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Original article

Critical evaluation of the Numerical Mathematics course program for the Computer Science degree program

Valoración crítica del programa del curso Matemática Numérica de la carrera Ciencia de la Computación

Avaliação crítica do programa da disciplina de Matemática Numérica para o curso de graduação em Ciência da Computação

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ABSTRACT

The Bachelor's Degree in Computer Science at the University of Havana aims to adapt its curriculum to social needs through an innovative and flexible approach. The objective was to analyze the Numerical Mathematics program, assessing its relevance within the Secondary curriculum, taking into account aspects such as course placement, the teaching-learning process, and the bibliography used. The research was conducted in the field of computational mathematics education, specifically in curriculum design, focusing the analysis on the Numerical Mathematics course. Its relevance and connection to the curriculum, its position within the curriculum, as well as the pedagogical strategies employed and support materials were examined. Fundamentals of inquiry-based learning, the use of cognitive computing tools, the development of conceptual maps, and the use of virtual learning environments were incorporated. As a result, it was evident that the program is designed to train

professionals capable of applying mathematical and computational methods to social problems. Areas requiring improvement were identified, including updated bibliography, and actions were proposed to refine the curriculum design. These modifications seek to strengthen consistency with the graduate profile and better respond to the demands of the contemporary labor market, fostering comprehensive and relevant training. It was concluded that there are key problems in the current course design, and recommendations for modification were made, with a view to optimizing its structure and functionality within the curriculum.

Keywords: numerical methods; program; science; computing; curriculum design; training.

RESUMEN

La Licenciatura en Ciencia de la Computación de la Universidad de La Habana tiene como propósito adaptar su currículo a las necesidades sociales mediante un enfoque innovador y flexible. El objetivo estuvo dirigido al análisis del programa de Matemática Numérica, evaluando su relevancia dentro del plan de estudios E, teniendo en cuenta aspectos como la ubicación de los cursos, el proceso de enseñanza-aprendizaje y la bibliografía utilizada. La investigación se desarrolló en el campo de la educación matemático-computacional, específicamente en el diseño curricular, centrando el análisis en el curso Matemática Numérica. Se examinó su pertinencia y vínculo con el currículo, la posición que ocupa dentro del plan de estudios, así como las estrategias pedagógicas empleadas y los materiales de apoyo. Se incorporaron fundamentos del aprendizaje basado en la indagación, el uso de herramientas informáticas cognitivas, la elaboración de mapas conceptuales y el aprovechamiento de entornos virtuales de aprendizaje. Como resultado, se evidenció que el programa está concebido para formar profesionales capaces de aplicar métodos matemáticos y computacionales a problemas de índole social. Se identificaron áreas que requieren mejoras, entre ellas la actualización de la bibliografía, y se propusieron acciones para perfeccionar el diseño curricular. Estas modificaciones buscan fortalecer la coherencia con el perfil del egresado y responder mejor a las demandas del mercado laboral contemporáneo, fomentando una formación integral y pertinente. Se concluyó que existen problemas clave en el diseño actual del curso, por lo que se plantearon recomendaciones para su modificación, con vistas a optimizar su estructura y funcionalidad dentro del plan de estudios.

Palabras clave: métodos numéricos; programa; ciencia; computación; diseño curricular; formación.

RESUMO

O Curso de Bacharelado em Ciência da Computação da Universidade de Havana visa adaptar seu currículo às necessidades sociais por meio de uma abordagem inovadora e flexível. O objetivo foi analisar o programa de Matemática Numérica, avaliando sua relevância dentro do currículo E, levando em consideração aspectos como a inserção no curso, o processo de ensino-aprendizagem e a bibliografia utilizada. A pesquisa foi conduzida na área de educação matemática computacional, especificamente em design curricular, com foco na análise do curso de Matemática Numérica. Sua relevância e conexão com o currículo, sua posição dentro do currículo, bem como as estratégias pedagógicas empregadas e os materiais de apoio foram examinados. Fundamentos da aprendizagem baseada em investigação, o uso de ferramentas de computação cognitiva, a criação de mapas conceituais e o uso de ambientes virtuais de aprendizagem foram incorporados. Como resultado, ficou evidente que o programa é projetado para formar profissionais capazes de aplicar métodos matemáticos e computacionais a problemas sociais. Áreas que requerem melhorias foram identificadas, incluindo bibliografia atualizada, e ações foram propostas para refinar o design curricular. Essas modificações buscam fortalecer a coerência com o perfil do egresso e responder melhor às demandas do mercado de trabalho contemporâneo, promovendo uma formação abrangente e relevante. Concluiu-se que existem problemas importantes na concepção atual do curso, e foram feitas recomendações de modificação para otimizar sua estrutura e funcionalidade dentro do currículo.

Palavras-chave: métodos numéricos; programa; ciência; computação; concepção curricular; formação.

INTRODUCTION

Computer Science studies the theoretical foundations of informational and computational processes, their application in the implementation of computational systems, in correspondence with the vertiginous development of science and technologies, which provide solutions to the computerization demanded by contemporary society (Figueroa Mora *et al.*, 2023).

In Cuba, the program is characterized by a solid mathematical and computational background, which develops in graduates a high level of abstraction and logical reasoning skills that allow them to

analyze, conceptualize, model, algorithmize, implement, evaluate, and reuse computing systems, offering consistent solutions to problems arising from society that can be easily generalized; as well as quickly assimilate new computational paradigms and constantly developing new technologies (Díaz Cobos *et al.*, 2012; Díaz Silvera & Rodríguez Pérez, 2023).

The emergence of the study of computer science in Cuba dates back to the late 1960s. That same year, the Department of Computer Science was established at the University of Havana. Beginning in 1973, the curricula and programs of the three universities where it was taught (the University of Havana, the "Marta Abreu" Central University of Las Villas, and the University of Oriente) were unified.

According to the rationale for the E curriculum (2017), the University of Havana was established in 1976 as the Rector Center for the Computer Science Program. The first program, known as Plan A, was implemented in 1977. In 1981, Plan B was introduced, which includes the Professional Internship course. Plan C, launched in 1986, allows for greater flexibility in content and offers elective courses based on student interests. Plan C was updated in 1998, and Plan D (2008) evolved toward a more comprehensive and humanistic educational model, introducing concepts such as core and elective curricula to personalize student training. Finally, Plan E (2017) was developed based on previous experiences and in collaboration with employers, ensuring that graduates have the necessary skills to face current labor market challenges.

According to Plan E, the fundamental objective of the Bachelor's degree in Computer Science is the creation of computational systems, based on mathematical-computational approaches, for the solution of specific or interdisciplinary problems.

On the other hand, the success of a curricular strategy lies in achieving a comprehensive education that balances intellectual aspects and values that foster the students' harmonious development. This must be achieved without neglecting the practical and social context in which it is carried out.

The evaluation of a curriculum should be based on specific criteria that allow for assessing its strengths and weaknesses. This helps to determine which elements should be maintained as it is and which require modification or improvement.

Critical analysis of curricula is essential for curricular development. This process of continuous improvement is an ongoing task in Higher Education. In this regard, the University of Havana has

been undergoing a process of ongoing transformation, aiming to align itself with new scientific and technical knowledge and advances, as well as with the growing demands of social development.

The objective of this article is to critically analyze the curriculum for Numerical Mathematics, within the Applied Mathematics discipline of the Computer Science program, taught at the University of Havana, Cuba.

MATERIALS AND METHODS

This study critically analyzes the curriculum for Numerical Mathematics, within the discipline of Applied Mathematics, Computer Science program, taught at the Faculty of Mathematics and Computing at the University of Havana, Cuba.

García Milian *et al.* were taken into account. (2016) and Bellido (2022), which are intended to allow for systematic analysis and criticism of a study program.

A study was conducted in the field of mathematics and computational education, specifically curriculum design. The unit of analysis was the Numerical Mathematics course in the Computer Science program at the University of Havana. The relevance and connection with the curriculum, course location, the teaching-learning process, and the bibliography were studied.

As a result of the analysis of the teaching-learning process in the course, it is proposed to use inquiry-based learning as part of the didactic strategy of the discipline (Lappas & Kritikos, 2018). In addition, the framework proposes the use of cognitive computing tools such as Python software for computer programming (Kong *et al.*, 2021), CMAP software for building conceptual maps (Ferreira *et al.*, 2012) and Moodle (EVEA-UH), to present students with challenging problems to solve (Peña Cruz & De la Peña Consuegra, 2022).

RESULTS

General information about the course program

The object of study of the subject Numerical Mathematics is the fundamental numerical methods and their application to approximate, in an efficient and algorithmic manner, the solutions to problems expressed mathematically.

There is a growing need for methods and algorithms to solve, using modern computers, the various mathematical models that arise from science and technology.

The course prepares future graduates to be able to analyze, apply, modify, and adapt general numerical methods to specific situations, using them efficiently on computers, as well as developing new algorithms for solving practical problems expressed through mathematical models.

The curricular location and number of hours of the subject (Table 1).

According to study plan E, the general objectives of the subject are:

1. Solve a problem by selecting or adapting a suitable numerical method and developing efficient algorithms for using available computing resources.
2. Use, modify, or adjust scientific calculation libraries to adapt them to the numerical resolution of specific mathematical models.
3. Analyze the specific computational aspects of numerical methods in solving mathematical models, to increase the efficiency of the chosen method and the accuracy of the results.
4. Solve a problem by selecting or adapting a suitable numerical method and developing efficient algorithms for using available computing resources.
5. Use, modify, or adjust scientific calculation libraries to adapt them to the numerical resolution of specific mathematical models.
6. Analyze the specific computational aspects of numerical methods in solving mathematical models, to increase the efficiency of the chosen method and the accuracy of the results.

Table 1. Curricular location and number of hours of the Numerical Mathematics subject within the Applied Mathematics discipline, Computer Science degree, face-to-face modality, study plan E

Subject	Curriculum	Hours	Year	Sem.	Eval.
Numerical Mathematics	ESSENTIAL	64	2	3	EF
Odds	ESSENTIAL	64	2	4	
Statistics	ESSENTIAL	64	3	5	
Optimization Models	ESSENTIAL	64	3	5	EF
Applied Mathematics Project	OWN	32	3	6	
Total hours	288				

The subject includes the following Essential knowledge to be acquired: objectives and working methods of numerical mathematics; error classification and estimation; error propagation; numerical stability; general iterative methods for solving nonlinear equations and systems of equations; systems of linear algebraic equations; direct solution methods; matrix factorizations; matrix with specific properties; iterative methods; convergence conditions for iterative methods; function approximation using polynomial interpolation; piecewise interpolation, *splines*; least squares approximation of data; approximation of periodic functions; discrete and fast Fourier transformation; and numerical differentiation and integration.

Students should acquire the following skills by the end of the course:

- Estimate and limit absolute and relative errors in the numerical solution of equations and systems of equations.
- Locate and approximate the roots of nonlinear equations.
- Perform the transformation of a nonlinear equation into an equivalent that guarantees the convergence of iterative methods for calculating its roots.
- Select the appropriate algorithms to solve systems of linear equations and adapt them appropriately.
- Recognize the most appropriate method to approximate a specific function.
- Numerically approximate the derivative of a function.
- Numerically integrate a given function.

From a methodological and teaching organization point of view, the subject is taught through introductory classes on new content (lectures), workshops in laboratories, and seminars.

The lectures explain the essence of the fundamental types of methods that solve the problems under study, and emphasize the mathematical, numerical, and computational specifics of the algorithms chosen to illustrate each type.

The exercise classes will primarily illustrate the numerical and computational particularities of the algorithms studied, through the discussion of proposed exercises and the results of computer runs, using existing software systems or those previously developed for this purpose by the students themselves.

During the seminars, students demonstrate the knowledge and skills acquired through individual study and research on topics related to the subject. Seminar topics are suggested to be related to applications of the subject content.

To evaluate the teaching-learning process, the subject applies partial evaluations and a final exam.

Relevance and connections with the rest of the curriculum

The course program met, as a whole, the educational expectations, the advancement of scientific and technological knowledge, and the practical commitment to society. The content demonstrated its up-to-date nature and consistency with the curricula of other universities in the country and around the world, which include these topics in various university programs.

The program outlined the skills students need to develop to become quality professionals, taking into account the social, political, cultural, and economic values of the society where they will perform their social role.

The content and problem-solving teaching made it possible to address issues that Cuban society is demanding, such as image processing problems, materials design, routing issues, tumor and skin lesion modeling, among others.

It was observed that a close and direct link is maintained between the graduate profile, the program objectives, as well as the rest of the courses contained in the discipline and the curriculum.

There are connections between the course and other subjects and disciplines in the curriculum of the program. The program connects with preceding courses, such as Algebra I and II, Mathematical Analysis I and II, and Logic, which are taught in the first year of the Computer Science program.

In the Artificial Intelligence discipline, the Machine Learning course includes topics such as supervised and unsupervised learning, probabilistic and regression models, neural networks, deep learning, as well as experimental design and evaluation. These topics are based on optimization algorithms to minimize a loss function, which allows for the identification of patterns encoded in feature vectors. These algorithms also use the concepts of numerical error, solution precision, and numerical linear algebra, which often enables efficient computations.

On the other hand, the Information Retrieval Systems course, within the Information Systems discipline, establishes the following objective: to evaluate, compare, and classify documents efficiently and accurately, which demonstrated a connection with the Numerical Mathematics course.

Regarding the links among the subjects of the Applied Mathematics discipline, it is observed that the Statistics subject was related to Numerical Mathematics, since the latter provides the numerical methods necessary to perform regression, least squares and standard deviation estimation. The Optimization subject is also connected to the Numerical Mathematics subject, since iterative methods, their stopping criteria, Jacobian estimation, inverse computation substitution and convergence analysis of numerical methods are essential elements for function optimization. Furthermore, the Numerical Mathematics subject was related to the Applied Mathematics Project subject, which integrates all the contents of the discipline to solve a research problem associated with social practice.

Location in the curriculum and correspondence with previous and subsequent content

The subject requires the precedence of the disciplines Basic Mathematics (subjects Mathematical Analysis I, Mathematical Analysis II, Algebra I, Algebra II) and Computational Mathematics (subject Logic).

As for the correspondence with subsequent contents in the curriculum, the discipline is recognized in the E curriculum as a precedent of the Artificial Intelligence, Information Systems and Computer Systems disciplines, which use it in their contents, as already discussed.

This order of subjects within the curriculum was deemed appropriate. However, care must be taken to ensure that the proposed organization allows for a general approach to the content. This ensures the systematization of the reflective process of review and adjustment to the topics and learning objectives.

Analysis of the bibliography

This step allows for an analysis of the bibliography based on three fundamental elements that must characterize it for the program to fulfill its purpose: relevance, currency, and source. The bibliography is relevant to the proposed content and is made available to students in digital format. The program identified that the bibliography is outdated and is mostly in digital format and in English.

DISCUSSION

The object of study of the subject Numerical Mathematics is the fundamental numerical methods and their application to approximate, in an efficient and algorithmic manner, the solutions to problems expressed mathematically.

In this regard, it was observed that the course program and its contents prepare future graduates to be able to analyze, apply, modify, and adapt general numerical methods to specific situations for solving practical problems expressed through mathematical models.

Through its work system, the course contributes to fostering the values of responsibility for assigned tasks; honesty, emphasizing a sense of belonging and duty to society; dignity, through a revolutionary commitment to fulfilling professional duties; and sensitivity, fostering a love for the profession.

From a methodological and organizational perspective, the course is taught through introductory lectures, practical classes (laboratory exercises), and seminars. This allows for the gradual assimilation of knowledge and the practical application of the content, revealing the advantages and disadvantages of each algorithm in specific situations, as well as its use in other subjects in the curriculum.

The course program met, as a whole, the educational expectations, the advancement of scientific and technological knowledge, and the practical commitment to society. The content demonstrated its up-to-date nature and its alignment with curricula from other universities in the country and around the world.

The content and problem-solving teaching made it possible to address issues that Cuban society is demanding, such as image processing problems, materials design, routing issues, tumor and skin lesion modeling, among others.

A close and direct connection was observed among the graduate profile, the program objectives, and the rest of the courses in the discipline and the curriculum. Thus, the content and its learning during the course are a fundamental element in the development of the teaching-learning process for a group of subjects taught later in the curriculum, such as Optimization, Statistics, Machine Learning, among others.

The order of precedence of the subjects within the curriculum was deemed appropriate; however, care must be taken to ensure that the proposed organization allows for a comprehensive approach to the content, from the general to the specific. This ensures the systematic review and adjustment process to the topics and learning objectives.

The connection between this discipline and Ordinary Differential Equations, within Basic Mathematics, should be considered, given that this course studies numerical methods for solving these types of equations. In other curricular designs, such as at the Technological University of Panama, these topics are taught in Numerical Mathematics; however, in the E curriculum, due to content load and time constraints, it was decided not to teach these topics in this course and instead transfer them to Ordinary Differential Equations.

As part of the improvement of the teaching-learning process in the course, it is recommended to include engineering problems as part of the didactics in the subject programs, such as those that appear in the texts of Burden *et al.* (2017) or Chapra and Canale (2015).

In this sense, inquiry-based learning is proposed as part of the discipline's teaching strategy (Lappas & Kritikos, 2018). This learning focuses on student participation through active discovery and learning in environments that include active participation, personal action, observation, exploration, and experimentation.

The goal of this learning framework is threefold: to help students understand the fundamentals of the subjects, to provide students with the opportunity to practice and refine their critical thinking skills, and to convey to students the purpose of scientific inquiry.

Inquiry-based learning is related to the educational theory of constructivism, in which students learn through a process of engagement.

The main components are divided into five major actions:

1. Engage: participate in activities that encourage and facilitate learning situations, with or without prior knowledge.
2. Explore: They investigate the nature of problems and try to build their understanding.
3. Explain: They try to connect their previous experiences with current learning.
4. Elaborate: apply or extend previously introduced concepts and experiences to new situations.

5. Assess: A snapshot of the student's understanding is provided to assess whether they have acquired the intended knowledge and skills.

Furthermore, the framework proposes the use of cognitive computing tools such as Python software for computer programming (Kong *et al.*, 2021), CMAP software for concept mapping, and Moodle (EVEA-UH) to present students with challenging problems to solve.

An example of the application of inquiry-based learning in the subject of Numerical Mathematics would be:

- The "engagement" action: The materials available in Moodle allow students to be motivated to actively learn.
- The "exploration" action:
    - Direct methods are characterized by transforming the original equations into equivalent equations that can be solved more easily. The most popular direct method is LU Decomposition.
    - Iterative methods begin with a guess at the solution and then repeatedly refine the solution until a certain convergence criterion is reached. The most popular iterative methods are Jacobi iteration and Gauss-Seidel iteration.
    - Representation of algorithms: After recognizing numerical methods, students will use pseudocode to represent algorithms.
- The action of "explaining": students are able to use CMAP software to build their concept maps.
- The action of "elaboration":
    - After the formulation of an algorithm, computer programming leads from the original formulation of a computer problem to executable computer programs.
    - It focuses on understanding fundamental mathematical concepts and mastering problem-solving skills using numerical methods.
    - Students offer a variety of graphic presentation formats that help simplify complicated issues and convey meaningful insights into the problem.
- The action of "evaluating": Concept maps, algorithms, and source codes can be evaluated against various criteria to assess students' understanding.

Furthermore, the bibliography was relevant to the proposed content and was made available to students in digital format. However, the program identified that the bibliography was outdated and was mostly in digital format and in English.

Therefore, it is recommended to use the most recent Spanish versions published in the basic bibliographies of the subjects. It is suggested to use the Spanish version of the basic bibliography book (Burden *et al.*, 2017). It is pertinent to add to this bibliography the Cuban text by Álvarez *et al.* (2012), which is very useful for teachers, as it develops a didactic-methodological approach to the subject. In addition, it is recommended to add the texts by Chapra and Canale (2015) and Kong *et al.* (2021).

Given the vast experience of the subject group, it is recommended that you publish your own text, including methodological notes on how to organize the teaching-learning process.

In summary, the evaluated program offers essential contributions to the Numerical Mathematics course in the Computer Science program at the University of Havana. It is necessary to update the bibliography and modify the teaching methods for this discipline, which translates into changes in the methodological guidelines of the curriculum.

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Conflict of interest

Authors declare no conflict of interests.

Authors' contribution

The authors participated in the design and writing of the article, in the search and analysis of the information contained in the consulted bibliography.