Designing a Digital Ecosystem for Complex Thinking: Integrating Open Educational Resources with Sustainable Development Goals

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Abstract

This paper presents an approach to sustainability education through the design and testing of a digital ecosystem integrating Open Educational Resources (OER) within complex learning environments. By employing OER in the pedagogical strategy, the study aligns with the United Nations' Sustainable Development Goals, aiming to ensure inclusive and equitable quality education. We examine how these resources, coupled with self-regulated learning strategies, prepare learners to address sustainability challenges. The research demonstrates the utility of OER in facilitating accessible innovative teaching and learning methods that can be customized to various educational contexts, supporting curriculum development that embeds sustainable principles. The role of OER in educational technology and e-learning is explored, emphasizing their potential to democratize access to education and enable a participatory approach to learning. The findings indicate that OER facilitate the acquisition of knowledge and skills pertinent to sustainability and empower learners to become proactive, self-directed participants in their educational journey towards sustainability. Finally, the paper offers insights into inclusive education practices that foster sustainability, thereby contributing to a more sustainable future.

Keywords: Educational Technology, Educational Innovation, Higher Education, Open Education, SDGs.

1. Introduction

Complex thinking is crucial in today's rapidly changing world where individuals must navigate complex social, technological, and environmental challenges. Complex thinking is a cognitive process involving the analysis, synthesis, and evaluation of information to solve problems, make decisions, and understand holistic issues [1]. The significance of complex thinking in education is highlighted by authors advocating for instructional designs that foster deeper understanding and problem-solving abilities [2]. Conversely, the necessity of adaptive learning environments that cater to the non-linear and interconnected nature of knowledge, essential for mastering complex concepts is underscored by [3]. This discussion sets the stage for examining how digital ecosystems, particularly those integrating Open Educational Resources (OER), can enhance complex thinking in educational settings.

This article aims to present a novel approach to sustainability education by designing and testing a digital ecosystem that integrates OER with the Sustainable Development Goals (SDGs). Unlike previous studies, our focus is on combining OER's flexibility with structured complex learning tasks to cultivate self-regulated learning and critical thinking skills. The study aims to offer educators actionable strategies for embedding sustainable principles into curricula and demonstrate how tailored educational technologies can facilitate more effective and inclusive learning outcomes. These insights will significantly benefit stakeholders looking to leverage digital resources for education that is both transformative and aligned with global sustainability efforts.

2. Background

A. Sustainable Development Goals and Complex Thinking

The SDGs provide a global framework for addressing some of the most pressing challenges faced by humanity, including poverty, inequality, climate change, environmental degradation, peace, and justice. Global challenges require the development of complex and computational thinking skills to effectively tackle significant issues. [4] utilized the SDGs to address localized, real-world challenges aiming to benefit diverse societal groups. [5] highlighted the role of complex thinking training in fostering capable citizens who can positively impact the SDGs. [6] explored how computational thinking aligns with the SDGs, finding that complex thinking can lead to novel solutions for global challenges. Moreover, [7] argued for enhancing computational thinking to support SDG 4, which focuses on providing inclusive and quality education and promoting lifelong learning.

Addressing global issues through the SDGs presents an opportunity to leverage complex thinking. [8] suggested that integrating innovative educational methods with SDG-related topics and collaborative activities can enhance learning effectiveness and align outcomes across diverse learners. [9] examined learning outcomes related to SDG 11, which focuses on sustainable cities and communities, discussing the importance of educating students on the ethical use of AI technologies. Additionally, [10] fostered innovative educational tools in international training settings, aiming to achieve the SDGs by enhancing social entrepreneurship skills and complex thinking. This educational approach, ranging from AI to urban sustainability, prepares students to address and resolve critical contemporary challenges, fostering active and informed participation in crafting a sustainable future.

B. Open Educational Resources and Instructional Design

Instructional design plays a critical role in shaping educational experiences, particularly in the integration of technology to enhance learning outcomes. Effective instructional design must engage learners in solving real-world problems, which promotes active learning and retention [11]. Authors like [12] support this by highlighting that multimedia elements, when used judiciously, can optimize learning by aligning with cognitive processes such as dual coding and reducing cognitive load. Considering the technological, pedagogical, and content knowledge

(TPACK) framework, which ensures that technology's integration into education enhances teaching and learning without overshadowing content delivery [13]. This emphasis on thoughtful integration leads to the exploration of how technology can drive educational innovation.

Open Educational Resources (OER) are important in enhancing accessibility to educational content globally. OER offers the flexibility to adapt and redistribute educational materials, meeting diverse educational needs [14]. According to [15], the integration of OER into curricula enhances student engagement by providing more interactive and tailored learning experiences. The cost-effectiveness of OER allows institutions to allocate resources to other critical areas of development [16]. This utilization of OER not only democratizes education but also catalyzes the development of new teaching methodologies.

The challenge for instructional designers and educators is to harness technology in ways that fundamentally improve the educational process. Technology should be used to create environments that support constructing knowledge through exploration and inquiry rather than mere consumption of information [17]. The ADDIE model is a systematic framework used extensively in the field of instructional design to create effective educational and training programs. The Analysis phase is the foundation, where instructional designers identify the learning needs, goals, and objectives based on the learners' requirements and context. The Design phase involves selecting the right instructional strategies and media that align with the defined objectives and learner characteristics. The Development phase, where the actual creation of instructional materials takes place, following the blueprints established in the design phase. The structured approach of ADDIE ensures that each phase builds upon the outcomes of the previous, culminating in effective educational solutions. This perspective directs attention towards the practical applications of instructional design and technology in preparing learners for the complexities of the modern world.

C. Complex and Computational Thinking

Computational thinking and complex thinking, although intertwined, address different dimensions of problem-solving and decision-making. [18] defines computational thinking as involving problem formulation and solution processes that can be executed by an information-processing agent, emphasizing its broad applicability beyond mere programming. In higher education, the incorporation of computational thinking is regarded as a crucial competency for students, enabling them to solve problems effectively and excel in the modern digital work environment [19]. Furthermore, it enhances communicative abilities, and the capacity to organize, present, and scrutinize data [20]. By integrating computational thinking with an emphasis on developing complex thinking skills, higher education equips students to actively engage with and navigate complex problem situations.

Authors like [21] argue that computational thinking enables individuals to handle complex problems through systematic analysis, abstraction, and algorithm design, making it an indispensable skill in various fields. [22] further asserts that computational thinking enhances one's ability to think creatively, reason systematically, and work collaboratively, skills that are crucial for navigating today's digital landscape. These foundational capabilities set the stage for exploring how computational thinking interplays with and supports complex thinking in diverse contexts.

The synthesis of computational and complex thinking offers a robust framework for educational practices and cognitive development. By combining the structured, algorithmic approach of computational thinking [18] with the holistic, systems-oriented perspective of complex thinking, educators and learners can address more sophisticated and realistic challenges. This integration not only enriches the learning experience but also equips individuals with a comprehensive toolkit for innovation and adaptation in an increasingly complex society.

3. Motivations and Objectives

The imperative for integrating digital ecosystems in educational settings is driven by the need to enhance learning experiences and outcomes through technology. The rapid evolution of digital tools and platforms has provided unprecedented opportunities to foster more engaging and effective educational environments. However, the design and implementation of such ecosystems require a structured, evidence-based approach to ensure they meet educational needs and align with learning goals. There is a need for educational interventions that support the development of competencies through effective learning technologies.

4. Methods

The study adopted a design-based research (DBR) approach to examine the development of a digital ecosystem for complex thinking, integrating OER with challenges related to Sustainable Development Goals (SDGs). This methodology supports the dual aims of refining practice and enhancing understanding of the educational phenomenon under investigation. The use of DBR was justified by the need to iteratively design and test the digital ecosystem within actual educational settings, thus ensuring the practical relevance and theoretical rigor of the findings.
ADDIE, which stands for Analysis, Design, Development, Implementation, and Evaluation, is a widely used framework in instructional design for creating effective educational programs. The application of the ADDIE model in the design of the "SolarCT" course ensured a systematic approach to creating an educational experience that is both effective and engaging
In the development of the digital ecosystem, the ADDIE framework facilitated the mapping and organization of educational components, allowing the research team to visually articulate the integration of Open Educational Resources (OER) and Sustainable Development Goals (SDGs) challenges within complex learning environments. This modeling process helped identify key interactions and dependencies between the digital resources and learning activities, ensuring a coherent and structured educational pathway for users. The first prototype was tested by 34 university students from a public university in Peru who consented to participate in the study. Data collection occurred in a single session with each student working independently within a digital environment. The age range of the participants was from 18 to 73, and they were divided into four age categories. This iteration enabled iterative refinement by providing a clear, shared visual representation that could be easily adjusted in response to stakeholder feedback and pilot testing outcomes. This approach is crucial for aligning the digital ecosystem's design with both educational goals and user experience requirements, promoting effective learning and engagement.

5. Results

A. The Course

The "SolarCT: Computational Thinking and Energy” course represents an innovative approach to integrating computational thinking and renewable energy education. The design process for this course was developed to ensure that it not only meets educational standards but also addresses the urgent need for skills in sustainable energy solutions. The primary focus was on leveraging OERs to make learning accessible and adaptable to a global audience.

The course was conceptualized with the aim of fostering critical competencies in renewable energy technologies, particularly solar photovoltaic systems, and the application of computational and complex thinking in energy analysis. A multi-disciplinary approach was adopted, combining elements from environmental science, engineering, and computer science to create a holistic learning experience.

A review of existing literature on solar energy systems and computational thinking was conducted to define the core content. Simultaneously, a thorough search for available OERs was undertaken. The resources were evaluated based on their relevance, quality, accessibility, and alignment with the Sustainable Development Goals, particularly Goal 7: Affordable and Clean Energy.

The contents were structured into four themes focusing on key aspects of solar energy systems. Each theme was designed to build on the previous one, facilitating a progressive learning process. Interactive elements, such as videos, task-based learning tasks and quizzes, were integrated to enhance engagement and practical understanding.

B. References

The assessment of complex thinking skills was measured on a scale from 1.00 to 5.00, with different ranges indicating varying levels of competency. Specifically, scores from 1.00 to 2.33 were considered a low level of competency, suggesting a basic understanding of the subject. Scores between 2.34 and 3.66 were deemed a medium level, indicating a more developed skill set but not yet expert. Scores from 3.67 to 5.00 were categorized as high, representing advanced proficiency and mastery in the competencies.

Results showed that most of the participants (73.5%) scored in the high competency range. A smaller fraction of the participants (23.5%) scored in the medium range, and only a minimal number (2.9%) fell into the low range. Moreover, self-assessment data indicated that 25 participants perceived themselves as having high complex thinking skills, demonstrating strong confidence in their abilities. Eight participants viewed their skills as medium, showing moderate confidence, while only one participant rated their skills as low. This self-perception data is critical for customizing educational approaches to meet the varied needs and perceptions of learners, with the aim of enhancing their actual complex thinking skills.

C. Participants' engagement time with OER

The pilot study explored the relationship between the time participants spent on questions and their levels of complex thinking competency, shedding light on how time influences cognitive processing during assessments. The findings show that 50% of the participants spent an average of 185 seconds to respond to the assessment questions within the digital ecosystem. Another 29% of participants required significantly more time, averaging 638 seconds per question. This data reveals that half of the participants answered the questions in about 3 minutes, while nearly a third took around 10 and a half minutes.

D. Participants’ engagement time with OER according to their Complex Thinking Competency level.

All participants categorized with low complex thinking competency (3%) required an average of 638 seconds to respond to each question within the digital environment. Participants with a medium level of competency displayed varying response times, specifically 181 seconds or 638 seconds, representing the minimum and maximum durations observed in the study. Regarding participants with high complex thinking competency, the response times were diverse: 35.3% took 185 seconds, 20.6% needed 638 seconds, 11.8% responded in 193 seconds, and 2.9% answered in 181 and 272 seconds respectively.

By analyzing the time taken by participants with different competency levels, educators and researchers can identify patterns that may suggest efficient cognitive processing, and engagement. This information is valuable for designing targeted interventions aimed at improving complex thinking skills. For instance, longer response times at lower competency levels may indicate areas where instructional support can be intensified.

6. Discussion

The SolarCT course exemplifies a progressive educational model that integrates computational thinking with renewable energy concepts, focusing particularly on solar photovoltaic systems. According to the course evaluation, the majority of participants achieved high competency levels in complex thinking, with 73.5% scoring in the upper tier of the assessment scale. This aligns with [8] assertion that integrating interdisciplinary approaches in education through SDG-related topics and collaborative activities can enhance learning effectiveness and align outcomes across diverse learners. These findings suggest that the integration of computational thinking with practical energy solutions can significantly enhance learner competency, providing a robust foundation for future educational strategies in sustainable energy education.

Moreover, the engagement time with OER revealed distinctive patterns that correlate with participants' complex thinking competencies. Data indicates that participants with lower competency levels required longer to respond to assessment questions, averaging 638 seconds, while those with higher competency varied significantly in their response times. This observation supports the theory of [12] that multimedia elements can optimize learning by aligning with cognitive processes such as dual coding and reducing cognitive load. In this case, cognitive processing speed can reflect the depth of understanding in complex educational settings. Consequently, these insights could drive the development of targeted instructional materials that cater specifically to varying levels of learner proficiency, thereby optimizing educational outcomes in complex interdisciplinary settings.

7. Conclusion

In this article, we present the outcomes of developing and testing the Solar CT course, which is part of a digital ecosystem designed to teach complex and computational thinking to university students. The Solar CT course was developed to provide learners with strategies to effectively apply complex and computational thinking skills related to current challenges aligned with SDGs. The core concept is that mastering these skills begins with effectively analyzing and solving problems through systematic thinking and computational methods.

The study's results indicated that the course should offer a variety of learning pathways. Each pathway must be structured to allow students to assess its impact on their thinking skills. The course design and elements should clearly illustrate the connections between complex and computational thinking concepts. Based on a trial with students, the course successfully engaged students, leading to a serious evaluation of different learning scenarios presented within the course. This is one measure of the course's effectiveness. Further comprehensive testing in diverse educational settings, including students without prior digital learning experience and students from various socioeconomic backgrounds, is recommended. A lean process was then employed to refine the course content, making it more streamlined and user-friendly. Necessary resources such as manuals, lesson plans, and supporting materials will be provided to facilitate educators in implementing this digital ecosystem in the classroom.

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