Pedagogía y Sociedad
UNIVERSIDAD DE SANCTI SPÍRITUS José Martí Pérez
ISSN: 1608-3784 RNPS: 1903

Recibido: 11/9/2023, Aceptado: 19/12/2023, Publicado: 10/1/2024
Volumen 27 | Número 69 | Enero-Abril, 2024 |

[Translated article]

Methodology for competency-based learning of Physics-Mathematics students

Metodología para el aprendizaje, por competencias, de estudiantes de Física-Matemática

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How to cite this article (APA, Seventh Edition)

Herrera Castrillo, C. E. (2024). Metodología para el aprendizaje, por competencias, de estudiantes de Física-Matemática. *Pedagogía y Sociedad, 27*(69), 126-148. https://revistas.uniss.edu.cu/index.php/pedagogia-y-sociedad/article/view/1717

ABSTRACT

Introduction: This article deals with the design of a methodology for the competency-based learning of students majoring in Physics-Mathematics.

Objective: To propose a methodology for competency-based learning of students majoring in Physics-Mathematics, using the interdisciplinary approach technology.

Methods: The research was developed under an interpretative paradigm, a predominantly qualitative mixed approach, with a sample of 75 students, six teachers and one Mathematics-Physics degree coordinator. The instruments for data collection were: interviews with teachers and academic authorities, semi-structured questionnaire and focus group with students, classroom observation guide and document review.

Results: The implementation of competency-based learning methods proves to be very useful in teaching and has achieved satisfactory results in the acquisition of both knowledge and skills.

Conclusion: The study evidences the need to implement a methodology for competency-based learning of students majoring in Physics-Mathematics. In addition, it highlights the importance of strengthening the use of technological resources by teachers and the value of competency-based learning methods to improve teaching and learning in this area.

Keywords: competencies; learning; mathematics; physics; students

RESUMEN

Introducción: Este artículo trata sobre el diseño de una metodología para el aprendizaje, por competencias, para estudiantes de la carrera Física-Matemática.

Objetivo: Proponer una metodología para el aprendizaje, por competencias, para estudiantes de la carrera Física-Matemática, utilizando tecnología en enfoques interdisciplinarios.

Métodos: Se trabajó bajo un paradigma interpretativo, un enfoque mixto con predominancia cualitativa. Se contó con una muestra de 75 estudiantes, 6 docentes y un coordinador de carrera de Física-Matemática. Los instrumentos para la recolección de datos fueron: entrevista a maestros y autoridades académicas, cuestionario semiestructurado y grupo focal a estudiantes, guía de observación a clases y la revisión documental.

Resultados: Conducen a que la implementación de métodos de aprendizaje, por competencias, es de gran utilidad en la enseñanza y ha logrado buenos resultados tanto en el desarrollo de conocimientos como de habilidades.

Conclusiones: El estudio evidencia la necesidad de implementar una metodología para el aprendizaje por competencias, en estudiantes de la carrera Física-Matemática. Además, se destaca la importancia de fortalecer el uso de recursos tecnológicos por parte de los docentes y se resalta el valor de los métodos de aprendizaje, por competencias, para mejorar la enseñanza y el aprendizaje en esta área.

Palabras clave: aprendizaje; competencias; estudiante universitario; física; matemáticas

Introduction

Worldwide, globalization brings with it changes in lifestyles. In 2020, the National Autonomous University of Nicaragua (UNAN-Managua, Spanish acronym) initiated a curricular transformation, adopting a competency-based approach. This allowed the implementation of various methodologies focused on meaningful and quality learning, with the purpose of preparing students for the world of work. The changes included the organization of curricular components into career-specific axes, instead of subjects, and the modification of the evaluation system, which is now based on a scale of 2 to 5 (UNAN-Managua, 2020).

In this context, a pilot study was carried out on a methodology for competency-based for any subject or component of the Physics-Mathematics major. The objective was to provide teachers and students with tools to facilitate learning, both in face-to-face sessions and in independent study. In addition, the aim was to improve communication between teachers of different subjects and to address the difficulties that students faced due to the lack of solid mathematical knowledge (Herrera Castrillo, 2023a).

The proposed methodology is based on competencies and seeks to promote the development of knowledge, as well as to awaken interest and motivation for Mathematics and Physics. In addition, it is expected that this research will lay the foundations for future studies and contribute to the development of a competency-based curriculum in Higher Education. The methodological value of this work is highlighted, since it presents the necessary steps to implement the proposal in a logical and integrated manner (Jara Gómez, 2023).

The methodology can be adapted to different areas of knowledge, such as engineering, education, economics, among others. The use of Information and Communication Technologies (ICT) in the learning of Mathematics and Physics has been a challenge, it is evident that the incorporation of simulators and mathematical assistants motivates students and improves results. In addition, the feasibility of this research is highlighted thanks to the institutional support, the available human resources and the active participation of students in decision making (Herrera Castrillo, 2023a).

In summary, this study proposes a methodology for competency-based learning for Physics-Mathematics students, using technology in interdisciplinary approaches.

Theoretical framework or conceptual references

Learning implies lasting changes in a person's behavior and skills, resulting from experience (Feldman, 2010).

In the university of the 21st century, it is necessary to rethink the ways of functioning in response to new educational paradigms, technological advances and epidemiological situations (Suárez Soza, 2022).

Learning is a complex and multifaceted process, influenced by internal and external factors, as well as by social, historical, political, cultural and dialectical interaction. It highlights the importance of a student-centered approach and meaningful learning, adapting to generational changes and new technological conditions (Anonymous author cited in Jarquin Matamoros, 2021).

To achieve meaningful learning in university students, it is necessary to make reforms both at the individual level and in the subjects addressed. According to Ausubel and Vygotsky (as cited in Pozo, 2006), explicit and formally structured instruction that presents information clearly is required. Learning should be analyzed from a vertical and horizontal perspective (Figure 1):

Figure 1: *Learning Axes*

Source: Pozo, 2006 (p. 78)

Globalization has driven an educational approach focused on the development of competencies, which are considered dynamic attributes that combine knowledge, skills, attitudes and responsibilities, in addition to describing the learning outcomes of an educational program. Their use in education allows teachers to focus on the learning process and adapt curriculum planning to the individual needs of students, preparing them for quality jobs (Anderson et al., 2022).

Interdisciplinarity is crucial in current scientific progress, and universities must integrate it into the teaching process, particularly to link Mathematics and Physics, promoting the development of competencies and improving professional training (Llano Arana et al., 2016). Mathematical models are systems that represent theories, and numerical sets are examples of abstract structures used in this context (Herrera Castrillo, 2023b).

For Huincahue (2022) “mathematical models are intended to bring two systems into dialogue, commonly called reality and mathematics, which can be studied as systems to be united or related” (p. 62).

Therefore, Brito-Vallina et al. (2011) established:

> In a mathematical model a set of relationships (of equality and/or inequality) defined in a set of variables that reflect the essence of the phenomena in the object of study is established. Formally, a mathematical model M is a structure, where R is the set of relationships and V is the set of variables. (p. 130).

The physical model refers to an abstracted and simplified representation of a physical system, which can be treated in a quantitative and manipulable way, such as the case of a simple pendulum (Adúriz Bravo and Izquierdo Aymerich, 2009).

In education, teaching and learning are fundamental, especially in virtual education based on media and communication technologies, where ICTs play a regulatory role in the teaching process and are integrated into learning methodologies (Gallar Pérez et al., 2015).

However, at present, Higher Education often uses ICTs in a limited way, as simple communication channels, without taking advantage of their full potential. For example, WhatsApp groups are mainly used to send and receive

work, without using all their functions to generate discussion spaces, share various types of content or make group video calls (Gallar Pérez et al., 2015).

Methodology

Research approach

The approach used in this research study was mixed, encompassing both the description of the educational setting and the collection of data from teachers and students. Quantitative and qualitative methods were combined, including surveys and numerical data analysis, as well as the interpretation and understanding of the experiences and perceptions of the participants in the study area.

According to Hernández Sampieri and Mendoza Torres (2018):

> Mixed methods can be implemented according to different sequences, sometimes the quantitative precedes the qualitative, at other times the qualitative comes first; they can also be developed simultaneously or in parallel, and it is even feasible to merge them from the beginning and throughout the entire research process. (p. 10)

Grimaldo Muchotrigo (2009) states that:

> Qualitative methodology is applied to studies at the micro level, so it normally attempts to go deeper into the situation under study. In this sense, there must be a balance between precision, scope and approach to explain the universe under study. (p. 6)

Type of research

The analysis of this work reveals that it is mainly a descriptive study, whose objective is to describe the facts and characteristics of the population and sample in question. In other words, this research focuses on describing the reality in the classroom, analyzing and explaining the teaching process through the interpretation of numerical data.

> Descriptive research has the purpose of systematically describing the facts and characteristics of a given population or area of interest, seeking to discover them, analyze their meaning and importance, their appearance, frequency and development. It measures, classifies, interprets and evaluates providing, in this way, systematic and

> comparable information with other sources. (Valdivia González and Blandón Dávila, 2014, p. 59).

Purpose of the research

According to Neill and Cortez Suárez (2018), "applied research (...) is characterized because it takes into account the practical purposes of knowledge, and takes theoretical results as a basis, thus making it possible to advance practical applications" (p. 31).

For Martínez González (2007), the objective of applied research is:

> To apply the knowledge obtained by investigating a specific reality or practice in order to modify and transform it as far as possible to improve it. In education, this type of research is especially relevant because of the interest it has for teachers and educators, as well as for educational centers and institutions and those responsible for educational policy, to improve learning and teaching practices, the organization of centers and their dynamics, the involvement of students, and other factors associated with achieving better educational results and quality. (p. 21).

Context-based research

Context-based research is non-experimental in nature and is characterized by not manipulating independent variables or using randomized control groups.

> In a non-experimental study no situation is constructed, but rather existing situations are observed, not intentionally provoked by the researcher. In non-experimental research, the independent variables have already occurred and cannot be manipulated; the researcher has no direct control over these variables and cannot influence them because they have already occurred, as well as their effects. (Agudelo et al., 2008, p. 39).

Population and sample

According to Arias Odón (2012), the population "(...) is a finite or infinite set of elements with common characteristics for which the conclusions of the research will be extensive. Its characteristics will be determined by the problem to be investigated and the research objectives" (p. 81).

In this research, the population consisted of 214 students (97 females and 117 males) of the Physics-Mathematics program at FAREM-Esteli, 18 professors

(9 females and 9 males) and a major coordinator who teach different subjects and components of the aforementioned program.

For Arias Odón (2012), “the sample is a representative and finite subset that is extracted from the accessible population” (p. 83). This author defines the representative sample as: “that which, due to its size and characteristics similar to those of the whole, allows inferences to be made or results to be generalized to the rest of the population with a known margin of error” (p. 83).

In this study, students from first to fifth year of Physics-Mathematics during the first and second semester of 2022 were selected as a sample (Table 1). It is important to note that the proposed methodology is independent of the curriculum and can be applied in any public or private university in the region.

Since this research is of a mixed nature, with a qualitative predominance, the sampling used is non-probabilistic. According to Cabezas Mejía et al. (2018), this type of sampling “is simply carried out in response to reasons of convenience, that is, the probability that the elements of the population have to integrate the sample is unknown” (p. 100).

Table 1: *Research Work Sample*

Year	Male	Female	Total
1st year Physics-Mathematics	3	3	6
2nd year Physics-Mathematics	10	5	15
3rd year Physics-Mathematics	11	8	19
4th year Physics-Mathematics	9	8	17
5th year Physics-Mathematics	9	9	18
Total	42	33	75

In the case of professors, the following criteria were taken into account:

- Be active professors, who are or have taught Physics or Mathematics components or subjects, in the semester I of 2022 or semester II of 2021.
- Have at least one year of teaching experience at FAREM-Esteli.

Regarding the authorities, the Coordinator of the Physics-Mathematics program was interviewed.

It should be noted that another criterion for the selection of the samples was the voluntariness of the participants.

The sources of information include:

- 75 students of the Bachelor's degree in Education Sciences with a major in Physics-Mathematics.
- 6 professors who teach subjects and components of Mathematics and Physics involving Mathematical Equations.
- The coordinator of the Physics-Mathematics major.

Results

The methodology for competency-based learning was designed taking into account the results derived from the application of the instruments, such as the interview with professors (Table 2), who made the following evaluations:

Table 2: *Opinions on the Competency-Based Approach*

What is your opinion regarding the competency-based approach in the training of Physics-Mathematics students?					
Professor 1	**Professor 2**	**Professor 3**	**Professor 4**	**Professor 5**	**Professor 6**
They are of great help, since each of the components are involved and add something for the overall growth of the students.	It is the ideal approach for training professionals who will transmit knowledge in the classroom.	Very much in agreement with this approach, since it allows us to prepare our students with elementary competencies to perform in the future, with a scientific thinking, but above all based on the human being, with high values	It is excellent; it achieves significant learning in students. It allows students to be able to work in the working world in their line of work.	It allows us to monitor the achievement of the competencies established in the students, identifying which ones need to be reinforced so that they can achieve them.	It is an interesting approach; however, the demands of the approach are very flexible.

It can be perceived that professors welcome working with a competency-based approach, but there are still certain doubts regarding the demands of the subjects or components, due to the level of complexity that occurs in Physics and Mathematics classes, which does not imply that there is no development of skills and abilities necessary for today's world.

As Blandón Dávila (2019) indicates, the role of professors is crucial, since they are responsible for presenting mathematics in an attractive way, using available didactic materials, applying diverse teaching methodologies and

adapting to the needs and interests of the students. In addition, they must pay attention to diversity and manage the classroom effectively. Everything that is worked on in the school environment leaves an impact on student learning.

Therefore, a methodology was designed to comply with aspects mentioned by all participants in this study (Figure 2). As a result, a proposal was obtained with the following elements:

Figure 2: *Elements of the Competency-based Methodology*

As shown in the figure, for the design of the proposal, elements were taken into account in a logical sequence and based on the theoretical foundation of the literature review.

The competency-based model for Physics-Mathematics students is based on a series of stages and approaches that promote meaningful and interdisciplinary learning. The general process of this model is described below:

Experience and diagnosis: The terminus a quo is the students' previous experience; and an initial diagnosis to identify their knowledge, skills and attitudes in relation to Physics and Mathematics is performed. This allows knowing the students' starting point and adapting the methodology to their needs.

Reflection and improvement: The results of the diagnosis are analyzed and reflected upon to identify areas for improvement. Specific strategies and actions are formulated to address the identified weaknesses and enhance the students' strengths.

Competency of knowledge: The model focuses on the development of competencies, that is, on the dynamic combination of knowledge, skills and attitudes. Students are expected not only to acquire theoretical information, but also to know how to apply it in real situations and develop practical skills.

Interdisciplinary integration: Since this is a model for Physics-Mathematics students, an interdisciplinary integration between both disciplines is promoted. It seeks to establish connections and relationships between the concepts and principles of Physics and the mathematical tools necessary for their understanding and application.

Use of ICT resources: The available technological resources, such as Information and Communication Technologies (ICT), are used to enrich the teaching-learning process. Digital tools, simulations, specialized software and other technological resources that facilitate the understanding and study of Physics and Mathematics are used.

Consolidation of learning: The consolidation of what has been learned is promoted through practical activities, problem solving, projects and real situations. Students are encouraged to apply the concepts and skills acquired in concrete contexts and develop critical and creative thinking.

Competency-based evaluation: The evaluation is carried out taking into account the competencies developed by the students. Not only the knowledge acquired is evaluated, but also the skills demonstrated and the attitudes shown towards the learning and application of Physics and Mathematics.

In the particular case of this research, concepts of Physics-Mathematics from Sepúlveda (2004), Mañas Baena and Martínez Alonso (2015), and Zill (2018) were used, which were key in the design of the resources and for the implementation of the proposal, by working interdisciplinarity.

It is important to mention that, as the proposal was created, it was implemented with the students, in order to evaluate it, where the six professors who are part of the research sample were involved, who contributed ideas for the improvement of the methodology in a competency-based approach. Satisfactory results were obtained from this proposal (Figure 3).

Figure 3: *SWOT Analysis*

The methodology for competency-based learning has many internal strengths, as shown in Figure 6, where it is considered to be accessible, because it promotes meaningful learning, where the student's experiences are taken into account to consolidate it and put it into practice. The development of competencies is indispensable, achieving to take the knowledge to the reality that surrounds them, and to make them learn in a practical way the theoretical contents that correspond to them in all the areas, in this case focused on the Physics-Mathematics major.

The proposal is as follows:

This methodology is based on the three fundamental knowledges: knowing how to know, knowing how to be and knowing how to do, which are related to professional training from the perspective of competencies. Competencies are defined as dynamic combinations of personal resources, complex systems of understanding and action that encompass “knowing how to know”, “knowing how to be”, “knowing how to do” and “wanting to think, be and do”.

In other words, this methodology seeks to integrate and develop both theoretical knowledge (knowing how to know) and practical skills (knowing how to do) and personal attitudes and values (knowing how to be) necessary for professional practice. In addition, it focuses on fostering critical reflection and creative thinking (wanting to think, be and do) as an essential part of the training process.

By adopting this competency-based approach, the objective is to provide students with a comprehensive education that goes beyond the development of theoretical knowledge. The aim is to foster the development of practical skills and socio-emotional competencies that will enable them to effectively face the challenges of the ever-changing world of work.

According to Cejas Martínez et al. (2019), the three fundamental knowledges refer to the expected outcomes of training. These knowledges are knowledge (know), competencies (know how) and attitudes (personal commitment). These three domains are closely related and are crucial to understanding the training objectives.

The combination of these knowledges, according to Cejas Martínez et al. (2019), ensures the achievement of training outcomes. For this purpose, the following criteria are considered to guide the achievement of the training actions:

- Relevance, which refers to the objectives that are intended to be achieved and deserve the efforts that will be invested in their achievement.
- Clarity, which refers to the clarity of formulation, which should not be linked to the exclusive behavioral conception of the objectives.
- Possibility of evaluation, which refers to the application of immediate and objective tests.

Action in the face of concrete and complex situations in the professional environment leads to the acquisition of experience, which in turn results in a deeper understanding of experiences, ideas, reflections and contrasts. For this reason, starting from a diagnosis facilitates the development of competencies in students, regardless of their study plan, curriculum, subject or specific component.

In other words, by actively facing real and challenging situations in the professional environment, students have the opportunity to acquire practical experience, through which they achieve a more complete understanding of what they have lived, thought, reflected and contrasted. Therefore, starting from an initial diagnosis is fundamental, since it allows identifying the needs and strengths of each student in an individualized manner.

By basing the development of competencies on the initial diagnosis, students are given the opportunity to apply their knowledge and skills in relevant and meaningful contexts. This allows them to acquire a deeper understanding of the professional reality and to develop the necessary competencies to successfully address the challenges they will face throughout their careers.

> Pedagogical reflection is a metacompetency that would integrate diverse personal resources, such as cognitive, metacognitive and emotional (Correa et al., 2014); to activate these resources it is necessary the existence of a situation that generates uncertainty or that could not be resolved (Dewey, 2004) and emerged from experience (Shön, 1992). This metacompetence would decant when there is a re-signification of the object of reflection (Brockbank and MacGill, 2002). (All these authors were cited in Lara-Subiabre, 2018, p. 102).

Figure 1: *Logical sequence of the proposal*

The logical sequence that follows (Figure 4) starts from the new information that is intended to be inculcated in the student up to how to evaluate the development of indispensable competencies for the working world, through multidisciplinary work where the intention of creating something is always present.

New information refers to the knowledge that students must learn and that is necessary for their professional development. This information allows them to acquire specific and generic competencies in any area of knowledge.

For Rosell Puig and Paneque Ramos (2009), teaching methods are dynamic components of the teaching-learning process, since they are based on the actions of teachers and students; who also state that, although some authors separate them from learning methods, they are actually closely related and form a dialectical unit. According to them, when applying a teaching method, it is important to take into account the logical operations that predominate at

each stage of the teaching-learning process and to prioritize those that facilitate the independent and creative activity of students.

These authors also state that there are several classification criteria for teaching methods, which results in a wide variety of approaches. Among the best-known classifications, those referring to the degree of participation of the subjects, the level of assimilation of the teaching contents and the problem-solving methods are summarized (Rosell Puig and Paneque Ramos, 2009).

Current studies support the idea that interdisciplinary approaches are gaining importance in the teaching-learning process since, although there are difficulties in their implementation, results are being obtained that favor professional training (Llano Arana et al., 2016).

According to Tamayo y Tamayo (2011), “the prefix inter (between) indicates that between disciplines a relationship is to be established; determining the type of relationship leading to a study of the levels of interdisciplinarity” (p.5).

In the consolidation stage, the work done is reviewed and areas for improvement are identified. Feedback is sought on issues that contribute to the success of the evaluation and the development of necessary competencies.

Once the methodology has been carried out, it is necessary to evaluate it using different instruments to verify the development or improvement of competencies. According to Morales López et al. (2019), competency-based educational models should organize teaching so that students develop their skills to solve real problems.

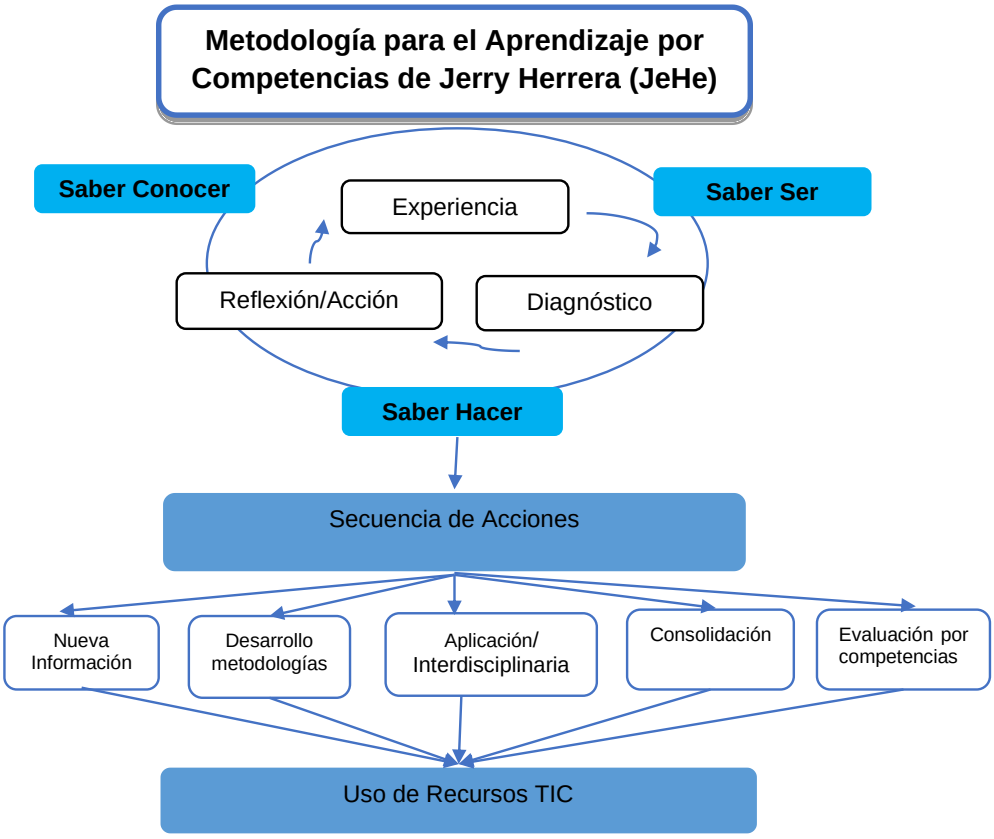
Evaluation in competency-based education requires the teacher to determine the student's performance level. However, since competencies are not directly observable, it is necessary to infer them through specific actions that must be previously operationalized (Morales López et al., 2019).

At all times, the methodology for competency-based learning, allows the use of ICTs, which are of great help in the teaching and learning processes.

According to the perspective of this work, the implementation of technological resources such as cell phones, tablets and personal computers is proposed, as well as the use of simulators and mathematical assistants, which facilitate the educational processes.

The implementation of this competency-based learning methodology must be carried out with creativity and pedagogical balance to ensure its correct development (Figure 5). It cannot be applied in a mechanical way, but requires the integrality of all key elements through methodological strategies. This can only be achieved through a horizontal relationship between professors and students, where the student is the active subject of the educational process.

Figure 5: *Methodology for Competency-based Learning*



The proposed methodology for competency-based learning in Physics and Mathematics, using technology, seeks to develop students' professional competencies. This methodology aims to facilitate the process of assimilation of learning in a creative way, providing a relevant and practical training. It is based on elements that are integrated to generate meaningful learning in any scientific field. The information gathered from professors, students and university authorities, together with the documentary review, has been fundamental for its construction. This Methodology can serve as a reference and support for teachers of all disciplines, since competency-based learning

is crucial for the employability of students, awakening their interest, curiosity and passion to learn and be competent in the working world.

Some examples of application of the methodology are shown below (Figure 6).

Figure 6: *Examples of Application of the Competency-based Learning Methodology*

Conclusion

A review of the scientific literature shows that in education, competencies are a key aspect to investigate the improvement of teacher training from their professional practice, whether initial or continuous, and for this it is important to have reliable and validated tools to evaluate progress and educational change.

The presentation of the elements that make up the methodology made it possible to demonstrate that it develops professional and digital competencies in Physics-Mathematics students.

This work deepens and makes visible an important line of research focused on the professional and digital competencies of Physics-Mathematics students in their instruction process.

The proposed methodology allowed students to obtain better results by using ICTs with an interdisciplinary approach.

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Conflict of interest

The author declares no conflicts of interest.