Unlocking Sustainable Development Goals through Computational Thinking: A Search to Inform Computers Education from Citizen Science Dataset

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ABSTRACT

Linking sustainable development with computational thinking promotes high-impact problem solving, integrating fundamental concepts of computer programming. This study analyzed the relationship between computational thinking and the Sustainable Development Goals (SDGs) using text mining and data visualization techniques. A text mining method was employed to analyze computational thinking and its sub-competencies (decomposition, pattern recognition, abstraction and algorithm) appearances in the OSDG Community dataset, consisting of 32,120 text fragments labeled with the associated SDG. Results revealed that computational thinking and its subcompetencies: decomposition, pattern recognition, abstraction, and algorithm, were frequently linked to SDGs 4 (quality education), SDG 5 (gender equality), SDG 6 (clean water and sanitation), and SDG 11 (sustainable cities and communities). The findings demonstrate the potential of computational thinking to provide innovative solutions to global problems and support the achievement of the SDGs. The study can be of value to stakeholders in the social, governmental, academic and business sectors interested in sustainable development and educational innovation in the application of computational thinking.

CCS CONCEPTS

• **Applied computing** → Document management and text processing; Document searching; Education; • **Human-centered computing** → Visualization; Visualization application domains; Visual analytics.

KEYWORDS

Educational innovation, Computational thinking, Data visualization, Text mining

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1 INTRODUCTION

Computational thinking is a skill and way of thinking that allows people to understand and solve problems using computers and algorithms. The idea behind computational thinking is that all problems can be broken down and analyzed into smaller parts to be solved efficiently through programming. In [1], authors delineate computational thinking as a concept introduced into the problem-solving process and as a systematic way of thinking in computer science and various other disciplines. Authors from [2] state that computational thinking has provided a greater impetus to build an all-encompassing social network and foster a DIY culture enabled by digital technologies. Computational thinking has been recognized as one of the central pillars supporting the sustainable development of individuals and our digital world [3]. The Sustainable Development Goals are global targets set by the UN to address global environmental, economic, and social challenges. These goals include eradicating poverty, ensuring education and gender equality, reducing economic inequalities, promoting sustainable development, and protecting the environment.

Concerning these two themes, computational thinking and sustainable development are closely related in several aspects. On the one hand, computational thinking allows individuals to develop skills to create sustainable technological solutions to environmental challenges. For example, machine learning algorithms can be used to develop weather forecasting and monitoring systems to improve preparedness for and mitigation of natural disasters. On the other hand, technology can also drive sustainable development since using more efficient, and cleaner technologies can help reduce the environmental impact of industry and agriculture. For example, sensors and automatic control systems can be used to improve energy efficiency in factories and homes, thereby reducing energy consumption and greenhouse gas emissions.

In summary, computational thinking and sustainable development are two crucial aspects in the search for a more sustainable future. They complement each other, where computational thinking allows the development of technological solutions, and sustainable development promotes their proper use and implementation. Computational thinking has gained interest and influence in various

fields. In education, studies have focused on how computational thinking is learned and taught [4], assessed [5] or developed from technological strategies [6], [7]. Reviews have also been conducted in particular branches of knowledge such as STEAM fields [8], [9] or health sciences [10]. Regarding Education for Sustainable Development in higher education institutions is the review in [11]. So far there are no studies on the social dimension of computational thinking in education, which connects with the other two constructs object of this study: SDGs and citizen science. Therefore, this study aims to analyze a citizen science dataset of text excerpts labeled with the proposed SDGs to reveal the appearances of computational thinking and its subcompetencies, decomposition, pattern recognition, abstraction, and algorithm to demonstrate the potential of computational thinking in providing innovative solutions to a wide range of problems and support the achievement of the SDGs

2 RELATED WORKS

The construct of computational thinking is intrinsically psychopedagogical, dynamic and in constant evolution since the first definition proposed by Wing in [12]. At the present time, it can be stated that computational thinking is a type of cognition with a high level of abstraction that allows solving problems and needs of daily and social life as well as creating and expressing ideas and, for this purpose, it is supported by concepts, practices and perspectives of Computer Science, either from traditional computer programming or from more advanced digital enabling technologies such as the different areas that make up artificial intelligence [13]. Although programming tasks are the best way to demonstrate computational thinking skills, it is pertinent to note that one does not necessarily have to involve mobile devices for their development, hence the idea of computational thinking unplugged [14]. In the development of computational thinking are integrated a set of skills typical of computer science, such as: decomposition, pattern recognition, abstraction and algorithmic thinking [8]. Programming is not an end, but a manifestation of the skill. Based on this conceptual framework and, within the new learning ecologies, the development of computational thinking is part of the set of learning and skills necessary for the 21st century, since it allows the resolution of complex problems of daily and social life [15]. It has been shown how it contributes to the educational transformation aimed at developing learning connected to the present and future challenges of humanity. Likewise, it has a social aspect that contributes to a critical awareness and ethical review of its impact on society, as well as a practical application at the service of citizenship as an exercise of responsibility [16]. Both Education for Sustainable Development and the development of computational thinking are characterized as transversal competencies in the field of education and empower students to face changes.

Studies linking computational thinking based on solving sustainable development problems increase the potential for social impact. For example, in [17] authors developed an open platform with interactive web applications to complement teaching and encourage computational thinking for courses in computational physics, chemistry and materials science, using Jupyter notebooks and their representation as interactive web applications, where the code is ready to be implemented through a series of open approaches that allow content to be created and distributed and motivate on the basis of the reliability, sustainability, ease of acceptance and use. In the same sense, in [18] authors discovered the ecological difficulties in the integration of new technologies to promote inclusion and sustainability for the future, so they worked with robotic programming and the promotion of computational thinking and executive functioning, with special attention to vulnerable populations. Another development that links computational thinking and sustainability is that in [19] with a balanced scorecard tool integrated with computational thinking in university education, evidencing that students' logical thinking can be improved, which, in turn, is essential to maintain competitiveness. In the integration of artificial intelligence, sustainable development goals and scientific thinking, in [20], with the help of digital creativity tools. Computational thinking supports the formulation of alternatives for sustainable development.

Educational innovation plays an important role in promoting computational development practices linked to sustainable development. In [21] authors state that the application of pedagogical tools, such as problem-based learning or research-based learning and environmental tools, such as life cycle assessment and computational thinking, promote a sustainable approach to working on "soft skills" competencies in sustainability. Also, in [22], authors proposed an innovative method of educational teaching that integrates data visualization techniques and critical thinking training with computational thinking, to improve students' literacy in decision-making. In [23], authors worked with educational innovation and sustainable development, inspiring the logic of thought, with visual programming language, parametric virtual reality modeling, and hands-on 3D printing activities while integrating the Sustainable Development Goals and related thematic issues to develop practical skills and problem-solving skills. In [24], authors developed a waste separation game where they postulated for players to apply their knowledge by practicing computational skills sorting garbage correctly, evaluating the performance of the computational thinking player, through his ability to separate garbage, involving the Sustainable Development Goals in the application of learning. Applications of educational innovation in fostering computational thinking supports students' motivation [25]. Linking educational innovation strategies with the promotion of computational thinking can achieve interesting results to cultivate talent towards sustainable development.

3 METHODOLOGY

In this work, a text mining method was used to analyze computational thinking and its sub-competencies (decomposition, pattern recognition, abstraction and algorithm) appearances in text excerpts and the sustainable development goals targeted by these texts. This analysis allowed us to identify patterns and trends in the discussion of computational thinking and its relationship to the SDGs. In addition, the years in which these texts were published were analyzed to see how the topic has evolved. Through this methodology, it was possible to obtain an overview of the current state of computational thinking concerning Sustainable Development Goals and how it has evolved.

3.1 Dataset

In this research, we used the OSDG Community Dataset, which consisted of 32,120 text excerpts and 172,769 assigned labels. The dataset utilizes publicly available texts such as publications, reports, and other written materials. The texts are divided into smaller, paragraph-length segments, which community volunteers label. The SDG labels may be suggested by the source of the text but may not always align with the content of the specific paragraph. Volunteers are presented with a simple question to confirm the relevance of the suggested label for the given text segment. Multiple volunteers label the texts to ensure a high level of accuracy. A significant portion of the documents, which numbered more than 3,000, originated from United Nations-related sources such as the SDG-Pathfinder and the SDG Library. These sources were chosen because of their relevance to the research topic and their high credibility level. The dataset played a crucial role in providing the necessary information to conduct a thorough analysis in verifying how computational thinking appears in the text excerpts and arrive at meaningful conclusions to which SDG impacts this competence.

The datasets contains for each text excerpt the following information:

1. doi - Digital Object Identifier of the original document
2. text_id - unique text identifier
3. text - text excerpt from the document
4. sdg - the SDG the text is validated against
5. labels_negative - the number of volunteers who rejected the suggested SDG label
6. labels_positive - the number of volunteers who accepted the suggested SDG label
7. agreement - agreement score based on a given formula

3.2 Data cleaning and preprocessing

In our analysis, we sought to verify the entire dataset of text excerpts using their DOI (Digital Object Identifier) identifiers. This was done to ensure the data's authenticity and provide a reliable source of information. However, during the verification process, it was discovered that only 32027 out of 32120 instances could be verified using the DOI. As a result, we chose to reject the elements that could not be authenticated and focused only on the instances that were successfully verified. This allowed us to obtain the year in which the text was published, which was essential information for our analysis. By using the DOI identifiers, we were able to ensure the reliability and accuracy of the data and to gain a deeper understanding of the trends and patterns in the use of computational thinking and its subcompetencies in the context of the SDGs.

4 RESULTS

Figure 1 presents the results from the text mining analysis performed on a citizen science dataset of text excerpts labeled with the proposed Sustainable Development Goals (SDG). The figure provides an overview of the number of appearances of the concept of computational thinking and its subcompetencies in the dataset. This analysis aims to highlight the extent to which these concepts are being discussed in the context of the SDGs and can provide valuable insights into the field's current state. By visualizing the

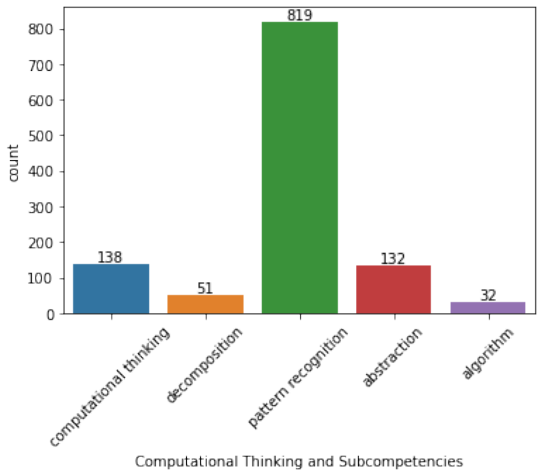

Figure 1: Number of appearances of Computational Thinking and its subcompetencies

frequency of mentions of computational thinking and its subcompetencies, this figure offers a snapshot of the level of engagement with these critical skills and helps to establish a baseline for future research in this area.

Figure 1 provides a clear picture of the frequency of appearance of computational thinking and its subcompetencies in the citizen science dataset. The analysis revealed that pattern recognition was the most prominent term found in the text excerpts, appearing significantly more often than the other subcompetencies, such as decomposition, abstraction, and algorithm. This result indicates that pattern recognition is a highly discussed and relevant aspect of computational thinking within the context of the SDGs. The frequency of mentions of pattern recognition highlights its importance in the field and provides insights into the current trends and priorities in using computational thinking for sustainability. This finding can inform future research and development in the area. It can guide the development of educational programs and initiatives to promote computational thinking and its subcompetencies for sustainable development.

Figure 2 shows a word cloud that visually represents the surrounding words of the term "computational thinking" in the text excerpts from the citizen science dataset. The word cloud was generated based on the frequency of occurrence of the words in proximity to "computational thinking" and provides a quick and intuitive way of understanding the most frequent terms that accompany it. This word cloud reveals the terms most associated with computational thinking and provides insight into the context in which the term is used in the text excerpts. By highlighting the keywords that are most linked to computational thinking, the word cloud helps to shed light on the areas of focus and the themes that are most relevant in discussions of computational thinking in the context of the SDGs.

Figure 3 shows a bubble chart representing the association between the Sustainable Development Goals (SDGs) and the term "computational thinking" in the citizen science dataset. This chart provides a visual representation of the frequency of mentions of each SDG

Figure 2: Words in the proximity to Computational Thinking term in the text excerpts

in proximity to "computational thinking" and allows for easy comparison of the different SDGs. The size of the bubbles in the chart corresponds to the level of association of each SDG with the term "computational thinking." The analysis revealed that SDG 4, which focuses on ensuring inclusive and equitable quality education and promoting lifelong learning opportunities for all, was the most prominent SDG linked to the term "computational thinking" in the dataset. This result highlights the importance of education and lifelong learning in the context of computational thinking and its role in promoting sustainable development.

In addition to the bubble chart, Figure 3 also includes a bar plot that displays the count of text excerpts for each year in which they were published. This bar plot provides a visual representation of the trends in the publication of text excerpts that mention "computational thinking" over time. The analysis results reveal a clear upward trend in the publications that mention "computational thinking," with a notable increase in recent years. This trend highlights the growing interest and attention being given to computational thinking and its role in promoting sustainable development. The increase in publications on the topic highlights the importance of ongoing research and development in computational thinking. It underscores the need for continued efforts to promote its use for sustainable development.

In addition to analyzing the frequency of mentions of "computational thinking" as a whole, the analysis in this article also sought to examine the subcompetencies of computational thinking in more detail. The subcompetencies of computational thinking include decomposition, pattern recognition, abstraction, and algorithm. Figure 4 presents word clouds for each of these subcompetencies, providing a visual representation of the surrounding words for each subcompetency based on the frequency of their occurrence in proximity to the relevant subcompetency. These word clouds provide a quick and intuitive way of understanding the most frequent terms associated with each subcompetency and the context in which they are used in the text excerpts.

The analysis in this article also aimed to examine the associations between the subcompetencies of computational thinking and Sustainable Development Goals (SDGs). Figure 5 presents a bubble chart representing the associations between the SDGs and the subcompetencies of computational thinking. The bubble chart visually displays the frequency of mentions of each Sustainable Development Goal (SDG) concerning the subcompetencies of Computational Thinking. The size of the bubbles in the chart represents the level of association with the subcompetencies. The results of the analysis reveal that SDG 5 (gender equality), SDG 6 (clean water and sanitation), SDG 11 (sustainable cities and communities), and SDG 4 (quality education) were the most prominent SDGs linked to the subcompetencies of computational thinking. This result highlights the importance of these SDGs in the context of computational thinking and their role in promoting sustainable development. Figure 5 also shows a bar plot that displays the value count of the years in which the text excerpts were published. This bar plot provides insights into the trends in publishing articles that mention the subcompetencies of computational thinking over time. The analysis results reveal a rise in the number of publications through the years that mention the subcompetencies of computational thinking. This increase in publications highlights the growing interest and significance of computational thinking and its subcompetencies.

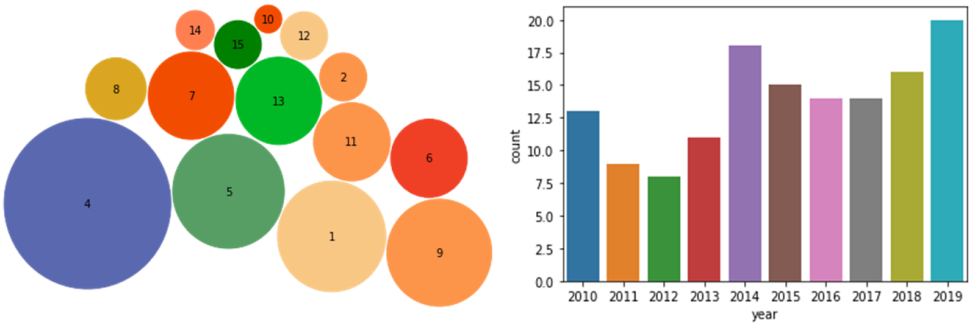

Figure 3: SDG related to Computational Thinking and the count of publications by year

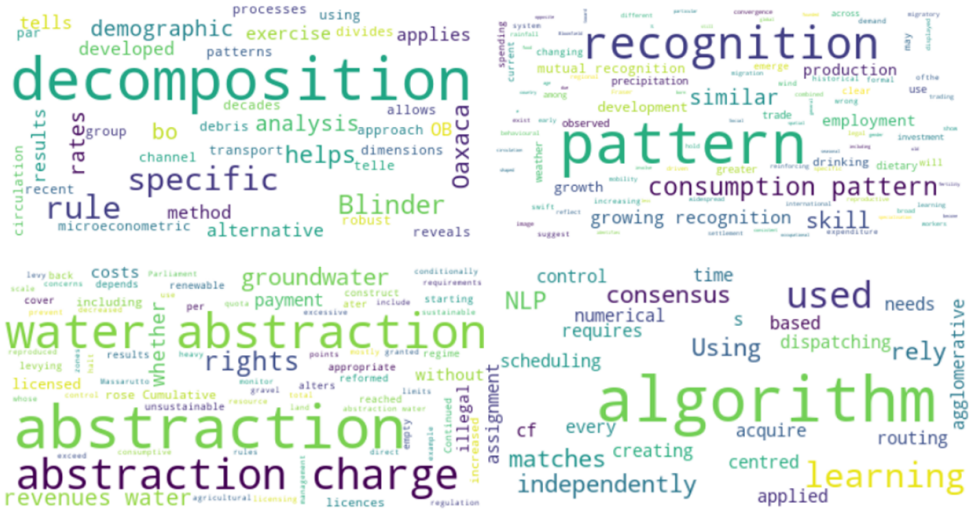

Figure 4: Words related to subcompetencies of Computational Thinking (decomposition, pattern recognition, abstraction and algorithm) in the text excerpt

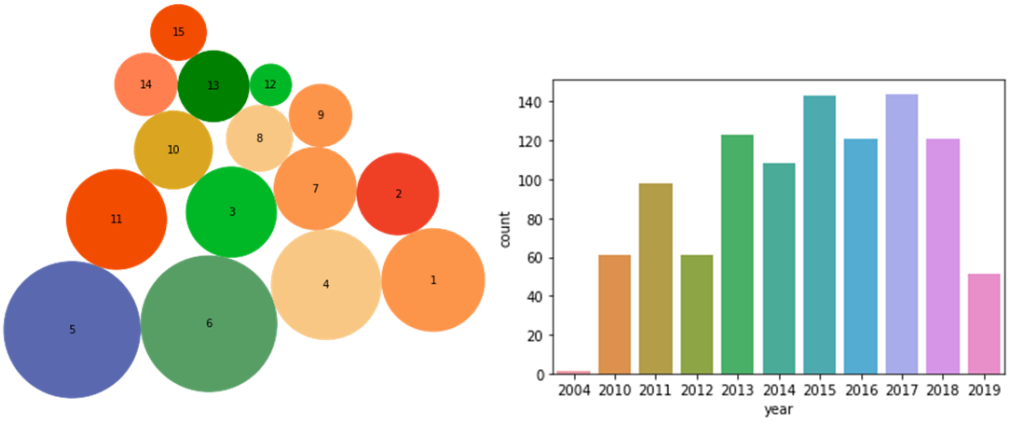

Figure 5: SDG related to Computational Thinking subcomptencies and the count of publications by year

5 DISCUSSION

The appearances of computational thinking and its subcompetencies in text excerpts linked to the Sustainable Development Goals (SDGs) are an essential indicator of the growing recognition of their significance in promoting sustainable development. Figure 1 shows the frequency of mentions of computational thinking and its subcompetencies in proximity to the SDGs. The analysis of these mentions provides valuable insights into the use of computational thinking in the context of the SDGs. It highlights the need for further research and development to unlock its full potential to advance sustainable development.

The linkage between computational thinking and the Sustainable Development Goals (SDGs) is crucial for advancing sustainable development and addressing complex global challenges. Figures 3 and 5 revealed that computational thinking and its subcompetencies, including decomposition, pattern recognition, abstraction, and algorithm, have a significant role in promoting sustainable development and advancing the SDGs, specifically SDG 4 (quality education), SDG 5 (gender equality), SDG 6 (clean water and sanitation), and SDG 11 (sustainable cities and communities). By incorporating computational thinking into various fields and industries, we can unlock its potential to support the SDGs' achievement and create a more sustainable and equitable world.

The current trend of the rise of the computational thinking term in articles over time reflects its growing significance in various fields and industries. Figures 3 and 5 showed that the current increase in the number of publications that mention computational thinking and its subcompetencies highlights the need for continued research and development in this area to fully unlock its potential to support the achievement of the Sustainable Development Goals (SDGs).

6 CONCLUSIONS

In conclusion, the current rising trend of computational thinking skills in the literature highlights the growing recognition of its importance in addressing complex global challenges and promoting sustainable development. The analysis of a citizen science dataset of text excerpts labeled with the proposed SDGs revealed that the appearances of computational thinking and its subcompetencies, decomposition, pattern recognition, abstraction, and algorithm, were frequently linked to the SDGs, mainly to SDG 4 (quality education), SDG 5 (gender equality), SDG 6 (clean water and sanitation), and SDG 11 (sustainable cities and communities). The findings of this study demonstrate the potential of computational thinking to provide innovative solutions to a wide range of problems and support the achievement of the SDGs. The increasing trend of mentions of computational thinking in the literature serves as a reminder of the need for continued research and development to unlock its potential to advance sustainable development fully.

Text mining and data visualization are powerful tools that allow us to extract insights from large datasets of text. Analyzing text excerpts allows it to uncover patterns and trends that might not be immediately apparent. In this study, text mining was used to extract information about computational thinking and its subcompetencies from a citizen science dataset of text excerpts. The results were then visualized using data visualization techniques, such as word clouds and bubble charts, to provide a clear and concise representation of the insights. This allowed us to better understand the relationship between computational thinking and the Sustainable Development Goals (SDGs) and to explore the trend of mentions of computational thinking in the literature over time.

The trend of mentions of computational thinking in the literature highlights the growing recognition of its importance for sustainable development. However, this study has limitations that should be considered when interpreting the results. Firstly, the text excerpts used in this study were limited to those that were published up to 2019. This means that the results may only represent part of the full range of discussions on computational thinking and its subcompetencies in the literature. Secondly, the majority of the sources for the text excerpts were limited to the SDG-Pathfinder and SDG Library databases. This means that the results may need to accurately reflect the broader discourse on computational thinking and its subcompetencies in the literature, as other sources may contain different perspectives or discussions on the topic. These limitations highlight the need for further research to comprehensively explore the relationship between computational thinking and the SDGs and gain a deeper understanding of the broader discourse on this topic in the literature.

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