CINTED-UFRGS Revista Novas Tecnologias na Educação

Theoretical Computer Science in Computing Education: an exploratory literature review in Brazil

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Abstract: This article presents an exploratory literature review investigating approaches to teaching Theoretical Computer Science within Computer Science Education in Brazil. Theoretical Computer Science, one of the foundations of Computer Science, is essential to understand its theoretical and mathematical aspects. This study examines how Theoretical Computer Science concepts are approached, integrated, and assessed in educational contexts, focusing on both Higher and Basic Education levels. The review indicates a predominance of plugged and game-based approaches, most of which employ digital educational tools to promote engagement and make abstract concepts more tangible. However, the findings reveal an absence of standardized assessment methods and a significant gap in initiatives that focus on Basic Education, indicating the need for research and methodological rigor in the learning outcomes of assessment.

Keywords: basic education; computer science education; higher education; theoretical computer science

Computação Teórica na Educação em Computação: uma revisão exploratória da literatura no Brasil

Resumo: Este artigo apresenta uma revisão exploratória da literatura que investiga abordagens para o ensino de Computação Teórica no contexto da Educação em Computação no Brasil. A Computação Teórica, uma das bases da Ciência da Computação, é essencial para a compreensão de seus aspectos teóricos e matemáticos. Este estudo examina como os conceitos de Computação Teórica são abordados, integrados e avaliados em contextos educacionais, com foco tanto no Ensino Superior, quanto na Educação Básica. A revisão indica uma predominância de abordagens “plugadas” e baseadas em jogos, das quais a maioria utiliza ferramentas educacionais digitais para promover o engajamento e tornar os conceitos abstratos mais tangíveis. No entanto, os resultados revelam a ausência de métodos padronizados de avaliação e uma lacuna significativa de iniciativas voltadas à Educação Básica, apontando para a necessidade de pesquisas e de maior rigor metodológico na avaliação dos resultados de aprendizagem.

Palavras-chave: computação teórica; educação básica; educação em computação; ensino superior

1. Introduction

Today, students live in an increasingly connected and technology-driven world, making it essential to develop skills to navigate a constantly evolving professional landscape. Therefore, it is no longer appropriate to restrict this development to Higher Education. Students should begin developing skills related to Computer Science (CS) in Basic Education[1] (Barr; Stephenson, 2011). Some countries, such as Israel, the United States, England, and

[1] In this article, “Basic Education” refers to primary and secondary education, i.e., levels 1, 2, and 3 of the International Standard Classification of Education (ISCED) (UNESCO, 2012).

Finland, have made efforts over the past decade to introduce CS to schools, most of them including at least fundamental concepts as mandatory topics (Ribeiro et al., 2023).

In Brazil, before 2022, there was no national standard defining the CS competencies to be covered in schools. This gap led to uneven implementation: schools with more resources included CS in their curriculum, while others, especially public schools, lacked initiatives and infrastructure (Ribeiro et al., 2023). In order to overcome this situation, the Brazilian National Education Council made CS part of Basic Education in 2022, complementing the National Common Curricular Base (BNCC). Approved in 2017, the BNCC is an official document that describes and organizes the knowledge considered essential for Brazilian children and adolescents at school (Brazil, 2017).

The policy was guided by recommendations from scientists and educators across the country, with the support of the Brazilian Computer Society. This supplementary document added to the BNCC defines competencies in CS for all levels of Basic Education (Brazil, 2022). The approval of this policy represents a significant advancement for Brazil, but the remaining challenges include teacher training, the development of appropriate educational resources, and the adoption of effective teaching methodologies.

Currently, most of the initiatives aimed at Basic Education in Brazil focus on programming activities, particularly the development of digital games and the use of visual programming languages, such as Scratch (Resnick et al., 2009), often with the development of Computational Thinking skills as a goal (Pimenta; Costa e Junior, 2024; Grebogy; Santos e Castilho, 2021; Silva; Fernandes, 2024). However, topics related to Theoretical Computer Science (TCS) are significantly underexplored, despite being associated with the development of essential skills for 21st-century students, such as abstraction, logical reasoning, problem solving, and pattern recognition. These skills, along with other concepts of TCS, are listed in the Computing complement of the BNCC. TCS refers to the branch of CS that studies the mathematical and abstract foundations of Computing, including formal languages, automata, computability, and complexity.

In Higher Education, the reality of the TCS area is marked by high failure rates, as the courses cover topics that are often perceived by students as excessively dry, abstract, complex, and disconnected from their future professional practice, which tends to reduce interest and motivation for learning (Ramos, 2009). This scenario may reflect the difficulty of introducing TCS in Basic Education. Given this context, this article aims to investigate how TCS has been introduced and evaluated in Computer Science Education (CSEd) in Brazil. In order to guide this investigation, a Primary Research Question (PRQ) was formulated. In addition, two Secondary Research Questions (SRQ) complement this investigation by addressing specific aspects of the topic. The questions are as follows:

- **(PRQ)** What teaching interventions related to TCS have been applied in CSEd, and what learning, engagement, or cognitive development outcomes have been reported?
- **(SRQ_1)** Which concepts of TCS are addressed?
- **(SRQ_2)** How have these interventions been assessed?

A study related to ours was found. The work presents a Systematic Literature Review (SLR) about TCS in Basic Education (Silva Junior; Cavalheiro e Foss, 2021b). The study analyzed 17 papers and articles from conferences proceedings and journals published over the last 20 years, which presented solutions related to this topic. The authors identified a gap in Basic CSEd, as most studies report the use of programming, games, and robotics to teach CS concepts. Given the current trend toward Computational Thinking and problem-solving, the authors argued that TCS should be more frequently considered in CSEd due to its analytic and problem-centered nature. This study differs from ours because it did not focus specifically on

Brazilian proposals but rather on a broader context. Moreover, the authors analyzed studies up to 2021, while we considered those up to 2025.

Finally, addressing the research questions presented, this work seeks to provide an overview of current Brazilian practices and to identify strategies that can help overcome the challenges of introducing or teaching TCS. The remainder of this article is organized as follows: Section 2 outlines the methods used for the exploratory review; Section 3 presents the findings, addresses the research questions, and discusses the results; and Section 4 concludes the article, suggesting directions for future research.

2. Methods

We follow a proposed guideline for SLRs in Software Engineering (Kitchenham et al., 2004), which suggests three main phases: *Planning the Review*, including the identification of the need for a review and the development of a review protocol; *Conducting the Review*, including the selection of studies, data extraction, and the synthesis; and *Reporting the Review*, for which we followed the PRISMA guidelines (Page et al., 2021). During the search process, we replaced the search string for the manual search.

Given the investigated topic, a manual search was conducted in conferences proceedings and relevant journals within the field of CSEd. This decision stemmed from the difficulty of constructing a search string broad enough to encompass all terms and expressions related to the theoretical concepts addressed, which could have led to the exclusion of relevant studies. Thus, manual search enabled for a more precise identification of studies aligned with the research objective. Moreover, evidence has shown that manual searches are beneficial and may even be more effective in identifying relevant studies (Kitchenham; Brereton, 2013).

The review protocol was developed on the basis of the research questions. The selected databases were chosen to cover the main Brazilian sources related to CSEd. The proceedings considered included the *Simpósio Brasileiro de Educação em Computação* (EduComp), *Simpósio Brasileiro de Informática na Educação* (SBIE), *Workshop sobre Educação em Computação* (WEI), and *Workshop de Informática na Escola* (WIE). Furthermore, the following journals were analyzed: *Revista Novas Tecnologias na Educação* (RENOTE) and *Revista Brasileira de Informática na Educação* (RBIE). We also considered the *Revista Brasileira de Informática Teórica e Aplicada* (RITA), *Revista Eletrônica de Iniciação Científica em Computação* (REIC) as well as the *Journal of the Brazilian Computer Society* (JBCS).

Considering that the inclusion of CS in the BNCC was only recently approved, in 2022, we conducted the manual search in these databases covering the years 2020 to 2025. This search was conducted up to September 2025; therefore, studies published after this period were not considered in this review. The studies of the proceedings and journals were selected through an initial screening of titles and abstracts. During this stage, all studies that met the following exclusion criteria were removed: (1) Not addressing TCS; (2) Mentioning TCS, but not as the main focus of the work; (3) Being a duplicate work[2]; and (4) Being a Systematic or Mapping Literature Review. All remaining studies that addressed TCS in an educational context were included.

We sought to retrieve the full papers and articles of all studies that passed the screening phase or whose titles and abstracts were insufficient to determine their eligibility. Finally, we repeated the analysis of the full texts for selecting the papers to be included in the review. The data extraction process, guided by our research questions, involved coding the selected studies according to their approach (e.g., use of games, educational tools, unplugged

[2] In this context, duplicate works refer to papers or articles that have an extended version. In such cases, only the extended version was considered, as it provides a more complete account of the study.

activities, courses, etc.), theoretical concepts covered, audience (Basic Education and/or Higher Education), and assessment method.

3. Results and Discussion

The proceedings of the selected conferences and journals within the chosen time frame totaled 3.147 documents: 220 from EduComp, 865 from SBIE, 385 from WEI, 323 from WIE, 630 from RENOTE, 292 from RBIE, 154 from RITA, 134 from REIC, and 144 from JBCS. Of these, 43 studies related to our research topic were selected through the manual search. Among them, 10 were excluded for not addressing TCS as the main focus; 4 for being duplicate works; 1 for being a mapping review; and 1 for not addressing TCS at all. Figure 1 presents the search outcomes using the PRISMA (Page et al., 2021) flowchart, adapted to our manual search strategy. The selected studies, along with their respective approach, theoretical topics, audiences, and assessment methods, are summarized in Table 1.

The forms of assessment were categorized as follows: *Informal Observation*, when observations made during the proposals application did not follow pre-established assessment criteria; *Formal Observation*, when pre-established assessment criteria were followed during the proposals execution; *Analysis of Solutions/Artifacts*, when the works evaluated exercises or artifacts produced during the proposals; *Comparative Assessment*, when comparisons were made between groups (e.g., control vs. experimental); *Pre/Post-Test*, when tests on the content addressed were conducted before and after the proposals; *Satisfaction Questionnaire*, used to measure students' motivation, interest, and appreciation regarding the proposals; *User Experience (UX) Questionnaire*, referring to surveys about UX; *Knowledge Questionnaire/Test*, applied to assess content during or after the proposals; and *Not Evaluated*, when the authors did not report any approach to evaluating the proposal.

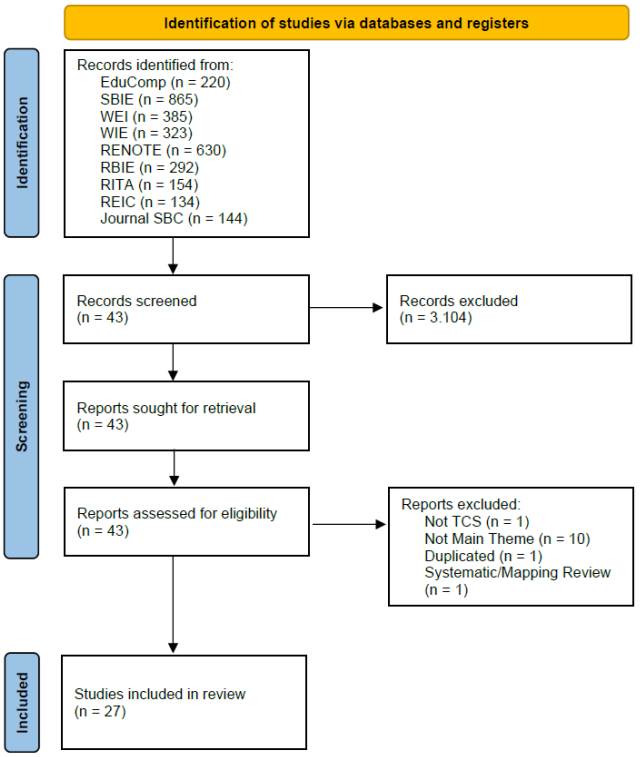

Figure 1 - PRISMA flowchart of the review
Source: Adapted from Page et al. (2021).

Table 1 - Studies addressing TCS in CSEd in Brazil

Study	Approach	Topic Covered	Audience	Assessment
Santos, Moro e Pozzebon (2023)	(Plugged) Game-Based Learning	Fuzzy Logic	Higher Education (undergraduate)	Not Evaluated
Mourão et al. (2025)	(Unplugged) Educational Game	Discrete Mathematics (propositional logic)	Higher Education (undergraduate)	Informal Observation and Satisfaction Questionnaire
Braga e Sasaki (2025)	(Unplugged) Educational Game	Graphs (eulerian paths)	Higher Education and Basic Education	Analysis of Solutions/Artifacts (only in Higher Education)

Bianch et al. (2025)	(Plugged) Educational Tool	Graphs (complex networks)	Higher Education	Not Evaluated
Finger et al. (2021)	(Plugged) Educational Tool	Numerical Methods	Higher Education (undergraduate)	UX Questionnaire
Silva Junior, Cavalheiro e Foss (2021a)	(Plugged) Educational Tool	Formal Languages (graph grammar)	Basic Education	Not Evaluated
Honda et al. (2022)	(Plugged) Educational Game	Graphs ((shortest) paths)	Higher Education (undergraduate)	Questionnaire (UX, Satisfaction)
Campano Junior et al. (2022)	(Plugged) Interdisciplinary-Based Teaching	Turing Machine	Higher Education (undergraduate)	Satisfaction Questionnaire
Silva, Santos e Lencina (2022)	(Plugged) Educational Tool	Analysis of Algorithms (cyclomatic and spatial complexity)	Higher Education (undergraduate)	Informal Observation, Analysis of Solutions/Artifacts and Satisfaction Questionnaire
Nascimento et al. (2023)	(Plugged) Educational Game	Computational Complexity (knapsack problem)	Higher Education (undergraduate)	Analysis of Solutions/Artifacts and Questionnaire (UX, Satisfaction)
Michels et al. (2024)	(Plugged) Educational Tool	Formal Languages (grammars)	Higher Education (undergraduate)	Analysis of Solutions/Artifacts
Cassanho, Michels e Barbosa (2024)	(Plugged) Educational Tool	Formal Languages and Automata (recognition machines)	Higher Education (undergraduate)	Analysis of Solutions/Artifacts and Satisfaction Questionnaire
Moura, Poltronieri e Finger (2024)	(Plugged) Educational Tool	Logic (truth table)	Higher Education (undergraduate)	UX Questionnaire
Alves e Guerra (2024)	(Plugged) Educational Tool	Turing Machine	Higher Education (undergraduate)	Questionnaire (UX, Satisfaction)
Malheiros e Haetinger (2024)	(Plugged) Programming	Discrete Mathematics	Higher Education (undergraduate)	Comparative Assessment
Teixeira, Fülber e Merlin (2024)	(Plugged) Educational Game	Formal Languages, Automata, and Turing Machine	Basic Education (10-12 years old)	UX Questionnaire
Arrojo et al. (2024)	(Plugged) Educational Tool	Logic (truth table)	Higher Education (undergraduate)	Questionnaire (Knowledge, Satisfaction)
Alencar, Pires e Pessoa (2020)	(Plugged) Educational Game	Graphs (eulerian paths)	Higher Education and Basic Education	UX Questionnaire
Vasconcelos e Guerra (2023)	(Plugged) Programming	Theory of Computation	Higher Education (undergraduate and graduate)	Satisfaction Questionnaire

Honda et al. (2023)	(Plugged) Educational Game	Automata (deterministic finite automata)	Higher Education	UX Questionnaire
Mattia et al. (2024)	(Plugged) Educational Game	Formal Languages (graph grammar)	Basic Education (early elementary)	Not Evaluated
Sena, Duarte e Araújo (2020)	(Plugged) Educational Game	Graphs (shortest path)	Basic Education (high school)	Pre/Post-Test
Classe e Castro (2021)	(Plugged) Gamification-Based Teaching	Logic and Theory of Computation	Higher Education (undergraduate)	Comparative Assessment and Satisfaction Questionnaire
Silva, Cavalheiro e Foss (2024)	(Plugged) Educational Activity	Automata (deterministic finite automata)	Basic Education (9th grade)	UX Questionnaire
Lima, Falcão e Andrade (2021)	(Plugged) Educational Tool	Formal Languages (stochastic Petri nets)	Higher Education (undergraduate and graduate)	Comparative Assessment, Pre/Post-Test, and Questionnaire (UX, Satisfaction)
Cordenonzi, Pino e Cardoso (2021)	(Plugged) Interdisciplinary Course	Discrete Mathematics	Higher Education (undergraduate)	Formal Observation, Analysis of Solutions/Artifacts, Comparative Assessment, and Knowledge Test
Vasconcelos e Menezes (2024)	(Plugged) Educational Tool	Logic (natural deduction)	Higher Education (undergraduate and graduate)	Questionnaire (Satisfaction, UX)

3.1. (PRQ) What teaching interventions related to TCS have been applied in CSEd, and what learning, engagement, or cognitive development outcomes have been reported?

The interventions mainly involved active and game-based learning approaches (Figure 2), with a predominance of plugged (digital) strategies (25 of the 27 studies). These included the use of educational tools (11 studies), as well as unplugged and digital games (two and seven studies, respectively). In addition, two studies used programming activities, two adopted an interdisciplinary approach, and two focused on game-based learning. The most frequent approaches identified were digital educational tools and serious games addressing topics such as Formal Languages, Automata, Graphs, and Turing Machine. In Basic Education, fewer initiatives were found, generally involving educational games designed to introduce fundamental concepts of TCS in an accessible and engaging way.

Regarding the outcomes, most of the studies reported positive effects on engagement and motivation, suggesting that interactive and gamified strategies help demystify the abstract nature of TCS. Students demonstrated increased interest and participation, as well as qualitative evidence of improved conceptual understanding through exploratory and hands-on activities. However, quantitative measures of learning gains were limited: few studies employed formal pre/post-tests or comparative evaluations. Thus, while the reviewed interventions indicate promising results in terms of engagement and perceived learning, more rigorous and standardized assessment methods are needed to validate their impact on conceptual and cognitive development.

3.2. (SRQ_1) Which concepts of TCS are addressed?

The concepts addressed by the reviewed interventions were the following: Logic (classic and fuzzy), Discrete Mathematics, Graphs, Numerical Methods, Formal Languages, Turing Machine, Analysis of Algorithms, Automata, Computational Complexity, and Theory of Computation. Except for Numerical Methods, Analysis of Algorithms, and Computational Complexity, all other topics were addressed in more than one study, Formal Languages being the most frequent (in six studies) (Figure 2). Graphs, Logic, and Automata closely follow, with five, four, and four studies, respectively. Although most of the proposals were aimed at Higher Education, Formal Languages were explored equally across Higher and Basic Education, with three studies at each level (Figure 3). It is worth noting that, among the Formal Languages, Graph Grammar was exclusively addressed in Basic Education. The same pattern observed for Formal Languages also applies to Automata: two studies targeted Basic Education and two targeted Higher Education.

Regarding Graphs, it can be observed that, except for one study, all others focused on concepts related to paths. Furthermore, the distribution of Graph-related studies among audiences was quite balanced: one study was exclusively for Basic Education, two exclusively for Higher Education, and two for both. Logic, on the other hand, was addressed only in Higher Education, although it appears in the BNCC competencies, such as in the skills EF03CO01 and EF05CO03, for example (Brazil, 2022). Turing Machines were also addressed in one study at the Basic Education level and in two at the Higher Education. From this, it can be observed that the topics most frequently introduced to younger audiences tend to be those with more *visual representations*, making them less abstract and easier to grasp compared to other content. Even Graph Grammars, although a formal language, can be approached visually, which facilitates students' understanding.

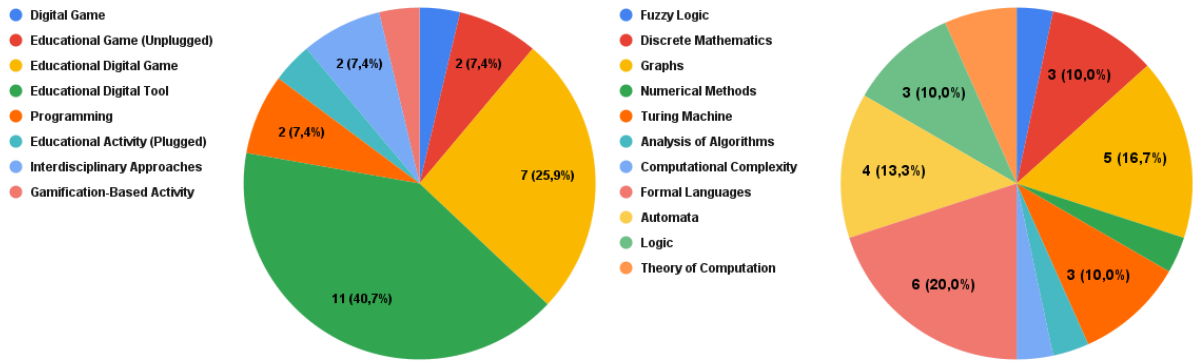

Figure 2 - Relative frequency of the approaches (left) and theoretical concepts (right)

3.3. (SRQ_2) How have these interventions been assessed?

The reviewed studies used heterogeneous assessment methods, with a clear predominance of qualitative and subjective approaches (Figure 4). Most interventions relied on UX and/or Satisfaction Questionnaires (11 and 12 studies, respectively), as well as Analysis of Solutions/Artifacts of students (six studies) to measure participation and perceived learning. Only a few studies implemented Comparative Assessments or Pre/Post-Tests to measure conceptual understanding more rigorously (four and two studies, respectively). Moreover, three studies used Observation (two informal and one formal). Besides the studies that used Pre/Post-Tests as assessment methods, two others also sought to collect data on learning outcomes by applying a Knowledge Questionnaire/Test. Finally, four studies did not reach the stage of assessment with the audience. If we analyze the evaluations according to the target audience, we can also observe that, in addition to the few initiatives

aimed at Basic Education (only seven), three have not yet undergone the evaluation stage (Figure 4).

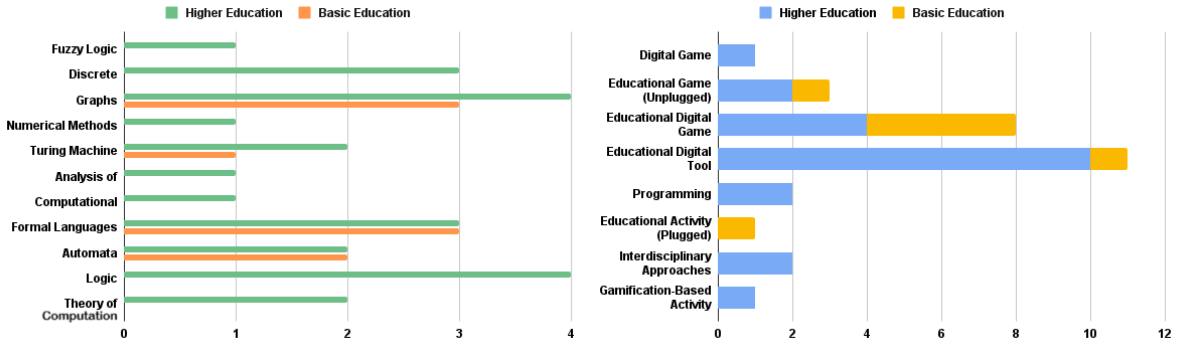

Figure 3 - Concepts addressed (left) and approaches applied (right) according to the audience

The predominance of qualitative and subjective assessment methods reflects the recent and experimental nature of active learning approaches in TCS Education. Since the field has long relied on abstract lecture-based instruction, the adoption of playful, game-based, and tool-supported strategies marks a pedagogical shift. Therefore, early studies are expected to focus on evaluating engagement, satisfaction, and UX, as these aspects help validate the feasibility and motivational potential of new approaches. However, the lack of emphasis on measuring learning weakens the empirical basis of the findings. In order to strengthen the evidence supporting these innovations, studies should also integrate qualitative and quantitative evaluations, using validated instruments to evaluate both engagement and learning effectiveness.

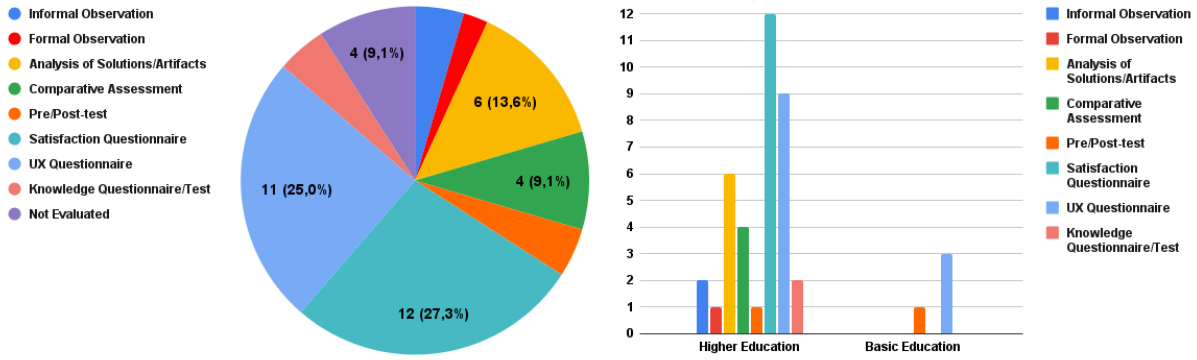

Figure 4 - Relative frequency of assessments (left) and by audience (right)

4. Conclusion

This article reviewed how TCS is being introduced within CSEd in Brazil. The findings reveal a predominance of active and game-based learning approaches, especially those employing digital educational tools and games to make abstract theoretical concepts more accessible and engaging. Although these initiatives represent a positive shift toward more dynamic pedagogical practices, the studies analyzed exhibit methodological diversity and lack of standardized assessment instruments. Consequently, learning measurement remains limited. Therefore, future research should adopt more rigorous and mixed-method evaluation strategies to strengthen the evidence on learning outcomes.

In the context of Basic Education, despite the recent inclusion of CS in the BNCC, initiatives addressing TCS remain scarce. This gap calls attention to the need for studies that integrate theoretical concepts into earlier educational stages. Advancing TCS teaching in

CSEd depends on consolidating pedagogical strategies that balance the theoretical rigor. As technological tools evolve and reduce technical barriers to coding, the promotion of deep computational reasoning becomes more important than ever. In this context, theoretical models can help separate conceptual understanding from syntactic skills, engaging students with the fundamental logic of CS. Investments in teacher training, along with the development of contextualized and engaging educational tools, can mitigate the perception of excessive abstraction often associated with TCS. Such efforts are essential to foster students' logical thinking, abstraction, problem solving skills, and computational reasoning, competencies that are fundamental to CS and essential to navigate an increasingly digital society.

This review also presents some limitations. No formal assessment of methodological quality was conducted for the included studies, as the analysis focused on providing a descriptive overview of initiatives rather than evaluating the internal validity of individual interventions. In addition, the search strategy relied on a manual search of selected Brazilian conferences and journals, which, while appropriate for capturing national initiatives and context-specific practices, may have excluded relevant studies indexed in global databases. Compared to automated searches, this approach limits reproducibility and may introduce selection bias. Despite these limitations, this review offers a consolidated landscape of Brazilian initiatives in TCS Education and identifies directions for future studies.

Acknowledgements

This work was supported by the Brazilian Federal Agency for Support and Evaluation of Graduate Education (CAPES), Financing Code 001, the SACCI Network, as well as the *Pró-Reitoria de Extensão e Cultura* (PREC) and the *Pró-Reitoria de Pesquisa e Pós-Graduação* of the Federal University of Pelotas.

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