A literature review on the educational use of Procedural Content Generation across disciplines

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Abstract

Procedural Content Generation (PCG) is a method to automatically generate content with little to no human assistance required. It emerges as a promising tool to generate educational content tailored to individual learning needs, a fundamental aspect of effective teaching. This review aims to provide an overview of existing research on the educational applications of PCG across disciplines. The key objectives of this paper include identifying the range of domains that have profited from the educational use of PCG, the challenges faced by specific disciplines as well as discerning the similarities and differences in their approaches. By addressing these objectives, this literature review seeks to identify areas for further research and provide insight into understanding the obstacles preventing the adoption of PCG in certain educational domains. By carefully surveying a sample of research conducted on the educational use of PCG in a broad range of disciplines, we found that computer science and mathematics have extensively leveraged PCG to enhance learning experiences, while natural sciences and social sciences could benefit from further research. To the best of our knowledge, fields like geography, physics and biology as well as arts, business and economics remain largely unexplored. Furthermore, challenges such as adjusting content difficulty, generating coherent exercises, and educational accuracy issues have been identified as significant barriers in various fields.

1 Introduction

Adapting to each student's needs and abilities is key to improving learning [1]. Procedural content generation (PCG) is a method to automatically generate content, which can be used to support this personalized approach [6]. Various studies have demonstrated that PCG is a promising tool for creating educational materials tailored to each individual, leading to greater improvements in student performance [23]. In addition, several experiments have shown that PCG can be used to create a wide range of exercises, thereby enhancing students' interest and enthusiasm for the topic [19]. Furthermore, PCG not only allows to create activities adapted to individual student needs but also reduces the time and costs required to develop educational materials [16].

This literature review aims to summarize the current research on the educational use of PCG in various disciplines. Gaining an understanding of what has already been achieved can help identify knowledge gaps and areas that could benefit from further research. More specifically, this research focuses on understanding which disciplines have profited from the educational use of PCG, identifying the benefits and challenges faced by each discipline and comparing the application of PCG in these domains. By answering these questions, this literature review will hopefully guide future work towards unexplored areas and help understand what challenges are yet to be overcome in the educational use of procedural content generation.

The structure of the remaining sections of this literature review is as follows: Section 2 describes the method used to identify, select and classify the papers included in this study. Section 3 discusses the range of disciplines that have profited from PCG and the discipline-specific benefits and challenges of PCG, while section 4 highlights the similarities and differences between the use of PCG across disciplines. Section 5 discusses the ethical implications of this research and potential biases that could influence the outcomes. Finally, section 6 summarizes the key findings of this paper, highlights the main contributions and proposes recommendations for future research.

2 Methodology

This literature review uses a comprehensive approach to explore the use of Procedural Content Generation (PCG) in education. The process began with the investigation of several academic databases, including Scopus[1], ACM Digital Library[2], and IEEE Xplore[3]. These databases were selected for their extensive collections of scholarly articles relevant to computer science, education, and technology. Pertinent keywords such as "procedural content generation", "PCG in education", and "adaptive learning with PCG", were used to collect an initial set of papers. During the review of each paper in this initial set, the "Related work" section was carefully examined to identify additional studies of interest.
Given the limited number of existing studies directly addressing the educational use of PCG, a systematic review was impractical. For instance, the query "(procedural AND content AND generation) AND education" in Scopus yielded only 57 papers, with just 22 cited more than five times. Therefore, we adopted a broad search strategy without strict systematic constraints.

Through group collaboration, a total of 182 papers were initially identified. Each paper was classified based on its abstract, resulting in 35 papers marked as "relevant" and 27 as "most relevant." The 27 most relevant papers were selected for their direct applicability to the research question and significant contributions to the field. Papers not investigating the direct use of PCG in education or those proposing approaches outside the scope of PCG were classified as "not relevant." The "relevant" papers, though containing interesting findings, were excluded for reasons such as redundancy with selected studies or a lack of focus on specific educational applications of PCG. Furthermore, to capture the most up-to-date findings, papers published more than 10 years ago were generally excluded. Exceptions were made for older papers that were highly relevant and significantly contributed to the field, especially in cases where more recent studies were lacking within a specific discipline. The definition of "educational disciplines" was restricted to traditional subjects typically covered in school curricula, namely mathematics, computer science, languages, natural sciences and social sciences. Papers focusing on broader educational goals, such as behavioural change through PCG, were excluded. However, some interesting studies in non-traditional fields are mentioned in the "Other" section of this research. Lastly, only papers written in English were considered for the accessibility of the research.
Each of the "most relevant" papers was read in full and analyzed in detail to identify key insights and implications. Using an iterative search strategy ensures that the review is complete and focused, providing a solid foundation for discussing the current state and future potential of PCG in education.

3 Discipline-specific benefits and challenges

Educational procedural content generation (PCG) has demonstrated its versatility and efficacy across a wide range of disciplines, significantly enhancing learning experiences. It offers many benefits across different disciplines, with some areas profiting more significantly than others. However, its implementation also presents challenges, often linked to the unique

[1] https://www.scopus.com/
[2] https://dl.acm.org/
[3] https://ieeexplore.ieee.org/Xplore/home.jsp

characteristics and requirements of each field. This section provides an overview of the studies done in various disciplines, identifying how each of them profited from the educational use of PCG and the challenges faced in these different domains.[4]

Table 1: Overview of key studies conducted in each discipline as well as their main contributions sorted by published year.

Discipline	**Year**	**Authors**	**Main Contributions**
Computer Science	2014	Smith and Harteveld. [22]	Demonstrated how PCG fosters collaborative mindful learning and enhances computational thinking skills.
	2017	Dong and Barnes [3]	Introduced a template-based puzzle generator for educational programming games, reducing development time by 80%.
	2017	Valls-Vargas et al. [24]	Developed a graph grammar-based generator to create puzzles for teaching parallel programming concepts.
	2018	Tiam-Lee and Sumi [23]	Presented a novel approach to generate programming exercises and provide guidance when confusion is detected.
	2020	Scirea [20]	Developed a PCG approach to generate puzzles adaptively to improve students' computational thinking skills.
	2020	Park et al. [16]	Introduced an ASP-based PCG approach to create adaptive game levels for teaching computer science concepts.
	2022	Lerlapon et al. [11]	Investigated Protobot, a game using PCG to generate mazes to improve algorithmic thinking skills.
	2023	Peeß et al. [17]	Introduced a grammar and parameterization-based generator for creating Python programming exercises.
Mathematics	2012	Andersen [1]	Discussed a model for generating adaptive content in a game teaching fractions.
	2014	Singhal et al. [21]	Developed a system for the automated generation of high school geometry questions.
	2017	Rodrigues et al. [19]	Developed a serious game using template-based PCG to generate math problems and motivate students.
	2017	Gupta et al. [5]	Introduced a framework for automating the generation of interdisciplinary math word problems.
	2021	Xu et al. [27]	Employed a template-based PCG approach to create diverse and solvable math problems, reducing workflow time by 56%.

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[4]Table 1 was generated with the assistance of LLMs, see appendix for further details

Discipline	**Year**	**Authors**	**Main Contributions**
	2023	Lifindra et al. [12]	Studied the impact of a math game with random maze generation on learning effectiveness.
Languages	2016	Huang and He [7]	Designed a tool for automatically generating short answer questions to assess reading comprehension.
	2018	Hooshyar et al. [6]	Developed a data-driven PCG approach to create educational games for improving early English skills.
	2018	Mu et al. [14]	Created a framework for generating questions that adapt to the student's pace while ensuring mastery of prerequisites for learning Korean.
	2022	Nugraha et al. [15]	Developed a serious game to enhance reading skills in preschoolers using adaptive PCG techniques.
Natural Sciences	2015	Kumar et al. [9]	Created an automatic fill-the-blank question generator for student self-assessment in science subjects.
	2018	Ar Rosyid et al. [2]	Deployed learning materials to game content, focusing on serious game development for science education.
	2023	Kumaran et al. [10]	Described an end-to-end PCG framework for creating levels in a serious game for environmentally sustainable education, usable by non-technical designers.
Social Sciences	2010	Yannakakis et al. [28]	Explored PCG for creating unique scenarios based on specific domains, players' skills, and learning objectives in conflict resolution games.
	2011	Grappiolo et al. [4]	Developed an adaptive serious game for conflict resolution, focusing on flexibility and strategy exploration.
	2016	Jouault et al. [8]	Proposed a method for generating high-quality questions based on history topics.
Others	2019	Pereira et al. [18]	Introduced a game for primary care physicians to learn about skin cancer, using PCG to reduce development time and adapt content to player knowledge.
	2020	Mitsis et al. [13]	Developed a serious game to raise awareness about obstructive sleep apnea and promote effective behaviour change using PCG.
	2023	Volden et al. [26]	Presented a framework to generate adaptive rules in a narrative puzzle game for kindergarten.

3.1 Computer Science

Research on the educational use of PCG in computer science has highlighted its potential to enhance learning by providing tailored and adaptive content. Park et al. introduced an innovative answer set programming (ASP)-based PCG approach to create adaptive game levels. This method not only increased the replayability of educational games, enhancing students' engagement but also reduced development costs [16]. Similarly, Sciera presented a PCG technique that generates puzzles adaptively based on player performance, improving students' computational thinking skills by automatically producing a variety of increasingly challenging levels [20]. Building on top of the study conducted by Scirea, Lerlapnon et al. developed *Protobote*, a maze-based game aimed at improving students' algorithmic thinking skills. Although it did not outperform traditional learning methods in improving participants' algorithmic thinking skills, it was found to be more engaging and interactive. This study also shows the ability of PCG to create near-limitless exercises, providing students with a collection of new and non-trivial challenges that would be infeasible to produce manually [11]. Likewise, Vall-Vargas et al. used graph grammar-based PCG to create puzzles for parallel programming education, showcasing the flexibility of PCG in addressing complex topics [24].

Only two studies demonstrated how PCG can be used to generate content outside the format of educational games. Peeß et al. introduced a grammar and parameterization-based generator for creating Python programming exercises, enabling the creation of a wide range of problems that can be adjusted based on various criteria such as difficulty and desired topic [17]. Tiam-Lee and Sumi also presented a PCG framework to generate programming exercises in a more traditional style, offering guidance when confusion is detected and adjusting the exercises based on student performance. Their experiment revealed that participants found this framework enjoyable and helpful, with guided students solving significantly more exercises [23].

One study specifically investigated how content creators can benefit from PCG to create educational resources. Dong and Barnes introduced a template-based puzzle generator for an educational programming game, highlighting PCG's benefits in saving development time and promoting creativity. Their experiment showed an 80% reduction in the time required to create complex puzzles with varied structures [3].

Lastly, Smith and Harteveld explored how PCG can foster collaborative mindful learning, particularly in enhancing computational thinking skills. This study emphasized the game's ability to encourage discussion and curiosity among players, especially young women [22].

Based on these studies, computer science stands out as a discipline that profits extensively from educational PCG. The dynamic and interactive nature of PCG aligns well with the requirements of computer science education, which often involves complex problem-solving and algorithmic thinking.

The implementation of PCG in computer science education also faces several challenges. The studies conducted by Scirea, and by Dong and Barnes, indicated that adjusting the difficulty of the generated exercises is challenging [20][3]. In Scirea's study, participants could not solve some puzzles because they were too complex [20]. Dong and Barnes also found that manually created puzzles included visual cues to guide students to the correct solution, whereas procedurally generated puzzles lacked these cues, sometimes making them almost impossible to solve, even for experts [3]. In addition, a few studies have shown a lack of coherence when using PCG, especially in text descriptions. Peeß et al. observed that some task information generated with their framework even gave away the solution to the exercise [17]. Tiam-Lee and Sumi also indicated that the generated exercises felt disjointed and did not form a meaningful story [23]. Finally, Smith and Harteveld emphasise that, although challenging, it is essential to create frameworks that provide enough flexibility and control to game designers in order to ensure that the content generated incorporates the right learning objectives [22].

3.2 Mathematics

The application of PCG in mathematics education has been investigated in various studies, showcasing that this discipline also greatly benefits from the educational use of PCG. Andersen discussed a framework for generating adaptive content in a game teaching fractions. This study demonstrated that PCG can successfully generate content tailored to students' skills [1]. Rodrigues et al. developed a serious game to motivate Brazilian 9-year-olds to learn mathematics, using template-based PCG to generate a near-infinite set of diverse questions. While not outperforming traditional methods, this approach enhanced engagement and motivation [19]. Lifindra et al. also investigated the effect of game-based learning, finding that PCG can make learning more interactive and effective by providing continuously new challenges and more practice material [12]. Singhal et al. focused on the automated generation of geometry questions for high school students, demonstrating how PCG can provide a diverse range of problems that combine various concepts and theorems [21].
Xu et al. used a controllable template-based PCG approach to create diverse and solvable math problems, reducing content creation time by 56% while ensuring that the questions generated are meaningful and relevant [27]. Gupta et al. developed a framework to automate the generation of mathematical word problems using inputs from various disciplines, benefiting interdisciplinary curricula [5]. Their pilot study showed that for 6 out of 10 given input concepts, their tool successfully generated new math word problems with a good level of accuracy. However, for the remaining 4 concepts, the newly generated math word problems lacked the desired structure and required manual adjustments. The ability of PCG to generate diverse and solvable math problems, as demonstrated by Xu et al. and Gupta et al., significantly reduces content creation time [27][5]. This allows educators to provide a wide range of relevant problems tailored to different difficulty levels and learning objectives, which is crucial for addressing the varied learning needs of students.

Although mathematics is a discipline where the educational use of PCG is quite prominent, several challenges still need to be addressed. Lifindra et al. and Rodrigues et al. both highlighted the need to adjust difficulty levels to ensure that problems are neither too easy nor too hard, which is crucial for maintaining students' engagement [12][19]. Similarly, Singhal et al. had to limit the set of concepts used, otherwise, the questions became too complex. [21]. Another significant challenge is ensuring that the generated content is coherent and relevant. Xu et al. reported that some of the language used in automatically generated content was not as sensible or fluent as that created by humans [27]. Likewise, Gupta et al. observed that 40% of the generated problems lacked the desired structure, highlighting the difficulty of maintaining consistency and quality. Additionally, they discussed the challenge of developing scalable frameworks that can easily incorporate new educational material [5]. Generating diverse and adaptive content that provides coherent and meaningful learning experiences remains a significant challenge in leveraging PCG for mathematical education.

3.3 Languages

Language studies also profit significantly from PCG, particularly in the areas of reading comprehension and foundational skills acquisition. PCG enables the creation of adaptive exercises, allowing students to learn at their own pace. Hooshyar et al. developed a serious game to improve early English skills, using PCG to adapt to users' needs and skills. Their experiment demonstrated significant performance gains when content was tailored to students' abilities . However, a 2019 study argued that Hooshyar et al.'s experiment did not accurately measure student progress and that empirical studies do not provide convincing evidence for the positive effect of adaptivity in education [25].
Despite this, other studies also demonstrated the potential of PCG to enhance learning. For instance, Nugraha et al. addressed the issue of illiteracy in Indonesia by developing a game which generates reading activities based on the player's performance. This showcases the potential of PCG to generate varied content and interactive activities that cater to different skill levels [15]. Similarly, Mu et al. combined adaptivity with progression ordering in an intelligent tutoring system, illustrating how PCG can sequence learning activities to adapt to students' pace, ensuring mastery of prerequisites for Korean language learning [14].
Additionally, Huang and He explored the automatic generation of short answer questions for assessing reading comprehension, improving efficiency, productivity, variety, and quality of question generation. This framework has the potential to enhance language education by providing a constant flow of relevant and challenging content to students [7].

Various challenges need to be addressed when implementing PCG in language education. Huang and He pointed out the complexity of creating high-quality questions. They noted that over 40% of the generated questions have deficiencies, primarily related to vagueness caused by the framework's inability to effectively incorporate context. For language learning, content should not only be grammatically correct but also contextually appropriate [7]. Furthermore, ensuring that the procedurally generated content aligns with educational goals and pedagogical principles is another significant challenge. The study conducted by Hooshyar et al. underlines the importance of incorporating educational theories into the content generation process to make it effective in a learning context [6]. Lastly, sequencing learning activities in a way that supports progressive skills development while maintaining a logical sequence of content requires careful refinement and validation of the PCG system [14].

3.4 Natural Sciences

The use of PCG in natural sciences education, although less prevalent, shows considerable promise. Kumar et al. presented a system for automatically generating questions in the format of fill-in-the-blank, demonstrating how automated question generation can support continuous learning and self-evaluation in scientific subjects and other disciplines. This approach can provide tailored questions that suit the study materials without requiring extensive work from teachers [9]. Kumaran et al. described an end-to-end PCG framework for creating levels in a serious game for sustainability education. This approach combined Large Language Models (LLMs) and PCG to enable non-technical designers to intuitively create educational games. The framework was assessed according to solvability, difficulty, variability and pedagogical relevance, showing encouraging results in making science education more accessible and engaging [10]. Finally, Ar Rosyid et al. developed a framework that seamlessly integrates learning materials into game content for serious educational game development. This illustrates how PCG can enhance the educational value of game-based learning in science. This is exemplified through the game *Chem Dungeon*, a game designed to help students learn and memorize the elements from the periodic table. The authors suggest that this approach could be applied to integrate various games and learning objectives in different disciplines, not just chemistry [2].

Despite these benefits, the implementation of PCG in natural sciences education also faces significant challenges. One of the major issues is maintaining the accuracy of the scientific content generated. The approach described by Kumaran et al., while promising, requires sophisticated capabilities to accurately interpret and generate scientifically valid educational activities [10]. Furthermore, ensuring that the questions are sufficiently varied and that the difficulty level is correctly adjusted is essential, as noted by Kumar et al [9]. This is also emphasised by the experiment conducted by Ar Rosyid et al., suggesting that future studies should incorporate adaptivity to ensure that the content is adjusted to the player's skills and progress [2]. Addressing these challenges is crucial to fully leverage the potential of PCG in natural sciences education, ensuring that it not only engages students but also delivers meaningful and accurate educational experiences.

3.5 Social Sciences

Research on the educational use of PCG in social sciences highlights its potential to create dynamic and adaptive learning experiences. Jouault et al. proposed a method for generating questions based on history topics, successfully creating diverse and content-dependent questions covering over 80% of the material [8]. Yannakakis et al. and Grappiolo et al. developed adaptive serious games for conflict resolution, the former in a multiplayer setting and the latter in a single-player mode. The development of adaptive serious games for conflict resolution demonstrates the potential of PCG to create engaging educational scenarios that enhance students' understanding of social dynamics and conflict management. Furthermore, the use of PCG enables players to experiment with resolving conflict scenarios from different perspectives and in a safe, consequence-free environment which adjusts based on their behaviour. This immersive and interactive approach stimulates the students to observe and reflect deeper on the impact of their decisions [28][4].

Implementing PCG in social sciences comes with its own set of challenges. The framework developed by Jouault et al. could only generate questions based on explicitly represented information, hence missing some of the underlying connections between topics. This is required to construct a deeper understanding of historical events and highlights the challenge of generating questions that accurately reflect the complexities of this field [8]. Furthermore, modelling realistic conflict scenarios that are both challenging and educationally meaningful, as discussed by Yannakakis et al. and Grappiolo et al., requires sophisticated algorithms and a thorough comprehension of social dynamics [28][4]. Addressing these challenges is essential to ensure that PCG systems in social sciences are both effective and engaging.

3.6 Other

The application of Procedural Content Generation in less traditional educational disciplines has shown interesting and intriguing possibilities. Volden et al. explored adapting difficulty levels in physical board games for kindergarten children, demonstrating how PCG can support cognitive skills learning through progressively challenging puzzles. This study also highlights the possibility of combining PCG with physical devices, showcasing its potential beyond digital formats [26]. Mitsis et al. explored the use of a genetic algorithm-based PCG in a serious game designed to educate about obstructive sleep apnea, indicating how tailored scenarios can enhance understanding of medical conditions through interactive learning [13]. Pereira et al. utilized PCG for storytelling in *Orange Care*, a game aimed at training primary care physicians about skin cancer, highlighting the role of PCG in creating diverse patient scenarios to simulate real-world medical diagnosis and treatment, providing medical trainees with a richer and more comprehensive training experience than traditional methods [18].

However, the challenges of implementing PCG in these less-traditional disciplines are notable. Volden et al. pointed out the difficulty in ensuring that the generated puzzles are adapted to the target audience, especially regarding the language use and adjustment of difficulty [26]. Mitsis et al. faced the challenge of creating medically accurate scenarios that are still engaging and challenging for players [13]. Pereira et al. also encountered difficulties in maintaining the narrative coherence and educational integrity of the patient scenarios generated by PCG [18]. Addressing these challenges is essential to maximize the educational potential of PCG in these unique and diverse disciplines, ensuring that the generated content is both engaging and educationally valuable.

4 Comparison between disciplines

The educational use of procedural content generation demonstrates both significant similarities and differences across various disciplines, reflecting the unique educational needs and challenges of each field.

4.1 Similarities

One similarity across most disciplines is the use of PCG to create **adaptive learning activities**. For instance, in computer science, Park et al. and Scirea utilize PCG to adjust game levels and puzzles based on player performance [16][20]. In mathematics, Andersen proposed a framework to tailor activities to the player's knowledge, ensuring that the content meets the student's current level of understanding. Similarly, in language studies, Mu et al. developed a framework that adapts to the student's learning pace, providing a personalized learning experience [14]. Yannakakis et al. and Grappiolo et al. presented adaptive games in social sciences, highlighting the importance of dynamically adjusting content to teach conflict resolution effectively, especially as outcomes heavily depend on players' actions [28][4]. Overall, adaptability is crucial for providing tailored learning experiences that meet individual student needs.

Another similarity is the role of PCG in **enhancing student engagement**. By generating challenging and diverse content, PCG significantly enhances student engagement. Rodrigues et al. observed increased engagement among students using a mathematical game with PCG-generated problems [19]. In computer science, Lertlapnon et al. found that games incorporating PCG were more engaging, even if they did not always outperform traditional methods in improving students' performance [11]. Nugraha et al.'s study on teaching reading skills revealed that their PCG framework made participants feel more challenged and focused [15]. Similarly, Ar Rosyid et al. demonstrated that PCG could efficiently combine educational materials and entertainment games to create engaging learning experiences in natural sciences [2].

Efficiency in content creation is also a widely recognized advantage of PCG across disciplines. Dong and Barnes highlighted an 80% reduction in development time for educational programming games using a template-based puzzle generator [3]. Xu et al. reported that using a PCG approach resulted in a 56% decrease in the time required to create math problems. [27]. Huang and He addressed the need for frameworks that automate question generation to reduce labour costs in developing exercises for reading comprehension assessments [7]. In the field of natural sciences, multiple studies aimed to alleviate the extensive effort required to create educational materials and enable even non-technical content creators to design educational activities effortlessly [9][2][10]. In social sciences, Jouault et al. developed a framework to efficiently generate high-quality questions to facilitate self-learning, particularly in situations where other resources are limited [8]. This efficiency allows educators and developers to focus more on enhancing the quality and diversity of educational content rather than spending excessive time on its creation.

4.2 Differences

Despite these similarities, **the implementation of PCG** varies significantly between disciplines. In computer science, PCG is primarily used to generate complex puzzles and game levels, as demonstrated by studies from Dong and Barnes, Park et al., and Scirea [3][16][20]. In mathematics, the type of content generated is more diverse. Some studies, such as those by Andersen, Rodrigues et al., and Lifindra et al., have applied PCG in the context of serious games [1][19][12]. Others, like Xu et al. and Singhal et al., have focused on generating a wide range of solvable problems and exercises in a more traditional format, using template-based and grammar-based methods [27][21]. In language studies, PCG is mainly utilized for generating reading comprehension tasks and activities for early skill development, as shown by Huang and He and Hooshyar et al. [7][6]. In social sciences, PCG has been used to create scenario-based questions and simulate real-life situations. For instance, Jouault et al. and Grappiolo et al. have developed frameworks that generate questions and scenarios tailored to students' knowledge and skills, fostering deeper engagement with the material [8][4].

Another difference is that different disciplines face **unique challenges** in implementing PCG. In computer science and mathematics, one of the key obstacles is tuning the difficulty and ensuring that the generated content is sufficiently varied to maintain interest and educational value as indicated in the studies conducted by Scirea and Rodrigues [20][19]. In contrast, in language education one of the main difficulties is to ensure that the questions align with the educational goals and are contextually suitable [6][7]. Meanwhile, in social sciences and natural sciences, due to the more nuanced and context-depend nature of these fields, the main challenge lies in ensuring the educational quality and accuracy of the generated content which is critical for effective learning outcomes [10][8].

5 Responsible research

The *Netherlands Code of Conduct for Research Integrity*[5] refers to five principles that researchers should adhere to in order to ensure good research practices and the integrity of their work. As part of an institution bound by this code, it is important to reflect on how this paper conforms to these principles.

- **Honesty**: This paper seeks to present an honest review of the studies conducted in the field of Procedural Content Generation (PCG) for education. We adopted an objective and analytical approach during the investigation of previous research and only reported facts that are supported by evidence. We acknowledge that, to some extent, personal beliefs and experiences can affect interpretation, but we mitigated this by directly reporting conclusions from the original papers. Moreover, by describing the research process and taking alternative opinions into consideration, we ensure that our findings are truthful and reliable.

- **Scrupulousness**: Reliable and trustworthy sources were used throughout this study to ensure the scrupulousness of the results presented. In addition, we used a collaborative approach and peer review to ensure that the method used and conclusions drawn are scientifically acceptable.

- **Transparency**: To ensure transparency, we provided a detailed description of the methodology applied to find relevant papers. Nevertheless, our process was not conducted in a systematic format, instead, we aimed to expand the collection of papers as broadly as possible. This choice was made due to the concern that there might not be sufficient papers to present meaningful results. While this approach might be more difficult for reproducibility, we documented our search process to the best of our ability, making the research steps as clear and verifiable as possible.

- **Independence**: No external considerations influenced this study, ensuring its independence. Our goal was purely scientific, with no hidden agendas or motives. We maintained impartiality throughout the design, conduct, and reporting of our research, unaffected by commercial or political interests.

- **Reponsibility**: The results presented in this study highlight the positive impact of using PCG in education, contributing to the United Nations' Sustainable Development Goal of "Quality Education"[6]. We ensured that our research is both scientifically and socially relevant, considering the interests of all stakeholders, including students, educators and content creators. This demonstrates our commitment to conducting research responsibly.

6 Conclusions and recommendations

In summary, while all disciplines can benefit from the educational use of PCG, computer science and mathematics profit the most due to the highly adaptive, versatile, and efficient nature of PCG. These fields often rely on clearly defined formulas and algorithms, allowing to easily generate educational activities based on these structured principles. Furthermore,

[5]https://www.nwo.nl/en/netherlands-code-conduct-research-integrity
[6]https://sdgs.un.org/goals

these fields particularly benefit from the ability of PCG to generate diverse, challenging, and personalized content, which enhances both student engagement and learning outcomes. On the other hand, subjects like languages, social sciences, and natural sciences often involve context-dependent and nuanced concepts which are much more difficult to generate with PCG. For instance, modeling historical events, supporting text analysis, or simulating ecological systems goes beyond simple rule-based generation. This highlights one of the biggest limitations of PCG, the lack of pedagogical understanding and contextual awareness. In addition, as highlighted in this review, PCG also lacks the ability to ensure the quality and educational value of the content generated. Regarding the similarities and differences of PCG across disciplines, PCG has been leveraged to create adaptive learning activities, enhance student engagement, and improve efficiency in content creation. While the underlying principles of PCG remain the same, its implementation changes to meet the specific educational goals and challenges of each discipline. This adaptability highlights the versatility and potential of PCG in enhancing learning experiences across diverse educational fields.

Although the use of PCG significantly contributed to certain educational fields, further research should be conducted in specific areas. Some studies have highlighted the potential of PCG to create educational scenarios in natural sciences and social sciences, but broader areas within these branches such as physics, biology, philosophy and geography have seen limited exploration. Additionally, the existing papers in these fields are relatively outdated, emphasising the need for new studies that incorporate more recent procedural methods. Other disciplines remain largely unexplored such as the arts, business and economics. These disciplines present both challenges and opportunities for the future application of PCG.

To illustrate potential applications of PCG in underexplored fields, we identified promising opportunities to expand the findings presented in this literature review to other disciplines. For instance, the method proposed by Singhal et al. could be utilized to assess students' knowledge of forces in physics, while the game designed by Valls-Vargas could serve as a foundation for teaching electricity concepts [21][24]. Additionally, PCG can create immersive learning experiences, as demonstrated by Yannakakis et al., enabling students to explore chemical reactions, the laws of physics, or the effects of climate change in an interactive and engaging environment [28]. These examples indicate the vast possibilities for extending PCG applications to other domains and how it can be leveraged to offer personalized, engaging and efficient learning experiences across the educational spectrum.

Lastly, due to the short time frame of this research, only a sample of papers was included in this literature review. Future studies are encouraged to allocate more time to the collection and analysis phase to ensure that all relevant studies are covered. Additionally, this review did not investigate the technical implementation of PCG across disciplines. Future research could focus on this aspect to identify the technical challenges of using PCG for educational activities. This would help enhance the practical application of PCG, ultimately contributing to improving the educational experience across a range of disciplines.

A Use of LLMs

Large Language Models (LLM) such as *ChatGTP*[7] and *Gemini*[8] have been used to assist with the organization and writing of this paper. This section provides more information regarding how these tools have been used and the measures taken to verify the correctness, reliability and relevance of the information. To ensure that the information reflected my own ideas, I initially provided the notes and summaries I made on each of the papers referenced in the review. I have then instructed the LLMs to only rely on these notes. Here is the prompt used at the start of the chat:

> "I am writing a literature review on the use of Procedural Content Generation in education across disciplines. Here are the papers I have read and my notes on each of them. In this chat, only rely on these to answer any follow-up questions."

After establishing the context, LLMs were mostly used to provide feedback on the flow of the text and guidance with re-phrasing certain sentences. All sections of this research were initially written by me and subsequently revised using LLMs. In most cases, only a few words of the original text were changed and often, other tools such as *Thesaurus*[9] were used to ensure the wording truly matched my style. In addition, LLMs were used to help with navigating Overleaf. A key example is the table 1 which provides a summary of the papers used and their key contributions. This was generated with *ChatGTP 4.o*. Before including it in this review, I cross-referenced all the information with my notes to guarantee the accuracy and integrity of the content.

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