SWOT Analysis of Early Exposure to Artificial Intelligence Competencies, Illustrated by an Example of Reinforcement Learning Accessible to Lower Secondary School Students

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This paper explores the process of early exposure to Artificial Intelligence (AI) competencies for students across various educational levels, focusing on its strengths, weaknesses, opportunities, and threats (SWOT). While the integration of AI into education presents both significant opportunities and challenges, its potential risks remain a critical area of ongoing research. In this contribution, we synthesize and explain findings from research on competencies, associated risks, and general experiences with AI in education at different levels, in order to develop a comprehensive SWOT analysis of the proposed process. The paper presents a lower secondary school research project as a case study, illustrating three key aspects: (1) the practical implementation of the proposed process, (2) competencies that students aged 12 to 18 can acquire through this method, and (3) the risks inherent in integrating AI into pedagogical practices. Additionally, we demonstrate the accessibility of reinforcement learning concepts to primary school students through an elementary example, showcasing how foundational AI principles can be effectively introduced at an early age. The findings highlight both the transformative potential and the challenges of equipping younger generations with essential AI competencies.

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1 Introduction

Artificial intelligence (AI) has become a cornerstone technology for science and industry (Samek & Müller, 2019; Huynh-The et al., 2023; EC, 2023). It is likely to have a profound impact on knowledge-driven processes in the coming years. As a result, it is essential to prepare future generations to engage with, utilize, and contribute to the development of AI technologies. Research into AI literacy in early education is gaining momentum, focusing on curriculum design, integrating AI tools in teaching, and creating pedagogical strategies, research methodologies, and evaluation frameworks (Su & Ng, 2023). Key challenges identified include insufficient teacher training, an underdeveloped curriculum, and a lack of clear pedagogical guidelines.

A crucial aspect of AI literacy is the development of digital competencies among educators and students. Digital competencies encompass not only technical skills but also pedagogical and ethical dimensions necessary for integrating AI effectively into education. Stojanov, Sekulić, and Risteski (2022) emphasize the importance of enhancing mathematics teachers' digital competencies, which can serve as a model for broader AI education initiatives. Additionally, Sekulić (2024) discusses the progress and future directions in digital competency development, highlighting the need for continuous professional training and policy support. Integrating digital competencies into AI education ensures that educators are prepared to guide students in responsible AI usage, fostering a more comprehensive understanding of technological impacts.

Research highlights the potential of AI to enhance individuals' well-being in education. Achieving this requires meaningful dialogue between researchers from diverse cultural and scientific backgrounds (Yang, Ogata, & Matsui, 2023), enabling AI to complement and amplify human intelligence - a concept referred to as human-centered AI. However, the integration of AI in education also comes with significant risks. A meta-study by Li and Gu (2023) reviewed these risks, categorizing them into eight distinct dimensions: misunderstanding of the human-centered AI concept, misuse of AI resources, mismatching of AI pedagogy, privacy security risk, transparency risk, accountability risk, bias risk, and perceived risk.

Concerning the competencies framework, for the purpose of this project, we consulted the UNESCO AI Competencies Framework for Students and Teachers, which provides a comprehensive structure for integrating AI literacy into educational systems (UNESCO, 2024). We used this framework to identify core competencies required to understand, apply, and critically assess AI technologies. Specifically, for students, it emphasizes foundational AI knowledge, ethical considerations, problem-solving, and adaptability. For teachers, it highlights instructional design, ethical leadership, and continuous professional development to support effective AI education. By leveraging this dual focus, we aimed to ensure that both educators and learners are equipped to navigate the evolving landscape of AI, fostering responsible and informed engagement with emerging technologies.

In what follows, we first overview the findings of the SWOT analysis in the form of an actionable list of projects that may develop relevant competencies of the students as well as illustrate the risks. We follow with a more detailed list of strengths, weaknesses, opportunities, and threats, and conclude with a list of possible further research identified but not yet analysed in this paper. We conclude with a summary of the findings.

2 Background research and methodology

The core of the paper builds upon a lower secondary school student project that illustrated the ability of students at age 12 to understand and develop reinforcement learning algorithms for obtaining strategies for simple mathematics games. The paper refers to this project as "The NIM project." We have found no other similar published projects aimed at primary school students, but we have no doubt that the proposed process will stimulate their appearance.

2.1 A case study project: Reinforcement learning illustrated with the game of Nim

The game of Nim is a simple mathematical game where players take one or two tokens per turn, with the player taking the last token losing. For a two-player game, there is an optimal strategy, which is proved by mathematical induction (Bokal, 2022). In a secondary school project, a student explored how effectively a computer could learn this strategy through reinforcement learning. Starting with random moves, the computer adjusted its strategy after each game based on outcomes. Winning moves increased in probability, while losing moves decreased. Over time, the probabilities for optimal moves approached 1. However, the learning speed depended greatly on the opponent's playing style. The study analyzed various types of opponent players:

- Random player plays randomly, with equal probabilities of taking one or two tokens (unless only one token remains).
- Winning player follows the optimal strategy—takes two tokens for 3n+3 tokens, one for 3n+2 tokens, and always takes one for 3n+1 tokens (where winning is impossible if the opponent plays optimally).
- Winning randomized player follows the same strategy as the winning player, but for 3n+1 tokens, it chooses randomly between taking one or two tokens with equal probability.

The distance between the learning player's strategy and the optimal strategy was calculated after each game in 200 learning sessions. The average of 100 learning curves for a fixed number of starting tokens was computed, playing against the three fixed-strategy players with varying initial tokens (1 to 10). This allowed us to compare the ability to learn the optimal strategy and the learning speed when learning was possible.

Figure 1 displays the average distance to the optimal strategy for variants starting with 1 to 10 tokens in a random player game, averaged over 100 sessions of 200 games each. With fewer tokens, the learning player converges to the optimal strategy faster. Since the random player makes moves at random, the learning player can still win with suboptimal moves, which are rewarded in these cases, making learning slower.

Learning progresses faster when the learning player faces a winning randomized player. If the learning player makes a mistake, the winning player wins, helping the learner identify suboptimal moves. Figure 2 shows that for any number of tokens other than 3n+1, the learning player quickly masters the optimal strategy, with the learning process being much faster than when playing against a random player.

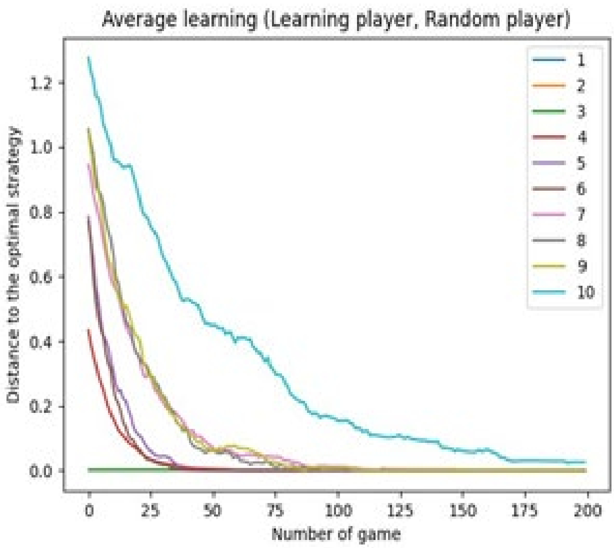

Figure 1: Average distance to optimal strategy learning against a random player
Source: Jerebic et al., 2024

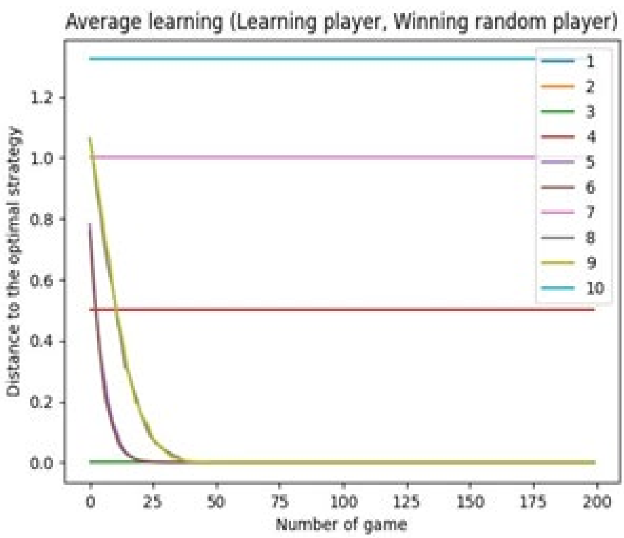

Figure 2: Average distance to optimal strategy learning against a winning randomized player
Source: Jerebic et al., 2024

Although learning is faster, the learning player has an advantage against the random player. The optimal strategy is always reached because the learning player can exploit the random player's mistakes. However, in games with a winning randomized player and 3n+1 tokens, no mistakes are made, so the learning player gains no benefit.

One might expect learning against a winning player to be as fast or faster than against a winning randomized player, but this is not the case (see Figure 3). The learning player never faces certain situations because the winning player always takes one token when there are 3n+1 tokens. As a result, while the learning player develops a strategy to beat the winning player, it never fully converges to the optimal strategy. Without further learning, it would struggle against a winning randomized player and even more so against a winning player that adapts with complementary responses in losing situations.

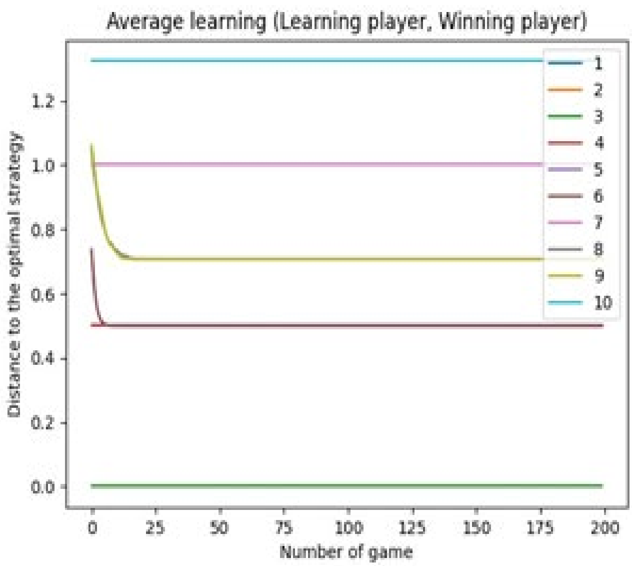

Figure 3: Average distance to optimal strategy learning against a winning player
Source: Jerebic et al., 2024

3 The dynamic SWOT analysis approach

Motivated by an opportunity presented by a lower secondary school student project (aged 12), we build upon competencies framework and illustrate which competencies were learned through the project, as well as through risk assessment based on Li & Gu (2023) and analysed in Jerebic et al. (2024), but extended by a wider bibliography review in the present contribution. We propose the following process of dynamically augmenting the presented SWOT analysis that can be applied whenever a new insight into SWOT elements is presented:

- identify a new source of information and its items,
- categorize the items of the source of information into strengths, weaknesses, opportunities and threats,
- associate the newly identified elements with the existing list of SWOT items,
- update the SWOT analysis,
- associate the newly discovered SWOT items with existing demonstration projects whenever possible,
- for the newly discovered SWOT items that cannot be associated with existing demonstration projects, develop new demonstration projects,
- disseminate the SWOT analysis and demonstration projects to interested parties.

This contribution is an intermediate report and a test of interest on using this process, for analysing the bibliography (Bacigalupo at al., 2016; Chiu et al., 2024; Filo et al., 2024; Jerebic et al., 2024; Li & Gu, 2023; Sattelmaier, Pawlowski, 2023; UNESCO, 2024; Zhang et al.; 2021). We intend to continue the research as proposed in the Future research section.

3.1 Overview of SWOT analysis

While the process from the previous section elaborates upon adding new SWOT elements or new illustrative projects to the body of knowledge on introducing AI into curriculum, in the following we list specific SWOT elements obtained in the process. They may serve as a list of reflection and learning opportunities to be discussed with the students after they either coded a selected project, or understood the principle and outcomes, possibly illustrating the understanding using the learning bot (Bokal & Bokal, 2024).

3.2 Details on Strengths

The dynamic inclusion of projects into a curriculum illustrating SWOT elements presents a basis for an up-to-date state-of-the-art curriculum that dynamically adjusts to the progress of respective fields and relevant discoveries. This key strength addresses the following other strengths of the approach, as taken from bibliography.

Ability to illustrate the effects of learning efficiency, authority and responsibility of the teacher. The NIM project demonstrates that the learning process is slow without authoritative and disciplined guidance (as when playing against a random player). However, in such a lost situation, the learner cannot acquire new knowledge, which can lead to apathy. If the teacher recognizes this danger, she can prevent it by deliberately making a mistake, thus allowing the students to take advantage of random opportunities to learn despite the potentially lost circumstances.

The integration of projects like the NIM project allows for dynamic adaptation and continuous curriculum updates, reflecting advancements in AI and pedagogy. The NIM project exemplifies how AI education can be integrated flexibly within existing curricula, allowing for real-time updates that reflect advancements in AI technologies and pedagogical strategies (Chiu, Ahmad, Ismailov, & Sanusi, 2024).

This project also demonstrates how different learning environments (e.g., random vs. optimal opponents) affect the efficiency and depth of learning. The project highlights the impact of different learning environments on student outcomes. For instance, facing optimal opponents accelerates the learning curve, offering insights into reinforcement learning dynamics.

Empowerment through practical application is reflected in gaining hands-on experience, not just theoretical knowledge, enhancing student's problem-solving and critical thinking skills. Students engage with AI concepts hands-on, moving beyond theoretical knowledge. This experiential learning fosters critical thinking, problem-solving, and a deeper understanding of AI principles.

The NIM project aligns with UNESCO's AI competencies framework by fostering foundational AI literacy, where students grasp core AI concepts such as reinforcement learning, decision-making algorithms, and probabilistic thinking (Filo, Rabin & Mor, 2024). It enhances critical thinking through the analysis of game outcomes, evaluation of strategies, and understanding of cause-effect relationships, thereby increasing cognitive flexibility. Furthermore, it promotes ethical awareness by introducing AI risks such as algorithmic bias and accountability, fostering early ethical considerations in technology use. Additionally, it cultivates human-centered AI understanding by enabling students to explore how AI can augment human decision-making rather than replace it, reinforcing the collaborative potential of AI-human interactions.

Teachers involved in the NIM project develop essential AI-related competencies as outlined by UNESCO AI Competencies Framework for Teachers, including pedagogical design for AI learning, ethical and inclusive AI education, and continuous professional development (UNESCO, 2024). This comprehensive development enables teachers to craft effective AI-integrated learning activities tailored to diverse educational contexts, promote fairness and inclusivity in AI instruction, and engage in lifelong learning to stay abreast of evolving AI technologies and pedagogical strategies.

The NIM project offers significant strengths in developing entrepreneurial competencies, particularly within the Ideas component, as outlined in the EntreComp Model (Bacigalupo et al., 2016). The project directly contributes to and highly supports the development of competencies such as spotting opportunities, vision, and valuing ideas. These competencies foster innovative thinking and strategic insight, equipping students with the ability to identify and capitalize on potential opportunities.

3.3 Details on Weaknesses

The perceived risk of introducing AI in education is a vaguely defined meta-risk (Li & Gu, 2023). It will be necessary for policymakers to be empowered about the risks of AI in order to issue appropriate regulations and guidelines. Nevertheless, we expect only few of them will be empowered to develop AI and understand its underlying mechanisms. The NIM project illustrates that risks are easier to understand but harder to mitigate. This is evident from the identified concepts needed to understand the reinforcement learning example, not included in the regular curriculum, compared to the actual implementation of the algorithms, which requires additional coding concepts (Jerebic et al., 2023).

The risk of mismatching of AI pedagogy. Learning materials, teaching concepts, and intelligent tools vary considerably between schools, leading to unsystematic pedagogy design (Zhang, Qin, Cheng, Marimuthu, and Kumar, 2021). Different approaches competing for resources further slow down the adoption of guidelines. The example of the NIM game illustrates that convergence towards the optimal strategy is slower. However, the diversity of approaches is not necessarily bad: if AI pedagogy converges too quickly, a uniform response could prevent the system from reaching the optimal strategy. Sharing best practices and comparing different approaches would be a reasonable compromise, as the game illustrates with the randomised winning player.

Accountability risks arise from weaknesses in the process of integrating AI into education. The responsibilities of educators, learners, and textbook publishers are unclear due to the dynamic nature of developing and managing AI models. Therefore, inefficient use of resources, extended learning periods, or insufficient strategies learned by learners can lead to unclear accountability. The NIM project highlights this by comparing (inefficient) learning against a random player with more efficient but potentially biased learning against a winning player, randomized or not.

Transparency risks represent a weakness, as shown by comparing the implementation of a winning player with that of a learning player. The winning player is programmed with optimal strategies, either clear decision rules or fixed probabilities. In contrast, the learning player must play numerous games to approximate these settings. Modern AI models rarely achieve such certainty or the explainability of clear decision rules, relying instead on less transparent probabilistic approximations. This vague encoding of decision rules highlights the risk of reduced transparency.

3.4 Details on Opportunities

Early exposure to AI competencies through projects like NIM can foster a generation of students proficient in AI, bridging gaps in current educational systems. This can present transformative opportunities for education, fostering a generation well-equipped for the AI-driven future (Sattelmaier & Pawlowski, 2023).

By embedding AI literacy within the curriculum, students are positioned to become future innovators and leaders in technology, addressing existing gaps in digital fluency across educational systems. AI projects like NIM encourage and facilitate cross-curricular connections, integrating mathematics, computer science, ethics, and social studies to provide a holistic educational experience. The scalable nature of the NIM project offers a flexible model for global AI curricula, adaptable to diverse educational contexts and resource environments globally, promoting inclusivity in AI education.

Furthermore, aligning with UNESCO's AI competencies framework, these initiatives support the development of advanced AI proficiencies, transitioning learners from foundational concepts to more complex topics like neural networks and natural language processing. Integrating ethical reasoning into AI curricula fosters critical awareness of the societal impacts of technology, encouraging responsible and reflective AI development.

Collaborative problem-solving within AI projects not only enhances technical competencies but also cultivates teamwork and interdisciplinary skills vital for real-world applications. Additionally, nurturing adaptability, which is in the core of reinforcement learning, and a growth mindset prepares students for continuous learning, ensuring they remain resilient and capable in rapidly evolving technological landscapes.

For teachers, the NIM project offers opportunities to enhance AI instructional competencies by developing innovative teaching strategies that effectively integrate AI concepts, aligned with UNESCO's AI competencies framework for teachers, (UNESCO, 2024). Through reflection upon the process as exemplified in this analysis, It also enables educators to promote ethical AI leadership, becoming advocates for ethical AI practices in education while guiding students to consider the broader social implications of technology. Moreover, teachers can engage in professional learning networks, participating in global communities of practice to exchange best practices and stay updated on AI educational trends. Ideating through the bot accompanying the theoretical analysis, the NIM project also offers significant opportunities for developing entrepreneurial competencies, (Bacigalupo et al., 2016, Bokal & Bokal, 2024). The opportunities are within the Actions component, and it promotes taking initiative, planning and management, and learning through experience. These competencies foster a mindset geared towards innovation and strategic thinking, providing students with practical skills and insights that are crucial for entrepreneurial success.

3.5 Details on Threats

By having a dynamic shaping of a curriculum, the key threat addresses stability of the learning process that is permanently under risk of changing its contents. This threat was in the NIM project illustrated through slowness of learning with the randomized opponent - in the presence of high variability, learning as convergence to the optimal learning approach is slow. However, there is an opposing threat as learning needs diversity and monotonicity can lead to deception. If the responses are not randomized in losing situations, some scenarios never arise for the learner. As a result, the learner gains no knowledge of these situations and cannot respond effectively. To address this, learners should be exposed to diverse experiences to develop appropriate reactions.

A threat of misuse of AI resources by users has been identified in the meta-study by Li and Gu (2023). With the NIM project, it has the most clear illustration: suppose a student would need to learn the optimal strategy of the game of Nim. If the student relies on one of the (artificial) winning players to provide winning moves, instead of understanding and developing the optimal strategy themselves, this would represent a misuse of AI resources.

The risk of bias in introducing AI into education is better seen as a threat rather than a weakness. Biased education could endanger society by manipulating knowledge, allowing AI providers to shape the information passed to future generations in their favor, rather than for the benefit of society as a whole. The NIM project illustrates this by comparing learning while playing against the winning player and against the randomized winning player. The former is biased, as it avoids exposing the mentee to certain situations, preventing them from developing proper responses. The latter exhibits self-centered authority, never allowing the mentee to win.

We interpret privacy security risks as threats: while low privacy security is a weakness, it is intimately related to malicious intents threatened by those with intent to abuse the weakness. The NIM project illustrates how learning bias limits the knowledge acquired, which is not initially perceived as a barrier by the mentee because it is not applied outside the narrow context of the learning context. However, when new contexts arise, the mentee's handicap results in inadequate responses, exposing the mentee to various risks, possibly including their safety or the safety of their activities.

Similarly, we interpret the risk of misunderstanding the concept of human-centered AI as a threat to the process. It is a meta-risk that encompasses the risks of bias, responsibility, transparency, safety, and privacy. These risks demonstrate how AI can deviate from serving humanity as a whole and instead cater to the narrow interests of certain individuals or groups. Mitigating these risks requires coordinated efforts from scholars, researchers, developers, educators, and users.

4 Discussion

AI being a state-of-the-art disruptive knowledge management and knowledge application technology is already showing a transformative impact on the education landscape, and there is no doubt it will significantly impact the careers of today's learners. Compartmentalising its aspects into competencies to learn and risks to avoid allows for a structural approach to mastering the body of knowledge required to navigate one's career in this landscape. Further dividing the competencies into strengths to apply and opportunities to seize allows the stakeholders of the education process to either seek opportunities given the strengths developed, or to develop strengths given the opportunities identified. Moreover, strengths and opportunities can be combined with individual interests, thereby allowing for personalised approaches to generally developed curricula.

Similarly, risks compartmentalized into weaknesses and threats can be considered as opportunities to either overcome by developing new knowledge or avoid by developing respective strengths. While some risks are generic to AI applications and are highly recommended to be understood, others arise in specific circumstances or with specific combinations of mentors, mentees, and challenges worked on.

Illustrating the above by student-developed AI projects has the advantage of bringing elementary principles behind highly complex technology to students as playful toy examples, allowing them to comprehend technical aspects of implementation in a highly controlled environment of games they understand. Additionally, these projects may strengthen their coding, modeling and abstract thinking competencies that are relevant for both scientific discovery as well as many arising workplaces. Using AI as aid may even prove advantageous in both developing the interest as in learning efficiency.

5 Further research

As mentioned in the section describing the process, the corpus of research investigated in this paper is far from exhausted. We intend to expand it with other competence frameworks (specifically, DigiComp requires a significant amount of work), and with other risk analyses.

The above discussion identifies opportunities for future research. A key direction is to develop an easily presentable and specifically scalable framework that would allow to identify competencies as strengths and opportunities, and risks as weaknesses and threats, and link them to reflection upon completed projects. In discussion with education stakeholders, the use cases for such a framework and its role in the introduction of human centered AI into education need to emerge and be publicised.

The next direction is to develop opportunities for students to actually partake in such example projects as the Nim project. Collecting this experience and reflecting upon SWOT elements touched through the projects would inform the AI education process, help it grow and mature. Moreover, maturity models could be developed and applied to track maturity of our understanding of both specific identified elements of SWOT, as well as their interplay and interaction with proposed AI understanding projects.

6 Conclusions

This paper has explored the early exposure of students to AI competencies, focusing on the strengths, weaknesses, opportunities, and threats (SWOT) of integrating AI into education. Through our case study of reinforcement learning was applied in the lower secondary school setting, the potential for young learners to develop essential AI-related competencies is demonstrated, as well as the risks associated with AI integration into pedagogical practices.

Our analysis highlights key AI competencies gained through early exposure. Computational thinking is enhanced as students engage in reinforcement learning projects like NIM, fostering problem-solving and algorithmic reasoning. Critical thinking and decision-making abilities are strengthened through interaction with AI models, enabling students to analyze strategies and predict outcomes. Ethical awareness is cultivated by introducing students to AI biases and ethical considerations such as transparency and accountability. AI education also fosters interdisciplinary connections across mathematics, computer science, and social sciences while encouraging entrepreneurial and innovative thinking.

Despite these advantages, integrating AI into education presents several risks and challenges. Variations in teaching methods and AI tools create inconsistencies, potentially leading to fragmented learning experiences. Lack of clear accountability and transparency in AI-driven decision-making complicates educator's roles in guiding students. Bias in AI models can reinforce misconceptions, while security and privacy threats expose students to potential misuse of AI-generated data. Additionally, an evolving curriculum may disrupt structured learning, and over-reliance on AI assistance can obstruct independent problem-solving skills. To address these issues, we recommend a dynamic SWOT augmentation process that incorporates new insights and projects to maintain an up-to-date educational framework. Future research should focus on developing a scalable AI competency framework, expanding practical AI learning opportunities through projects like NIM across diverse student groups, and establishing maturity models to track AI competency development.

By continuing to refine AI education through dynamic SWOT analysis and practical engagement, we can ensure that future generations develop the knowledge and skills necessary to navigate an AI-driven world responsibly and effectively. A structured and adaptive approach will enhance AI curricula while addressing potential risks. Collaboration among scholars, educators, and policymakers will be essential in shaping AI education into an inclusive and impactful learning experience, preparing students for the opportunities and challenges ahead.

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