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DEEP LEARNING-BASED CYBER PEDAGOGY MODEL TO IMPROVE 4C SKILLS (CRITICAL THINKING, COLLABORATION, CREATIVITY, AND COMMUNICATION)

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ABSTRACT

The need to strengthen 4C skills (critical thinking, collaboration, creativity, and communication) in vocational high school (SMK) students in the digital era is becoming increasingly urgent. However, the integration of Deep Learning (DL) in the cyber pedagogy framework to address these challenges is still limited. This study aims to develop a deep learning-based cyber pedagogy model to improve the 4C skills of SMK students. The approach used is Research and Development (R&D) with the prototype method through the stages of needs analysis, conceptual model development, validation, and dissemination. Preliminary analysis results show varying 4C skill profiles, with collaboration being the main strength (mean=3.13) followed by creativity (mean=3.08), while critical thinking remains the biggest challenge (mean=2.99). In addition, communication has the highest standard deviation (0.71), indicating a competency gap among students. The proposed model integrates DL to analyze student activities, such as written arguments, discussion interactions, and project originality, to generate adaptive and real-time feedback. Factors supporting the implementation of the model include the readiness of digital infrastructure, teachers' mastery of TPACK, and progressive institutional policies towards learning innovation. Conversely, the main challenges include limitations in AI literacy, resistance to pedagogical change, and issues of ethics and data security. This model offers a holistic approach that bridges pedagogy and advanced technology, creating personalized, collaborative, and data-driven learning. Thus, this research makes a strategic contribution to preparing highly competitive vocational school graduates who are relevant to the needs of the future digital industry.

I. INTRODUCTION

The development of digital technology and artificial intelligence (AI) has brought significant changes in improving the effectiveness of the learning process. Cyber pedagogy is a pedagogical approach that integrates digital technology into the learning process, and has been recognized as capable of creating a more interactive and adaptive learning environment [1]. In this context, the application of deep learning as part of AI offers great potential in recognizing complex data patterns and adjusting teaching methods to individual needs. However, despite the promising prospects of this technology, the application of deep learning in cyber pedagogy to develop 21st-century skills known as 4C Skills (critical thinking, collaboration, creativity, and communication skills) has received little attention.

Several previous studies have highlighted the importance of digital technology in supporting learning, such as the integration of digital technology in mathematics learning, which can improve 4C skills through a systematic approach based on literature analysis [2]. Furthermore, Computer Supported Collaborative Learning (CSCL) are widely used to foster student collaboration and creativity [3]. Another study emphasized the potential of game-based learning in enhancing students' critical thinking abilities [4]. However, none of these studies has embedded deep learning technology into the cyber pedagogy framework deeply. That gap leaves room for a more holistic approach.

The main problem faced in project-based learning in vocational high schools (SMK) is the lack of a holistic approach that can optimally train 4C skills. Conventional approaches often fail to provide personalized and adaptive learning experiences [5]. On the other hand, the role of TPACK (Technological Pedagogical and Content Knowledge) can improve 21st-century skills in vocational high school students through project-based learning and creative design [6]. Furthermore, the potential of deep learning can also create more inclusive and effective learning [7]. Based on these findings, the integration of deep learning in cyber pedagogy is a potential solution. Therefore, this study proposes a deep learning-based cyber pedagogy model to improve 4C skills. This approach will combine deep learning capabilities in in-depth data analysis with a digital pedagogical framework that supports online collaboration and individual creativity. The specific objectives of this study are to develop a deep learning-based learning model, determine the integration of deep learning with cyber pedagogy, and identify the supporting and inhibiting factors for its application. The urgency of this study lies in the urgent need to prepare vocational school graduates who have high technological competence and critical thinking, collaboration, creativity, and communication skills that are indispensable in the era of the Industrial Revolution 4.0 and Society 5.0.

The novelty of this study is the development of a holistic learning model that integrates deep learning with cyber pedagogy to train 4C skills. This study differs from previous studies that only focused on specific technological or pedagogical aspects without integrating the two [8]. The specifications of this model include the design of a deep learning-based learning system that can adjust teaching methods to students' learning styles, a technology-based collaborative learning environment, and the integration of learning projects to encourage student innovation. This research is expected to provide theoretical benefits, namely adding insight and contribution to the development of deep learning and cyber pedagogy-based learning models. In addition, it also provides practical benefits, namely by providing alternative learning models that can improve students' 4C skills.

II. RESEARCH METHODS

This study uses a research and development approach with a customized prototype method to produce a deep learning-based cyber pedagogy model to improve 4C skills. The prototype method aims to provide an initial overview of the application to be developed through prototype design, which will then be evaluated by users [9]. This research was conducted through four stages in accordance with the prototype method, involving the stages of needs analysis, conceptual model development, validation, and dissemination. The first stage was needs analysis to identify learning needs related to deep learning-based cyber pedagogy through a literature study. The second stage involved conceptual model development to compile an initial conceptual model based on the results of needs analysis and literature studies, as well as designing an initial prototype. The third stage involved conceptual model validation to ensure that the model met pedagogical and technological standards. The fourth stage involved dissemination and output to disseminate the research results.

III. RESULTS AND DISCUSSION

A. Descriptive Statistics Results

Based on the calculations, the mean, median, mode, and standard deviation values for each indicator of critical thinking, collaboration, creativity, and communication skills are presented in Table 1.

TABLE 1
MEAN, MEDIAN, MODE, AND STANDARD DEVIATION VALUES FOR EACH INDICATOR

Indicator	Mean	Median	Modus	Standar Deviasi
Critical Thinking	2,99	3	3	0,67
Collaboration	3,13	3	3	0,69
Creativity	3,08	3	3	0,64
Communication	3,06	3	3	0,71

Based on Table 1, the results of descriptive statistical analysis of the four 21st-century skills (4C) indicators show that the average (mean) score of respondents was in the range of 2.99-3.13. This indicates that, in general, critical thinking, collaboration, creativity, and communication skills were in the moderate to good category.

The critical thinking indicator obtained a mean of 2.99 with a median and mode of 3 and a standard deviation of 0.67. This value indicates that the respondents' critical thinking skills are still at a moderate level, with a relatively consistent distribution of answers. This condition suggests the need for learning strategies that emphasize the development of in-depth analysis, evaluation, and problem-solving skills. This condition is in line with findings that indicate critical thinking is the most challenging competency to improve through technology-based learning, thus requiring a more in-depth pedagogical approach [10].

The highest ranked item was collaboration indicator, with mean value of 3.13 (3; 3; stddev.[sd] = 0.69). These results suggest that the collaborative features of respondents are moderately good, at least as evaluated by themselves. This means that there is already a collaborative culture in the learning environment, but work still needs to be done to make teamwork more impactful and productive. The learning in the Digital Era context presents collaborative work through group discussion and projects that collaborate [11].

The mean, median, mode and standard deviations on the creativity indicator were 3.08 (Mean), 3 (Median), 3 (Mode) and 0.64 (S.D.) respectively. These results demonstrate that the creativity of respondents is quite matured where from the low standard deviation we can see a high level of consistency in their answers. That means, although the current level of creativeness is not yet optimum, most respondents have a uniform perception for creativeness. However, this achievement must go beyond merely repeating existing ideas, and instead allow students to create innovative solutions.

For the communication aspect, we found a mean of 3.06, a median of 3, mode of 3 and standard deviation of variance equal to 0.71. The average communication score among respondents is relatively higher, although the standard deviation indicates more differences in perception from this indicator compared to other indicators. This indicates that some respondents already have good communication skills, while others still face difficulties in conveying ideas or thoughts.

Overall, these findings confirm that collaboration is the main strength of the respondents, while critical thinking still requires further attention. The highest consistency was shown in creativity, while the greatest difference in perception occurred in communication. Thus, the results of this study can be used as a basis for developing learning strategies that emphasize the improvement of critical thinking and communication skills, without neglecting the strengthening of creativity and collaboration.

B. Conceptual Model Design for Cyber Pedagogy Learning

This deep learning-based cyber pedagogy conceptual model is a learning framework that utilizes a digital pedagogy (cyber pedagogy) approach with the support of Deep Learning (DL) technology to improve 4C Skills (Critical Thinking, Collaboration, Creativity, Communication) in vocational school students.

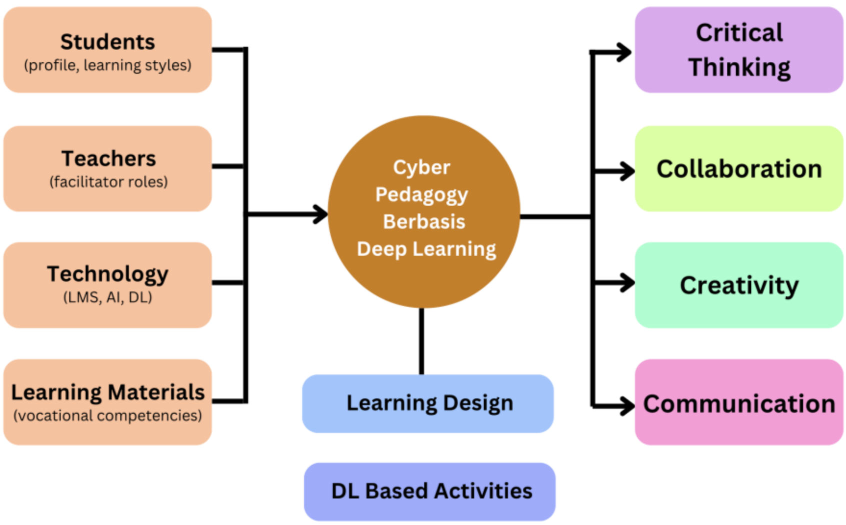

Fig. 1. Deep Learning (DL)-Based Cyber Pedagogy Learning Model

Based on Figure 1, this model shows the transformation flow from learning input to DL-based learning processes to the output in the form of students' 4C skills. First, at the input stage, learning begins by involving students as the main subjects who bring diverse backgrounds and learning styles. Teachers act as facilitators who design learning activities, while technologies such as LMS, AI, and deep learning engines serve as supporting tools. Learning materials are tailored to vocational competencies in vocational schools so that all input components are ready to support the learning process.

Second, all of these inputs are processed in the core of the deep learning-based cyber pedagogy model, where DL technology is used to analyze student learning activities, ranging from written answers, discussions, to presentations. The results of this analysis produce recommendations, scores, and feedback that help teachers adapt their learning strategies. Thus, technology and pedagogy complement each other to create a more meaningful learning experience.

Third, the learning design stage is carried out by developing project-based activities, problem-based learning, and collaborative discussions. Each activity is designed to bring out the 4C skill indicators, namely critical thinking through case studies, collaboration through teamwork, creativity through new ideas, and communication through presentations or discussion forums. With the support of DL modules, this design is able to provide an interactive, personalized learning experience that is relevant to the needs of the world of work.

Fourth, in the implementation of DL-based activities, students carry out learning by utilizing technology. Each student's contribution, both in discussions and in their work, is analyzed by the DL system to measure the skills that emerge. The results of the analysis in the form of automatic feedback are immediately given to students so that they can improve the quality of their learning, while teachers can monitor progress more objectively and in real-time.

Fifth, at the output stage, the result of the entire learning process is an increase in the 4C skills of vocational school students. Critical thinking skills are honed through analytical exercises, collaboration skills are developed through monitored group work, creativity grows from innovative activities encouraged by the system, and communication skills are trained through feedback on presentations and writing. Thus, this model emphasizes that the integration of cyber pedagogy and deep learning not only conveys material but also fosters 4C competencies, which are important assets for vocational school graduates in the digital industry era.

C. Integration of Deep Learning (DL) Technology with Cyber Pedagogy

The integration of DL technology is at the core of the proposed Cyber Pedagogy model, functioning as an intelligent engine that bridges digital learning activities with the achievement of 21st-century skills (4Cs). This is more than just using technology as a tool, but also rather as a pedagogical partner that can analyze, give feedback and personalize the learning experience adaptively. The second column in Table 2 provides a summary of how each component of the learning model caters to the needs identified through the data, thus making this integration of Deep Learning technology as both strategic and purpose-built.

TABLE II
INTEGRATION OF CYBER PEDAGOGY MODEL BASED ON DEEP LEARNING TO ENHANCE 4C SKILLS

4C Skills	Challenges Based on Research Findings	Role & Specific Applications of Deep Learning (DL)	Supporting Research
Critical Thinking	The average score (Mean 2.99) indicates that critical thinking competence needs to be strengthened.	Research in the field of Automated Feedback using Deep Learning (DL) can improve students' reasoning quality. The model is trained on a dataset consisting of various argumentative components, enabling the system to provide adaptive feedback that is substantive, not merely language-based.	Wambsganss et al. (2020)
Collaboration	The highest score (Mean 3.13), but collaboration needs to be made more effective and productive.	Epistemic Network Analysis (ENA) is an advanced analytical method (similar to AI/Machine Learning) that can model and visualize discussion connections, helping to uncover the "black box" of online collaboration activities. It enables the analysis of interaction processes and provides valid and meaningful insights.	Zhang et al. (2021)
Creativity	Consistency of responses is high (Standard Deviation 0.64), but creativity remains suboptimal and needs to be directed toward innovative solutions.	AI-based programs can enhance participants' creativity. The most effective condition is when AI provides adaptive feedback that encourages flexibility, innovation, and learner engagement.	Kreisberg-Nitzav & Kenett (2025)
Communication	The greatest variation in perception (Standard Deviation 0.71).	Analyzing errors, coherence, and perspective among English as a Foreign Language (EFL) teachers shows how AI tools influence students' writing, especially in idea development and organization.	Marzuki et al. (2023)

Based on Table 2, the need for this integration is reinforced by research findings, which reveal specific challenges such as critical thinking skills that still need to be improved (mean 2.99) and high variance in perceptions of communication skills (standard deviation 0.71). The DL integration mechanism in this model works by utilizing Natural Language Processing (NLP) algorithms and data analysis to process various forms of input from students, ranging from text in discussion forums, essays, to presentation transcripts. In line with the proposed framework, DL plays a role in several key aspects. The first is honing critical thinking skills. To address suboptimal critical thinking scores, the DL model can be trained to identify indicators of critical thinking in students' writing, such as the quality of arguments, the use of supporting evidence, and the identification of bias. The system will provide real-time feedback to students regarding the strengths and weaknesses of their analysis. This is in line with previous research that chatbots provide adaptive feedback to students as they write argumentative texts. Using artificial intelligence technology, this system examines whether students' arguments are backed by appropriate evidence and logical reasoning [12]. This directly underpins the utilization of DL to assess argument quality instantaneously.

Second, strengthening collaboration. Although collaboration scored highest (mean 3.13), DL can further improve its quality. The system can analyze interaction patterns within groups, such as each member's contribution, sentiment in discussions, and the interrelationship between ideas. This way, teachers can get a data-driven view of group dynamics and intercede when needed. Interaction data analysis can be used to identify the characteristics of

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effective collaboration, so that advanced data analysis techniques such as Epistemic Network Analysis (ENA), a computational analytical method (similar to AI/Machine Learning) for modeling and visualizing connections in discussions, can be used to unravel the “black box” of the collaboration process and provide deep insights [13].

Third, encouraging creativity. Creativity features the lowest standard deviation (0.64), suggesting a homogenous perception, although not necessarily an optimal one. DL technology can determine where students are, in terms of novelty or originality of ideas produced about their work. The AI program successfully increased participants' creativity, with the most effective conditions being those that provided feedback and adaptive difficulty (adjusted to participants' abilities), demonstrating AI's great potential to make creativity training more personalized, accessible to many people, and effective in supporting sustainable creativity growth [14].

Fourth, improving communication. The highest standard deviation in Communication (0.71) indicates the need for a more personalized approach. DL can analyze the clarity, coherence, and persuasiveness of students' oral presentations (through transcript analysis) and writing. The system can provide specific feedback, for example on sentence structure or the correct use of technical terms. AI tools such as Quillbot and WordTune are concrete examples of DL applications that serve to improve the quality of written communication, thus providing empirical evidence from the teacher's perspective that AI-based tools are indeed effective in improving writing quality, which is one of the main forms of communication [15].

Thus, the integration of deep learning in cyber pedagogy transforms the learning process into a responsive, data-driven ecosystem. This technology does not replace the role of teachers, but rather empowers them by providing in-depth analysis that would be difficult to do manually. In the context of vocational education, the use of smart technologies such as AI and DL is essential to prepare vocational school students for the demands of the dynamic digital industry. Through this model, every student interaction becomes valuable data that is processed to create a more personalized, effective learning path that focuses on strengthening the 4Cs competencies as a whole [16].

D. Supporting and Hindering Factors in the Implementation of Deep Learning-Based Cyber Pedagogy Model

Balance of facilitating and hindering elements gives a positive impact on the success of implementing Deep Learning (DL) - based Cyber Pedagogy models in vocation education. The details being the extent in which it would be possible to adapt well with models to enhance 4C skills@vocational schools. The technological infrastructure as well as teacher competence, student readiness and institutional policy support are several factors contributing to the successful implementation of this model. Adequate digital infrastructure, which includes available LMS, stable internet connectivity, and compatible computing devices have emerged as the primary foundation for running DL-based systems. Access and quality of technology infrastructure is one of the key determinants of success in implementing digital learning in Indonesia vocational schools [17], [23]–[24].

Secondly, teachers’ pedagogical and digital skills are decisive tool in this regard as teachers play the decorator role between technology and learning process. Teachers who master the TPACK approach will be better able to utilize DL technology to design adaptive and collaborative learning activities. This is supported by findings that the level of TPACK mastery among vocational school teachers has a significant positive correlation with their ability to effectively integrate technology into teaching practices [18]. Third, students' readiness for digital learning also supports the effectiveness of the model's implementation. Vocational school students who are familiar with technology have a higher potential to actively participate in AI-based learning environments. In addition, educational policy support from both the school and government levels, such as the Center of Excellence vocational school program and the integration of AI for Education into the national curriculum, also accelerate the adoption of this model. A culture of excellence within higher education institutions is essential for the success and long-term sustainability of innovations in teaching and learning, including digital transformation applications. Leadership effectiveness coupled with strong institutional policy support contributes to expediting the achievement of organizational goals [19], [27].

Nevertheless, several hurdles still render the deployment of this model difficult. On the one hand, technological resources are still limited in many vocational schools, particularly those located outside of cities. Hardware, fast internet networks and data storage servers are in limited provision. While programs like the Center of Excellence Vocational Schools (CoE) are supported with adequate infrastructure, many other schools continue to lag behind. This situation renders infrastructure a double-edged sword: a driver of progress to those, who are ready for it but also a barrier to those, who are not[20]

Second, teachers of AI and DL literacy lacked overall involvement in the system. Inadequate Pre-service Training Influences Teachers to Reflect DL as A Technical Tool instead of a Pedagogical Partner in the Learning ProcessAn inadequate pre-service training and a conscious awareness about how to use Data Literacy (DL) will make sure that the teachers reflect DL as just a technical tool for them rather than an assistant or partner. The majority of Indonesian teachers are still at a low level in the use of technology and will require intensive training to transform the technology into "AI-enhanced learning designers" [21]. Third, an obstacle is resistance against changes to the culture of learning. Some teachers and students might be uncomfortable with data- and algorithm-driven learning systems, especially when feedback comes from machines rather than humans. Fourth, ethical and data privacy issues should be taken into account as DL systems need big datasets to achieve the best performances. On the other hand, without clearly defined data security policies, misuse or leaking of information may occur [22], [25]-[26].

IV. CONCLUSION

Cyber Pedagogy models based on Deep Learning (DL) can trigger the enhancement of 21st century skills including 4C Skills (Critical Thinking, Collaboration, Creativity and Communication) in vocational high school students. The results of descriptive statistics indicate that the level of mastery of 4C skills is in the moderate to good range, where collaboration is the strongest aspect and critical thinking remains an aspect that needs special attention. Findings of such nature need to be taken into account in efforts towards the development and implementation of innovative learning models that inspire students not only to unlock these skills while inevitably collaborating, but also increase collaboration facilitated by integrated means of communication, critical thinking as well as creativity.

To fulfill these needs, the authors presented a DL-based Cyber Pedagogy model that involves a learning throughput from input (students, teachers and technology), process (DL-based adaptive analysis process) to output (enhanced 4C skills). By exploring the data with DL algorithms including Natural Language Processing (NLP) and Epistemic Network Analysis (ENA), this model identifies student learning performance, but also enables automatic feedback, individualized learning support for personalized learning, as well as sustains the collaborative and creative dimensions in a matrixed digital channel.

The application of DL in cyber pedagogy is strategic because DL makes technology a pedagogical partner that analyzes learning patterns, and adapts recommendations to support data-driven learning instead of being a mere tool. The readiness of graduates to resolve the fast-paced digital industry and complex world of work need is in line with demands from vocational education.

Nevertheless, the success of adopting this model is heavily reliant on some supporting factors in the form of adequate digital infrastructure, teachers' proficiency in applying TPACK and AI literacy, students' eagerness to engage with digital learning environments, as well as institutional policy support. However, there are still challenges in the forms of limited technological resources, low AI and DL literacy among teachers and resistance to change in learning culture as well as ethics and data privacy.

In conclusion, the growing phenomena of Deep Learning-empowered Cyber Pedagogy can serve as a basis for transforming learning paradigms in vocational schools from teacher-centered to an artificial intelligence-powered learner-centered learning stage. This model, with the appropriate policy support, infrastructure, and training can be an excellent building block to establish a smart collaborative vocational learning ecosystem relevant to Industry 4.0/5.0 era needs.

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