jovens ou adultos, utilizam em atividades cotidianas ou de trabalho, como análise e cálculo. volumes, proporções e proporções, bem como ajustes e tolerâncias.

Palavras-chave: didática, avaliação por competências, material didático, sequência didática.



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Introduction

This work seeks to have a positive impact on the teaching of the concepts, applications and uses of mathematics in the area of engineering through the management of didactic material in order to carry out gamification activities and increase the cognitive domain of the contents of study: analysis and calculation of areas, volumes, ratios and proportions and adjustments and tolerances, which are cross-cutting topics in the curriculum of the engineering study plans.

Ignorance, during the planning of classes, of the concept of didactics and its confusion with that of pedagogy (Díaz, 2013a) often leads teachers of higher education institutions to consider that there is a high deficiency in institutional didactic material and that Large investments in facilities and equipment are required. This generates a limited teaching planning and lack of physical and practical representations (geometric shapes) of the equations or analytical functions that are used for learning engineering, technology or technique, for example: the determination of areas and volumes of simple and complex bodies, the use of ratios and proportions for quantities such as money, and adjustments and tolerances for the organization of objects. And it is that the construction of the logical-mathematical thinking of the students is strengthened through observation, imagination, intuition and logical reasoning. These are basic abilities that require the linking of basic abstract concepts such as number, geometry, space, magnitudes and measurement (Arteaga and Macías, 2016).

Therefore, the piecemeal integration of logical-mathematical thinking (implicit action in traditional teaching or the Socratic method) is a condition that limits the cognitive association between praxis/coordination and reasoning in mathematics. To minimize this effect, the teaching of mathematics must be approached from different perspectives. An example of this is the massive open online courses (MOOCs), developed by various institutions and authors, who use online digital resources oriented to reasoning, but without representations or didactic material, with physical manipulations or playful. For this reason, the present proposal is considered innovative because it takes advantage of 3D printing as an additional tool to digital online resources, which is more oriented to praxis/coordination (explicit knowledge) than to abstraction and synthesis (implicit knowledge).



At the international level, the United Nations Organization (UN), through the United Nations Development Program (UNDP), has formulated the Sustainable Development Goals (SDGs). SDG 4, “Quality Education”, aims to achieve inclusive and quality education for all. Of course, this type of education includes reading comprehension and mathematical problem solving as essential factors that guarantee the achievement of sustainable development (United Nations Educational, Scientific and Cultural Organization [Unesco], 2018). By innovating in the creation through the manufacture of didactic material, high cooperation is achieved with the objective in question, which seeks to ensure that free basic education is the standard for all girls and boys by 2030, because the areas, the volumes, ratios, proportions, adjustments and tolerances are part of the transversal education of every individual, which although this item increases its complexity with the passage of educational degrees, it maintains the same significance. As for engineering students, providing access to technical training relevant to their context, and thereby reducing gender inequalities and economic income, will be a benchmark for underdeveloped countries by increasing enrollment in higher education (Organization for Economic Cooperation and Development [OECD], 2018). Therefore, taking into account the above, it is identified that there is a problem of international scope:

- Globally, 6 out of 10 children and adolescents have low reading and math problem-solving skills, which has limited access to quality higher education (Unesco, 2018).

And in response to this, the goal has been defined in the following terms: "By 2030, considerably increase the number of young people and adults who have the necessary skills, particularly technical and professional, to access employment, decent work and entrepreneurship" (Unesco, 2018).

The main purpose of this project is the integration of 3D printing in technical and technological education to facilitate students' access to the world of work and entrepreneurship. Thus, it is intended to promote the strengthening of the cognitive process of children, youth and adults as students who demand quality instruction in mathematics. This through playful didactic material aimed at exposing explicit knowledge that allows children to increase their minimum competence in mathematics and young people and adults to strengthen their labor competence.

Currently, national and international accrediting bodies (World Bank, 2018; Engineering Teaching Accreditation Council [Cacei], 2018; OECD, 2018) urge mathematics



teachers to take greater initiative to implement context-based teaching strategies. rigid situational scenarios of the competency model, excluding the alternative of learning through playful scenarios that are configured through gamification.

It is essential that the teacher has methodological and infrastructure support to reinforce their didactics in a way that promotes learning based on the analysis and synthesis of problems, where the student finds himself in a scenario of challenges that leads him to a state of purposeful concretion. , based on heuristics and self-learning of the parts (abstraction-manipulation) that are sequentially integrated to form a device, machine or system. However, at present, the didactic material required to use competitive teaching strategies is insufficient, is oriented only to the digital resource on the Web or is non-existent in institutions such as indigenous rural schools that lack electricity.

It is the responsibility of the institutions to provide sufficient resources to the teacher and the student so that they can develop their cognitive skills (table 1). It is an action that is projected as viable as long as there is funding and the establishment of emerging programs of educational innovation so that students become familiar from their own practice/coordination with reasoning skills and excel in higher education. or in the labor and occupational sphere, as stated in the goal of the fourth SDG.

From the documentary information analyzed, it was identified that even with the high capacity of instructional-procedural education of gamification, the cognitive elements of a system must be integrated to achieve the improvement of know-how, since abstraction accumulates and integrates as part of students' cognitive reasoning.

Tabla 1. Definición de habilidades cognitivas

Capacidades cognitivas	
Praxia/coordinación	Secuencia de movimientos sistematizados y secuenciales.
Memoria	Identificación de información (instrucciones) o hechos (procedimientos) previos a una nueva acción (evidencia).
Atención	Selección de los mínimos elementos para realizar una acción o actividad compleja.
Razonamiento	Establecimiento de un orden jerárquico entre actividades simples que se orientan a la creación de una evidencia.
Percepción	Interpretación del contexto a través del estímulo de los cinco sentidos del ser humano.

Fuente: CogniFit (2018)

An important consideration is that the teaching of gamification should not be applied massively and should be highly differentiated according to the learning styles of the students, especially in the creation/production of teaching material. In the bibliographic review of previous works, it was identified that the same traditionalist instruction (Socratic method) should not be applied in all situations, since learning can be both significant and, in an adverse situation, null. For this reason, it is also not possible to oppose the same traditional pedagogical methods —explanation, illustration or reproductive method—, since they precede the instructional sequences and have historically been functional (Skatkin and Kraievsky, 1978).

As an alternative to gamification and traditional education, for example, Juliao (2014) mentions praxeological pedagogy, which could be considered as a strategy for teaching mathematics and technical and technological education. From the perspective of the logic that precedes action, the development of didactic material for the teaching staff in higher education institutions is favored. Therefore, it is a relevant opportunity to support the achievement of the goals of the fourth SDG. However, by prioritizing the use of educated and complex logical reasoning, the valuable contributions of simple teaching are omitted or excluded.

Therefore, educational organizations specializing in engineering and technology should promote inclusive training (knowledge-action-execution), which should be interpreted as a reasonable succession of facts from simple didactic components aimed at



closing the gap between knowledge, analytics and their application in the technological context, such as mathematics and 3D printing, harmonizing a new compendium of knowledge and simultaneous and integrated actions. Focusing the application of mathematics on specific use cases such as the calculation of areas, volumes, ratios, proportions, adjustments and tolerances, whether in engineering, technology and technique or in another area of knowledge, implies a jump in quality with high relevance that moves away from discourse and approaches action (Bartlett and Benavides, 2016). Thus, in addition, elements of solution are provided to the dilemma caused by the excess of fragmented scientific knowledge, which disarticulates the abstraction of the technique in the student's reasoning when it is necessary to apply it in the labor sector. This dissociation is properly put on trial when students do not have a solid foundation in mathematics: a deficient formation of know-how throughout their lives, which, being transversal, is unfinished and permanently perfectible.

In this work it is considered that mathematical topics such as the identification, calculation and use of areas and volumes; ratios and proportions, and adjustments and tolerances are transversal generic skills whose mastery is given throughout life and with the obtaining of academic degrees. Next, with the support of Mochón's proposal (2012), the different uses of competence to which we refer here are clarified:

- 1) For the development of a child in his environment, it is important that he can identify and know the areas and volumes of simple geometric figures, such as the triangle and the rectangle, which are integrated to form complex geometries such as the trapezoid.
- 2) Also, for children, learning about ratios and proportions is essential, since it allows them to live in a respectful and equitable manner during their daily lives. The equitable distribution of food, family income and responsibility for housework are experiential examples of application.
- 3) The adjustments and tolerances are essential for daily dress, the size of shoes and clothes, as well as the approximation between the purchase of a change of clothes and another throughout the growth of the child—to consider adequate wear—is very important to keep the family economy healthy.
- 4) For youth and adults, knowledge of the areas and volumes is relevant for technical training. A construction technician (bricklayer), a metalworking technician (turner-



miller) or a graphic design technician (interior designer) requires mastery of areas and volumes to carry out their work efficiently and effectively. A professional in this area without command of space in two and three dimensions may see his accessibility to the world of work significantly reduced; on the contrary, mastery of space in two and three dimensions increases work qualification, since this know-how allows minimizing waste and maximizing productivity.

- 5) The ratios and proportions allow young people and adults in technical training to be able to undertake innovative actions and activities. Its ability to estimate the reduction of waste and the systematization of production processes means that the technician in training and the contracted technician are recognized as workers with high aptitude and attitude towards change and updating processes.
- 6) Adjustments and tolerances are the analytical elements that allow young people and adults to efficiently carry out repairs and adjustments in the manufacturing and production processes of products, whose commercial success depends on quality and customer satisfaction.

Conceptual elements

A particular objective is to strengthen the cognitive process of children, young people and adults (such as students) through the development of didactic material through 3D printing, in a way that promotes their reasoning capacity through praxia/coordination and encourages learning. heuristic learning using gamification, to develop playful teaching-learning contexts and attending to the diversity of learning styles.

Simultaneously, sufficient didactic resources (analytical and hardware) are developed to develop specific performances that allow children to increase their minimum competence in solving mathematical problems and for young people and adults their competence and job qualification through the improvement and optimization of the quality of its finished products.

The approach of the specific objectives has been determined from the following reflection questions that were formulated through the exposed challenges and the experience of the solutions implemented during the manufacture of didactic material through 3D printing.



- 1) Is it possible that through the development and use of didactic material for teaching mathematics (areas and volumes) manufactured by means of 3D printing, it is possible to strengthen the spatial cognitive process and praxis/coordination, which reinforces reasoning in children? , youth and adults?
- 2) Through the use of ratios and proportions didactic material manufactured by 3D printing in children and young people, can the student relate their employability and use in the social responsibilities of coexistence assigned (sense of equity and fair distribution of resources)?
- 3) Through the teaching of mathematics with the use of didactic material of adjustments and tolerances printed in 3D, will young people and adults be able to increase their satisfaction with the needs of clothing, housing and economic retribution?

The specific objectives that were derived from the reflection questions focus on the fulfillment of the mathematical skills used when solving self-actualization/work problems.

- 1) Improve the geometric and spatial understanding of the analytical concept of area and volume.
- 2) Relate ratios and proportions to the student's daily activities.
- 3) Involve the use of adjustments and tolerances with survival needs: clothing, housing and salary.

During the deduction of the reflection questions, it was identified that in the new educational models at the higher level (Meritorious Autonomous University of Puebla [BUAP], 2007) and upper secondary level (General Directorate of Training Centers for Work [DGCFT], 2015) the use of instructional didactic sequences for the teaching of mathematics has been proposed—product of the formative rigidity suggested by national organisms, the Ministry of Public Education (SEP), for example, and international organizations such as the OECD that issue recommendations based on the model of competencies with pedagogical support of constructivism—as elements of the didactics of basic, upper secondary and higher education, without the pertinent didactic resources. However, in practice it has become an unfinished strategic action that limits heuristic learning and implies a limitation of the cognitive abilities of students and the fulfillment of educational goals in children and employment goals in youth and adults.

The specific objectives address the immediate (local) problem that derives from the international problem exposed by the fourth SDG, the lack or absence of a didactic based on



heuristics and the relevant didactic material for teaching mathematical problem solving. This unfavorable condition results in a weakness and threat to the fulfillment of the commitment of national coverage to offer quality education in educational institutions at both the basic and upper middle and higher levels.

The assumption that was arrived at from the above is: if 3D printed teaching material is developed to simplify the teaching of mathematics from the perspective of gamification, then the participant/student modifies their aptitudes and attitudes towards learning. heuristic and autonomous mathematics through teaching resources that improve the conceptual reinforcement of skills for calculating area, volume, ratios, proportions, adjustments and tolerances.

During the transmission of the experience of this work to a group of higher level students, it has been identified that, without the adequate/pertinent didactic material, each requirement/sequence/proposed didactic instruction is limited by the diversity and will of the processes and actors. education, especially when knowledge is generated in the innovation of the teaching of professional profiles —considering that education is increasingly seen as combined with social responsibility that seeks to promote access to decent employment and entrepreneurship—, because the cognitive gap between educational performance and work performance is increased by the cognitive dissociation of abstraction-praxia reasoning.

The association between the specific objectives and the general objective consists in the manufacture of didactic material through 3D printing to improve the teaching of the diversity of mathematical-analytical representations frequently used in the curriculum of higher education institutions. This action will allow estimating attributes, indicators that are used/validated as criteria of relevance to favor access to higher education and employment in favor of continuous improvement in the local, regional, national and international quality of life, which are the goals set for 2030 (UN News Centre, September 25, 2015).

As part of the search and identification of bibliographic references for this experience, the concept of didactic sequences, the projection of use and application through practical cases and the use of pertinent didactic material have been prioritized. In the bibliographic background review, the analysis of documents that reported significant findings of case studies was prioritized and not a hermeneutical analysis. The scope has been determined political-sustainable-social by the implications of education in the development of the spheres described below:



- *Political, due to the nature of education that is framed in article 3 of the Constitution.*
- *Social, due to the implications of solving mathematical problems in the development of society.*
- *Sustainable, for strengthening the preservation of humanity through the innovation of survival practices.*

Regarding the tools and instruments to incorporate the didactic material, Díaz (2013a) comments that the didactic sequences have the purpose of organizing the learning situations that will be developed in the work of the students, regardless of whether their definition is approached from different perspectives. approaches. For example, the constructivist, where it is interpreted as an articulated set of learning and evaluation activities that, with the mediation of a teacher, seek to achieve educational goals.

From the socioformative approach, the didactic sequence is established as an instrument that plans systematized and sequential activities, daily or by project, that favor the intervention of the teacher who is a designer of didactic material and of the teacher in front of the group. In this way, teaching-learning transformations are articulated in favor of increasing educational quality, which includes an adequate dosage of time and spaces for pedagogical help to the group by external specialists.

Finally, from the humanistic approach, the didactic sequence implies the ability to act inclusively in the face of activities and problems in the context, with suitability and ethical commitment, integrating knowing, knowing-doing and knowing-being in a perspective of continuous improvement.

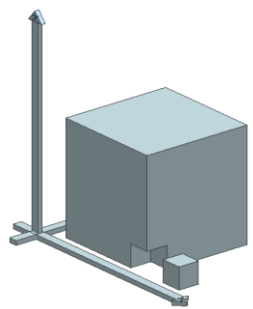
Regarding the use and application of didactic sequences to configure learning situations, Venegas and Díaz (2017) comment that they are a great opportunity to contribute to the development of knowledge, skills and attitudes, but with the support of didactics as a science, which provides the fundamentals for the development of relevant and innovative teaching material.

In this work it was motivating that students and teachers have collaborated in a multidisciplinary way in the development of didactic prototypes (figures 1, 2, 3 and 4), because this brought a greater and better conceptual understanding in students (autonomous work innovative) and closer work with teachers (academic collaborations), coupled with closer and more productive interaction (Hodson, 1992, cited in Gil et al., 2005).



For the transmission of the experience, 3D printed didactic elements have been used, such as the representation of a large volume defined geometrically and that of a small volume that represents a volume differential proportional to the total volume (figure 1). In this first moment, analytical relationships are imitated and conceptual reasoning is favored.

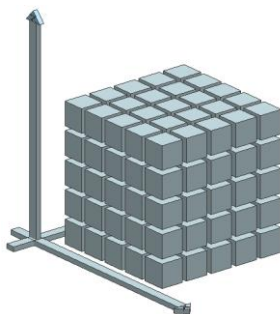
Figura 1. Representación de un volumen y su diferencial de volumen



Fuente: Elaboración propia

Figure 2 represents the association of a geometric body segmented in volume differentials with its analytical representation by means of a triple integral, which has the purpose of providing the total volume of the volume differentials as a result.

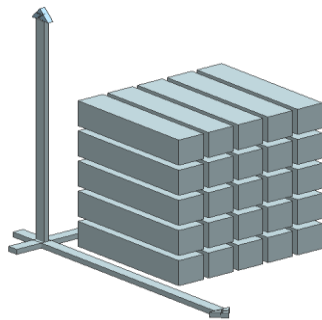
Figura 2. Representación del material didáctico de la integral $\iiint dy dz dx$



Fuente: Elaboración propia

Figure 3 shows the same triple integral to determine a total volume with the variation of volume differentials, an analytical condition of great recurrence in the teaching of integral calculus.

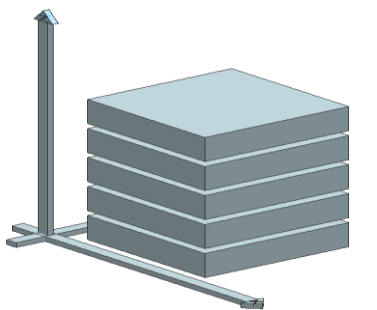
Figura 3. Representación del material didáctico de la integral $\iiint x \, dy \, dz$



Fuente: Elaboración propia

Figure 4 is the geometric representation of the same triple integral with different volume differential. This sequence exposes the student to practical reasoning about the same analytic representation with variations in limits. Likewise, it is possible to verify aspects such as precision and different resolution times for the same abstract concept.

Figura 4. Representación del material didáctico de la integral $\iiint xy \, dz$



Fuente: Elaboración propia

Theoretical orientation

To understand gamification in a simple way, various authors have concurred to visualize it as a technology that allows the use of game mechanics and techniques (ludic) in diverse contexts such as academic and work (Encalada, 2021; Liberio, 2019; Zepeda, Abascal and López, 2016).

From the perspective of playful teaching, gamification is considered as an emerging and alternative pedagogical-didactic strategy when there are limited abilities to solve everyday problems on the part of students and that deprive the acquisition of meaningful learning and conceptual cognitive development (Encalada, 2021).

Regarding the generation of didactic material using gamification as a pedagogical guide, it is considered that the purpose and importance lie in proposing innovative didactic strategies, for example, the representation of interpretations of abstraction (figures 2, 3 and 4) —through of 3D printing—in three dimensions of a length (line integral $\int dx$), an area (double integral $\int dx dy$) or a volume (triple integral $\int dx dy dz$), What are the purpose of learning materials in technical or technological education? (Alvarado, de la Cruz y García, 2005).

A viable alternative that allows promoting playful environments is the incorporation of computer-aided design (CAD), computer-aided manufacturing (CAM) and computer-aided engineering (CAE) systems. All three are three-dimensional modeling tools (analytically parameterized geometries through mathematical expressions) for the design of manufacturing or assembly drawings (Rodríguez, 2007).

Through direct observation and the use of a checklist, it was confirmed that students are capable of associating abstract academic knowledge with work applications. The foregoing favored both the teacher and the student in their performance and decision-making related to their professional training by competencies. The association also allows students to increase their accumulation of academic knowledge through experiential scaffolding, which is favored by constructivist theory, through the application of problem-based learning and project-based learning (Salinas, 2012). Regarding the evaluation of the didactic sequences, Pimienta (2011) and Tobón, Pimienta and García (2010) consider that the best alternative is through rubrics. And the cases where they apply can be:

- a) *Initials, when it is determined as a product of teaching and the adoption of learning.*
- b) *Follow-up, by leading the student's motivation to the benefit he pursues as learning.*
- c) *Consolidation, which link the learning content with social practice and stimulate the evaluation of the school by the student in the workplace.*

Regarding the design of didactic material, gamification is a set of innovative tools and instruments that present the complexity of abstract and analytical knowledge in a simple and concurrent way. This work considers that the pedagogy of constructivism is limited in its impact, due to the scarce didactic material that educational organizations have. For this

reason, it is essential to innovate in academic planning (playful didactic sequences), but also in execution (gamified contexts, media and resources) to reduce the academic-labour gap.

Although traditional and competency-based teaching denote a reliable construction process that profoundly modifies the cognitive system of individuals, it is detrimental to minimize the importance of other forms of learning such as praxis through play.

In the bibliographic review it has been found that to increase the quality of teaching, teachers require extensive support of teaching material, organized by the systematization and sequence of the manufacture/elaboration of both tangible and pragmatic technical or technological evidence (Skatkin and Kraievsky , 1978). Reason why the design and development of didactic material with a multidisciplinary orientation is necessary and indispensable.

Research in the teaching of mathematics documents that students perform better in those lessons where the theory is observed with applied examples and enough exercises (Rouquette and Ariza, 2007). On the other hand, the performance is very low when there is only the theoretical part and there are no examples with its application. For this reason, this document presents a teaching-learning experience with the support of a didactic material that integrates praxis/coordination and reasoning, where the professional in training can consult/manipulate the information associated with a class (previously or later) when Entrust him with the demonstration of verifiable academic productivity in evidence of learning mediated by technology, specifically 3D printing, which often allows interaction with hardware elements.

Methodology

The method used is descriptive. The transmission of an academic experience to a group of participants (students) who interact in a guided way with a 3D printed didactic material that represents analytical abstractions of the calculation of areas, volumes, ratios, proportions, adjustments and tolerances is described.

During the execution, six direct observation items typified by an Osgood scale were used in a checklist, which is used as a data collection instrument.

It was directly observed throughout the implementation of the didactic material as a support for the understanding of abstract concepts of mathematics in students of higher

education in engineering. In this process, the modification by appreciation of the students' attitudes before and after the presentation and use of the didactic material stood out. Thus, an assertiveness criterion was formed in the playful learning process that favored complex reasoning.

As the academic experience was exploratory, before the collective execution of the proposed strategy, the following implementation procedure was formalized.

- *Introduction to the generalities of the project by means of a presentation of five slides that show the objective and purpose of the didactic material produced.*
- *Explanation of the geometric representation of areas and volumes (perfect square binomial, perfect cube binomial, line integral, area integral and volume integral).*
- *Presentation of the teaching material and its relationship with the mathematical equation with slides. Participants are asked to solve the proposed exercises with the support of the didactic material.*
- *Manipulation of teaching material on the geometric representation of areas and volumes (perfect square binomial, perfect cube binomial, line integral, area integral and volume integral).*
- *Collection of data assessed in tables (emptying information from the checklist)*
- *Analysis of the information collected by the checklists by descriptive statistics.*
- *Interpretation of the results and presentation of the report.*

Figure 6 shows the checklist to collect information by direct observation, which is applied to each participant once they start working with the 3D printed teaching material, and which collects the level of aptitude based on the following Osgood scale, which documents the transition of the student's attitudinal capacities from the evaluator's approach and interpretation:

Less -3 -2 -1 0 1 2 3 More

The use of the Osgood scale in the checklist has been selected because, through the evaluation of multiple items that have opposite adjectives, it allows obtaining a clear and simple qualification that is used to understand the attitudes or feelings of respondents to an event, and thus a response associated with the object that represents it is acquired.

Figura 6. Lista de cotejo para observar cambios de aptitud

PARTICIPANTE:								
Memoria								
MEMORIA NO VERBAL								
Baja capacidad para retener la representación de equivalencia analítica y geométrica								Alta capacidad para retener la representación de equivalencia analítica y geométrica
Atención								
ATENCIÓN FOCALIZADA								
Baja capacidad para prestar atención a los detalles de ensamble de los materiales didácticos								Alta capacidad para prestar atención a los detalles de ensamble de los materiales didácticos
Coordinación								
TIEMPO DE RESPUESTA								
Baja motivación para trabajar conjuntamente expresiones analíticas y representaciones geométricas para resolver problemas de ecuaciones								Alta motivación para trabajar conjuntamente expresiones analíticas y representaciones geométricas para resolver problemas de ecuaciones
COORDINACIÓN OJO-MANO								
Lenta reacción de motricidad al tener un bloqueo analítico y recurrir al material didáctico para abordar el problema desde otra perspectiva								Rápida reacción de motricidad al tener un bloqueo analítico y recurrir al material didáctico para abordar el problema desde otra perspectiva
Razonamiento								
FLEXIBILIDAD COGNITIVA								
Torpe reacción de pensamiento para pasar del manejo del material didáctico a la representación analítica, para determinar la solución								Ágil reacción de pensamiento para pasar del manejo del material didáctico a la representación analítica, para determinar la solución
VELOCIDAD DE PROCESAMIENTO								
Lenta reacción medida en tiempo para reconocer patrones visuales simples								Rápida reacción medida en tiempo para reconocer patrones visuales simples

Fuente: Elaboración propia

In the development of the direct observation of the participant, it was considered that the variables to pay attention to were the praxis/coordination cognitive abilities (as dependent elements) and the Reasoning variable (as an independent element). In both cases, continuous quantitative variables are considered due to the need to measure the use of praxis/coordination and the use of reasoning (Table 2).

The measurement scale is ordinal, since the data is classified into categories that can be hierarchized into greater and lesser reasoning and greater or lesser praxis.

The data collection was carried out by the teacher on duty. It should be noted that it was estimated in person during the execution of the transfer of the experience due to the nature of the test, which consists of the identification of aptitudes and attitudes through the alignment of common goals, that is, the resolution of mathematical problems. in a simple way.



Tabla 2. Relación de variables

Unidad de análisis	Actitud	Aptitud
Tipo de variable	Ordinal	Ordinal
Elementos lógicos	Cuanto mejor es el diseño del material didáctico...	Tanto más mayor es...
Variables	Independiente: se favorece/fomenta el uso de la praxia/coordinación	Dependiente: el razonamiento para la resolución de problemas matemáticos

Fuente: Elaboración propia

As support to operationalize the variables, and following Liberio (2019) and Zepeda et al., (2016), the following subcategories of the variables were identified.

Praxia/Coordination

- *Non-verbal memory: ability to react implicitly to stimuli that come from the five senses or means of perception of the human being in the face of learning phenomena or events.*
- *Focused attention: the brain's ability to focus attention on an objective stimulus, regardless of the duration of said fixation.*
- *Response time: ability to perceive a simple stimulus and respond to it.*
- *Eye-hand coordination: competitive sufficiency that an individual achieves through the repetition of motor reactions elicited by visual stimuli.*

Reasoning

- *Cognitive flexibility: a person's willingness to react favorably or not favorably; generate response skills to unforeseen events.*
- *Processing speed: speed with which a person defines how to react to unexpected situations. It is the characteristic that enhances the qualities of an individual.*

The results of direct observation of the transfer of experience (figure 7) indicate that students show a high willingness to transition from the abstract study of mathematics to the playful manipulation of didactic material.



Through the gamification strategy and the use of 3D printed teaching material, the group of students showed an adequate command of the relationship between abstraction and the conceptual manipulation of hardware; a pertinent reasoning of the analytical equations and their final application/use in daily/work activities, which may well be the product of memorization. When verbalizing the experience with their classmates, similar coincidences were found in the conclusions of the activities, therefore, it is possible to affirm that the task provides significant learning.

The results obtained from direct observation indicate that the participants show a disposition towards self-reflection on their knowledge of the analytical equations and their corresponding physical representations (the area, volume, ratios, proportions, adjustments and tolerances), for which it is declaring as Satisfactory performance on the execution/manipulation carried out in the transfer of the experience.

Developing

The interpretation of the aptitude evaluation, planned through the simple average, distinguishes as a relevant factor the disposition of the students to carry out the instructional activities. This recognition represents an independent dimension to those declared as study variables in this work, which should be incorporated in future works to further specify the interpretation of the meaning of improving educational quality.

Figura 7. Comportamiento de la evaluación de aptitud

MEMORIA							
Baja capacidad para retener la representación de equivalencia analítica y geométrica						*	Alta capacidad para retener la representación de equivalencia analítica y geométrica
ATENCIÓN							
Baja capacidad para prestar atención a los detalles de ensamble de los materiales didácticos						*	Alta capacidad para prestar atención a los detalles de ensamble de los materiales didácticos
COORDINACIÓN							
Baja motivación para trabajar conjuntamente expresiones analíticas y representaciones geométricas para resolver problemas de ecuaciones						**	Alta motivación para trabajar conjuntamente expresiones analíticas y representaciones geométricas para resolver problemas de ecuaciones
Lenta reacción de motricidad al tener un bloqueo analítico y recurrir al material didáctico para abordar el problema desde otra perspectiva						**	Rápida reacción de motricidad al tener un bloqueo analítico y recurrir al material didáctico para abordar el problema desde otra perspectiva
RAZONAMIENTO							
Torpe reacción de pensamiento para pasar del manejo del material didáctico a la representación analítica, para determinar la solución						*	Ágil reacción de pensamiento para pasar del manejo del material didáctico a la representación analítica, para determinar la solución
Lenta reacción medida en tiempo para reconocer patrones visuales simples						*	Rápida reacción medida en tiempo para reconocer patrones visuales simples

Fuente: Elaboración propia

The graphic sequence shows the follow-up of the transfer procedure of the experience to the group of students.

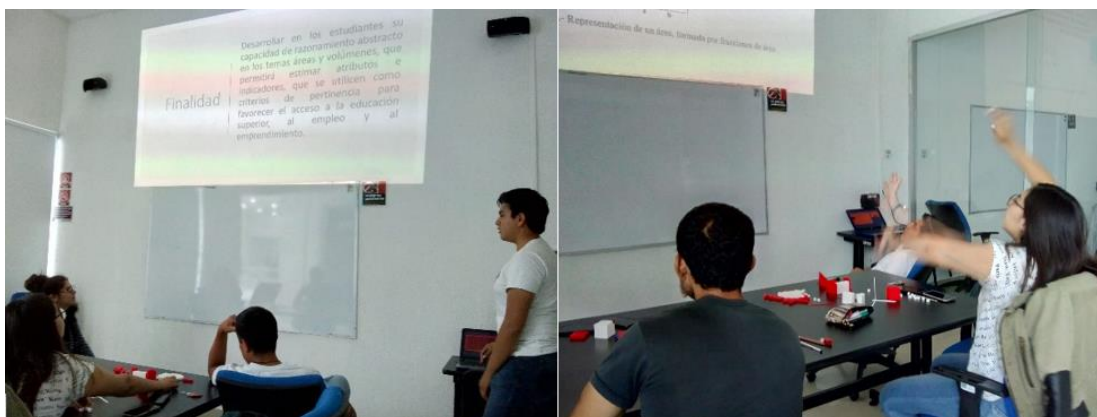
Figures 8 and 9 show the phase of the introduction and explanation of the generalities of the project by means of a slide presentation that shows the objective and purpose of the didactic material carried out.

Figura 8. Introducción a las generalidades del proyecto



Fuente: Elaboración propia

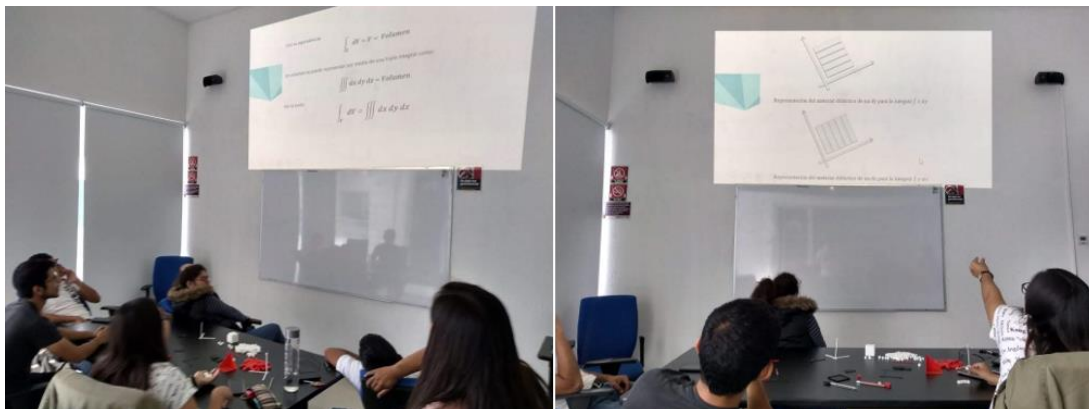
Figura 9. Presentación de diapositivas con generalidades del proyecto



Fuente: Elaboración propia

Figure 10 is a visual testimony of the presentation of the didactic material and its relationship with the analytical equation. At this time, the participants are asked to solve a set of exercises proposed with the support of the didactic material that involves the topics perfect square binomial, perfect cube binomial, line integral, area integral and volume integral.

Figura 10. Presentación del material didáctico y su relación con la ecuación matemática



Fuente: Elaboración propia

Figure 11 is a graphic sample of the manipulation of the didactic material on the geometric representation of areas and volumes through the topics of perfect square binomial, perfect cube binomial, line integral, area integral and volume integral.

Figura 11. Demostración del uso de material didáctico y trabajo con prototipos impreso en 3D



Fuente: Elaboración propia

Both the collection and the analysis and interpretation are executed continuously throughout the duration of the session, which was scheduled for two hours (figures 8, 9, 10 and 11). Regarding this factor, the students did not show gestures or postures of boredom or tiredness.

Results

The information generated (figure 7) allows validating the proposal to integrate didactic sequences based on gamification and previously elaborated for the teaching of mathematics, from the logical and formal perspective of content organization with the support of 3D printed didactic materials.

- The performance measurement items indicated that the participants show a greater cognitive capacity, to recognize their improvement in the performance of the evaluations on the geometric representations of the analytical equations in which they participate (Memory).
- The aptitude measurement items revealed that the tendency towards the favorable semantic differential is high, identifying aptitude improvements (Attention).
- The items related to the instruction show a notable improvement in the conceptualization of geometric representations from mathematical expressions and vice versa. The indicator that reflects this is the increase in the number of correct answers in the exercises addressed, if the comparison between the results is made. of the diagnostic evaluation and the evaluation after the instruction individually, in a group way, an increase in the arithmetic mean of the diagnostic evaluation was obtained from 3.5 to 4.8 correct answers in the evaluation after the instruction (Coordination).

The consistency of the results during the direct observation has exposed during the abandonment of the traditional learning method (pencil and paper) for the resolution of mathematical problems, it indicates that the proposal is viable and with a high degree of applicability during the collaborative repetition of the resolution. of problems in ludic scenarios that involve 3D printed didactic material (Reasoning).

Discussion

Gamification is linked to higher education through playful environments that emulate everyday or work situations, but, unlike these, insert supports (sequences and teaching materials) that motivate students to improve their dedication and efficiency and offer a space for that leaders emerge naturally (Guzmán, Escudero and Canchola, 2020).



During the development of the transfer of the experience, low motivation attitudes and apathy to participate in the mathematics teaching workshop using 3D printed teaching material were identified at the beginning.

The initial presentation through slides favored the beginning of a first change of attitude and promoted interest in the association of abstract knowledge with technology. The direct manipulation focused the students' attention on a work context, which clarified the application of academic procedures as a solution to professional problems. Finally, in the evaluation stage, it was observed how the handling of the 3D printed didactic material promoted confidence in the responses of the participants before an exam applied to verify learning. Figures 8, 9, 10 and 11 formalize a system of actions that contributes to enhancing skills to establish relationships between mathematical knowledge and communicative and reflective skills, while attending to the individual differences of students. (Hernández, Valdés, y Navarro, 2021).

It is extremely important that students from their professional academic training are instructed in the innovation of didactic material projects that can link school with life and work and that have an approach to science, culture, politics, among other areas (Díaz, López, Heredia and Rodríguez, 2013), because motivation is a factor derived from gamification that expresses the existence of two types of intrinsic and extrinsic motivation (Encalada, 2021).

In short, there is no specific way in which the teacher can work the competency-based education approach in an inclusive manner. It is necessary that their capacities be directed from an approach that defines and clarifies the generation of evidence of learning relevant to the occupational/labour reality, which in a strict sense underpins the principles of didactics and, in particular, from the approach of a new didactics. (Zepeda et al., 2016). In this work, the didactic sequences (Díaz, 2013b) are conceived as a script proposal to indicate the instruction of playful activities and as the best innovative alternative for teaching through gamification, since the systematic review of gamification has a significant impact on the academic performance of the students when using pertinent cognitive parameters that organize the gamification procedures that the teacher permanently accompanies (Holguín, Holguín y García, 2020).

Conclusions

The relationship between the variables is high because the conditions are met: the better the praxia/coordination through the use of 3D printed teaching material, the greater the reasoning for solving mathematical problems.

Thus, thanks to the design and use of 3D printed teaching material as a teaching strategy through gamification, students developed a better capacity for abstract reasoning in the following topics: areas, volumes, ratios, proportions, adjustments and tolerances. As a finding, it was found that an attribute that can evolve as a criterion is the personal satisfaction of performance in each activity carried out and another one is the observation of a greater attitude and willingness to learn to solve mathematical problems when 3D printed teaching material is used. , which favors access to higher education, employment and entrepreneurship.

The scope of the specific objectives, namely, to improve the understanding of areas and volumes, to relate ratios and proportions and to involve the use of adjustments and tolerances, is sufficient evidence to affirm that it is possible to reduce the cognitive educational gap between praxis / coordination and reasoning.

The general objective was achieved satisfactorily, since, by transmitting the experience of the researcher to the students, the integration of 3D printing in technical and technological education has been achieved to access employment, decent work and entrepreneurship, from the theory of cognitive constructivism, and using gamification to solve mathematical problems.

As an academic impact, the didactic material created to date is a resource that seeks followers day by day. To this end, the appropriate forums are used for its disclosure and dissemination. The acceptance shown by the academic community to the proposal presented (students and teachers) is convenient. The willingness of academics to emulate the experience in their own groups and institutions is highlighted.

Regarding the personal motivation achieved, new prototypes of greater complexity are experimented with, which associate both analytical knowledge and the technological formulation of physical behaviors and concur in evidence of learning that has the purpose of emulating the daily/work reality.

In turn, regarding the economic impact, the economic compensation generated as a direct impact consists of the best use of the resources invested for education by higher education institutions, as well as the improvement in the development of productive capacities for the realization of educational tasks and of daily use. Likewise, when each of the students joins the labor sector, good mathematical reasoning leads to assertive decision-making, which results in better use of resources and minimization of waste and failures.

Future lines of research

The formal possibility of applying 3D printed mathematical representations as a didactic resource at the basic educational level is analyzed, where a control group and an experimental group can be integrated, an experiment that establishes significant differences for the curricular updates of the study plans. . At the same time, formalize the implementation of an institutional workshop for the development of teaching material in higher education institutions. It is an alternative to contribute to the acquisition of own resources and provide the opportunity to offer maquila to other educational institutions that do not have the minimum resources for the implementation of their own rapid prototyping and 3D printing workshops.

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