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Implementation of Differentiated Instruction Based on Computer-Supported Collaborative Learning to Improve Students' Logical Thinking Abilities

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ABSTRACT

The low level of logical thinking and the standardization of teaching methods are the main obstacles for vocational high school (SMK) students in understanding abstract computer network materials. This study aims to design and analyze the effectiveness and practicality of a Moodle Learning Management System (LMS) based on Computer-Supported Collaborative Learning (CSCL) that integrates Differentiated Instruction and the Problem-Based Learning (PBL) syntax. This study uses the Research and Development (R&D) method based on the Smart Learning Environment Establishment Guideline (SLEEG). The effectiveness test was conducted through a quasi-experiment (Nonequivalent Control Group Design) on 71 grade X students at SMK PGRI Subang. The results showed: (1) the developed media is highly feasible (material validation 80.00% and media 75.33%); (2) the implementation of the differentiated LMS significantly improved Logical Thinking skills, evidenced by the experimental class's N-Gain score (0.58) which exceeded the control class (0.51), a significance value of $p = 0.000$ ($p < 0.05$), and a Cohen's d of 1.945 (large effect); and (3) student responses to the practicality of the media were rated "Very Good" (88%) based on the UTAUT2 model, with Behavioral Intention achieving the highest score (91%). It is concluded that the integration of Differentiated Instruction within the CSCL ecosystem is proven valid, practical, and highly effective in facilitating the cognitive diversity of vocational students.

Keywords: Computer-Supported Collaborative Learning (CSCL); Differentiated Instruction; Problem-Based Learning (PBL); Logical Thinking; Moodle LMS.

INTRODUCTION

The quality of education in Indonesia faces significant challenges related to the low capacity for high-level cognitive reasoning. The PISA report shows that the average performance of Indonesian students in mathematics, reading, and science still ranks near the bottom globally (OECD, 2023). This low achievement indicates the suboptimal cognitive reasoning capacity of students in facing complex problems. Theoretically, high-level cognitive reasoning capacity is closely related to Logical Thinking skills (Ab et al., 2019). In the context of Vocational High Schools (SMK), this gap in Logical Thinking skills directly implicates the high mismatch rate between SMK graduates' competencies and industry needs (Mukhlason et al., 2020). SMK graduates are required to have systematic troubleshooting skills bound by deductive rules to respond to the dynamics of the technology industry.

This problem is clearly reflected in vocational learning at schools. Preliminary study results in the Computer and Telecommunication Network Engineering (TJKT) program at SMK PGRI Subang showed that Fundamentals of TJKT is the most difficult subject for 61.2% of students. Specifically, the biggest challenge lies in the Telecommunication Network and Media element, particularly the IPv4 addressing material (55.6%). The abstract, procedural, and mathematical characteristics of IPv4 require robust Logical Thinking skills so that students can accurately design addressing allocations (subnetting) and routing. However, an analysis of the causes of learning difficulties indicates that conventional teaching methods, which tend to standardize strategies for all students (one-size-fits-all), are less relevant. The majority of students complain that the material feels too difficult or too easy, and they expect the availability of learning materials tailored to their ability levels and learning comfort.

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Efforts to address this cognitive diversity require the application of Differentiated Instruction. According to Tomlinson & Imbeau (2023), differentiated instruction is a proactive approach where educators modify four curriculum elements—content, process, product, and affect—based on students' readiness, interests, and learning preferences. Nevertheless, implementing differentiation in conventional physical classrooms often encounters technical barriers. Educators experience time and space limitations to simultaneously monitor and facilitate each individual learning path and group collaboration dynamic (Lindner & Schwab, 2025). Therefore, technological intervention is needed in the form of Computer-Supported Collaborative Learning (CSCL). CSCL provides a structured digital environment that facilitates the co-construction of knowledge and sociocognitive negotiation among students through computer networks (Stahl et al., 2006; Chu et al., 2017). Through the integration of the Moodle Learning Management System (LMS) as the CSCL interface module (Bradley, 2021; Rosmansyah et al., 2023), differentiated instruction can be automated and personalized without sacrificing the essence of teamwork.

To optimize the logic formation process, this differentiated CSCL approach is combined with the Problem-Based Learning (PBL) model. PBL uses authentic real-world problems as a starting point for learning, which requires students to analyze problem premises, identify learning needs, and formulate solutions sequentially (Barrows & Tamblyn, 1980; Hmelo-Silver, 2004; Hung et al., 2008). The problem investigation process in PBL acts as the main trigger for Logical Thinking skills, which in Dettmer's framework (2025) is measured through a chain of cause-and-effect reasoning, starting from identifying problem symptoms (Current Reality Tree) to testing solution simulations (Future Reality Tree).

Several previous studies have examined the use of technology in both PBL and collaborative learning. However, most developed adaptive digital learning systems still focus on individual learning paths, making them seem individualistic and ignoring social interaction (Kurniawan et al., 2025; Urwah, 2023). On the other hand, collaborative or gamification research based on PBL generally applies a uniform scale of problem difficulty for all groups, making low-ability students prone to cognitive overload and falling behind in discussions (Chen et al., 2021; Islam, 2025). In addition, existing digital differentiation applications are often limited only to learning style variations (Al Husaeni, 2025) without considering material leveling based on cognitive readiness. These limitations show that applying one or two approaches separately is not enough to solve the problem of diverse understanding in vocational classrooms.

Therefore, the simultaneous integration of these three components—PBL, Differentiated Instruction, and CSCL—is highly necessary. PBL acts as the main stimulus that triggers causality reasoning through authentic problems, Differentiated Instruction provides proportional scaffolding according to the level of cognitive readiness, while CSCL provides a digital ecosystem capable of automating these differentiated instructions without eliminating the essence of interaction and idea exchange among students. As a novelty contribution, this study explicitly designs a smart learning environment that bridges this gap by combining the advantages of PBL, tiered content differentiation, heterogeneous group process differentiation, and final task product differentiation within a single CSCL interface. This study aims to implement and analyze the effectiveness and practicality of this integrated Moodle LMS media in improving the Logical Thinking abilities of vocational students in IPv4 material.

METHOD

This study employed a Research and Development (R&D) method to develop an educational product and empirically test its effectiveness. The research process was strictly divided into two main phases based on the Smart Learning Environment Establishment Guideline (SLEEG) framework, which adapts the ADDIE (Analyze, Design, Develop, Implement, Evaluate) instructional design model and the ISO 21001:2018 operational standard.

The first phase is the product development stage, executed through the Analyze, Design, and Develop steps. The main focus in this phase is to engineer and validate the feasibility of the product in the form of a Moodle Learning Management System (LMS) based on Computer-Supported Collaborative Learning (CSCL) that integrates Problem-Based Learning (PBL) syntax with a Differentiated Instruction approach in the elements of content, process, and product.

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The second phase is the empirical product effectiveness testing stage conducted during the Implement and Evaluate steps. In this testing phase, the approach used is a quasi-experiment with a Nonequivalent Control Group Design. The research population consists of students at SMK PGRI Subang in the Computer Network and Telecommunications Engineering (TJKT) program. Sample selection was carried out through a purposive sampling technique involving two intact classes in Phase E currently studying IPv4 material. The sample is divided into an experimental class totaling 35 students and a control class totaling 36 students. Considering the relatively limited sample size covering only one school institution, the test results in this study have generalization limitations. These effectiveness findings specifically represent students with academic characteristics and facility availability like the research location and are not intended to be universally generalized to all vocational students. In the implementation stage, the experimental class received treatment in the form of differentiated instruction within the CSCL ecosystem, while the control class received regular PBL learning without differentiation.

Data collection instruments in this study consisted of three types. First, validation sheets completed by subject matter and media experts, using an adaptation of the Learning Object Review Instrument (LORI) 2.0, to measure the system's feasibility. Second, an objective multiple-choice test administered as a pretest and posttest to measure students' Logical Thinking skills. This test instrument underwent empirical feasibility testing, including validity (Pearson Product Moment), reliability (Kuder-Richardson 20), difficulty index, and discrimination index. Third, a Likert-scale questionnaire distributed to students' post-treatment to measure the system's practicality and user acceptance, based on an adaptation of the Unified Theory of Acceptance and Use of Technology 2 (UTAUT2) model.

Data analysis was conducted in stages using descriptive and inferential statistics. Media validity was calculated based on the percentage of actual scores provided by the experts. The effectiveness of the improvement in Logical Thinking skills was analyzed using the Normalized Gain (N-Gain) test. Hypothesis testing for the mean difference between the experimental and control classes was conducted using an Independent Samples t-test, after ensuring the data distribution met the normality assumption via the Shapiro-Wilk Expanded Test and the homogeneity of variance assumption via Levene's Test. The magnitude of the treatment's impact was measured using Cohen's d effect size. Meanwhile, the level of media practicality from the UTAUT2 questionnaire was analyzed using the cumulative score percentage for each construct.

RESULTS AND DISCUSSION

Development of CSCL-Based Differentiated Moodle LMS

The development of this Computer-Supported Collaborative Learning (CSCL)-based Moodle Learning Management System (LMS) was executed following the Smart Learning Environment Establishment Guideline (SLEEG) framework, which adapts the ADDIE model (Branch, 2009; Rosmansyah et al., 2023). During the Analyze stage, field study findings at SMK PGRI Subang confirmed that Fundamentals of TJKT (*Dasar-Dasar TJKT*) was the most challenging subject (61.2%), with IPv4 addressing being the most difficult abstract sub-topic for students to comprehend (55.6%). Furthermore, the needs analysis identified that 56.1% of the students desired a digital discussion forum, and 44.9% required a real-time chat feature to overcome communication barriers and the lack of shared storage space during group work. These findings served as the foundation for designing a student-centered CSCL ecosystem.

During the Design and Develop stages, Problem-Based Learning (PBL) syntax was systematically integrated with three Differentiated Instruction schemes (Tomlinson & Imbeau, 2023) within the Moodle LMS. First, content differentiation was presented across three levels of cognitive readiness: Level 1 (theoretical concept understanding of IPv4/VLSM and OSPFv2), Level 2 (practical configuration guides on the GNS3 simulator), and Level 3 (network forensic analysis using Wireshark). Each material level was provided in two learning preference formats: Interactive Video (visual, auditory, kinesthetic) and Interactive Book (textual, independent). Second, process differentiation was facilitated through the Meeting Room (Discussion Forum) module in Moodle by utilizing the Separate Groups feature. This feature divided students into heterogeneous teams based on their learning readiness levels to foster peer-scaffolding dynamics. Third, product differentiation granted autonomy to each team to present their network problem scenario solutions as either technical reports or visual presentation slides within the Workshop module, followed by a peer-assessment process.

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During the prototyping-based development cycle, an internal evaluation (alpha testing) revealed errors, specifically cross-group forum privacy leaks and a failure in the automatic material unlocking system. Addressing these findings, improvements were made by reconfiguring the Separate Groups option and adjusting the logic of Activity Completion and Restricted Access to reference the parent grade, which captured the highest score from either the Interactive Video or Interactive Book formative quizzes. Once the prototype was stable, a feasibility test was conducted by three experts (two university lecturers and one TJKT practitioner teacher) using the Learning Object Review Instrument (LORI) 2.0 (Nesbit et al., 2009). A summary of the expert validation results is presented in Table 1.

Table 1. Percentage Results of Validation for Learning Materials and Moodle LMS Media (LORI 2.0)

No	Learning Material Evaluation Aspect	Percentage	Criteria	LMS Media Evaluation Aspect	Percentage	Criteria
1	Content Quality	80.00%	Feasible	Presentation Design	73.33%	Feasible
2	Learning Goal Alignment	86.67%	Highly Feasible	Interaction Usability	82.22%	Highly Feasible
3	Feedback & Adaptation	66.67%	Feasible	Accessibility	73.33%	Feasible
4	Motivation	86.67%	Highly Feasible	Standards Compliance	70.00%	Feasible
	Average	80.00%	Feasible		75.33%	Feasible

Based on Table 1, the validation score for teaching materials reached 80.00% (Feasible) and media validation reached 75.33% (Feasible). Qualitative recommendations from the validators regarding the improvement of feedback functions and portability were followed up by integrating the instant answer checking feature in H5P formative quizzes, embedding the Completion Progress block for real-time learning progress indicators, and optimizing the interface layout to be responsive when accessed via mobile devices.

The successful design of this LMS architecture has both theoretically and practically filled previous research gaps. The automation of tiered learning material presentation via *Restricted Access* addresses the primary constraint identified by Lindner & Schwab (2025), wherein conventional differentiation practices in physical classrooms frequently fail due to limited time and educators' manual managerial capacities. Furthermore, content differentiation within this LMS does not merely focus on learning style variations, as seen in Al Husaeni's (2025) study, but rather emphasizes the tiering of cognitive readiness. The integration of students into *Separate Groups* forums following independent learning also successfully prevented the overly individualistic learning isolation often found in adaptive digital platforms (Kurniawan et al., 2025; Urwah, 2023). This CSCL integration serves as a tangible manifestation of Vygotsky's constructivist theory regarding the Zone of Proximal Development (ZPD) (Wibowo et al., 2025), wherein digital collaboration facilitates the interactive co-construction of knowledge. The flexibility of final assignments within the *Workshop* module also resolves the limitations found in the studies by Nurwanti (2024) and Adhami & Taghizadeh (2024) which still applied homogeneous tasks within their collaborative environments.

The Effectiveness of Improving Students' Logical Thinking Skills

The testing of the treatment's effectiveness was conducted through the implementation (Implement) and evaluation (Evaluate) stages using a quasi-experimental design (Nonequivalent Control Group Design). Prior to the experiment, 60 test items were empirically tested for their feasibility on 60 students outside the research sample, resulting in 40 valid items ($r_{xy} > 0{,}2542$), high reliability ($r_{11} = 0{,}894$ via KR-20), as well as proportional difficulty and discrimination indices.

The experiment commenced with a pretest, followed by the administration of treatment over two PBL-CSCL-based meetings (the experimental class implemented Differentiated Instruction, while the control class received no differentiation), and concluded with a posttest. Before conducting the mean difference test, the data distribution was confirmed to meet the assumptions for parametric statistics, namely being normally distributed based on the Shapiro-Wilk Expanded Test ($p = 0.383$ for the Experimental N-Gain; $p = 0.098$ for the Control N-Gain, where $p > 0.05$) and having homogeneous variances based on Levene's Test ($F = 2.245$; $p = 0.139$, where $p > 0.05$). The baseline equivalence test using an Independent Samples t-test on the pretest data also proved that there was no significant difference between the two classes ($t = -1.391$; $p = 0.169 > 0.05$). A

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summary of the descriptive statistics, N-Gain scores, and the main hypothesis testing results is presented in Table 2.

Table 2. Summary of Descriptive Statistics, N-Gain, and Logical Thinking Hypothesis Testing

Group	N	Pretest Mean (SD)	Posttest Mean (SD)	N-Gain Category	t_{value}	Sig. (2-tailed)	Cohen's d	Effect Size Category
Experimental	35	41.57 (12.81)	75.21 (5.70)	Moderate	8.193	0.000	1.945	Large Effect
Control	36	46.25 (15.38)	73.75 (7.76)	Moderate				

Based on the data in Table 2, the experimental class recorded an average score gain (N-Gain) of 0.58, slightly higher than the control class with an N-Gain of 0.51. Although this absolute mean difference in N-Gain is relatively small, the primary hypothesis testing using an Independent Samples t-test on individual N-Gain data proved a statistically significant difference, with $t_{value} = 8{,}193$ and significance $p = 0.000$ ($p < 0.05$). Because the significance value was well below the 0.05 alpha level and $t_{\text{calculated}}$ exceeded the critical threshold t_{tabel} (1.995), H_0 was rejected and H_a was accepted. The calculation of the effect size magnitude using Cohen's d yielded a value of 1.945, falling well above the 0.80 threshold (large effect category / extremely strong influence).

The t-test and effect size analysis essentially measure not only the absolute mean difference but also evaluate this difference relative to the data distribution. The large effect size in this study did not stem solely from the range of N-Gain score differences; rather, it was driven by the very low standard deviation in the distribution of scores within the experimental group. This indicates that the CSCL-based Differentiated Instruction treatment delivered highly consistent, equitable, and uniform improvements in Logical Thinking skills across nearly all students in the experimental class, thereby rendering the treatment effect statistically robust. The high effectiveness of this treatment reinforces recent findings by Rahmasytoh et al. (2026) which confirm that integrating PBL with digital media and scaffolding techniques yields a significantly more substantial impact on enhancing higher-order cognitive skills compared to conventional PBL implementation.

Descriptive statistical analysis revealed a compelling baseline reversal phenomenon. Prior to the intervention, the experimental class had a lower baseline mean score (41.57) than the control class (46.25). However, following the treatment, the posttest mean score of the experimental class successfully reversed this status, surpassing that of the control class (75.21 versus 73.75). Furthermore, the distribution of N-Gain scores in the experimental class was more consistent and evenly spread, as indicated by a smaller standard deviation (0.029) compared to the control class (0.038). This finding regarding standard deviation equalization indicates that the Differentiated Instruction approach has the potential to accommodate diverse initial student comprehension levels. Students with lower baseline capabilities were supported in achieving mastery through material customization, while advanced students were able to further refine their skills.

The substantial impact of this treatment can be theoretically explained through *The Logical Thinking Process* framework (Dettmer, 2025) integrated into the PBL syntax. When confronted with complex network problem scenarios (such as DHCP Server glitches, NAT Masquerade rules, and OSPFv2 failover on the GNS3 simulator), the presence of scaffolding materials partitioned across three readiness levels is theoretically assumed to prevent cognitive overload in students. This aligns with recent research developments, such as the study by Annisa et al. (2026), which confirmed that adaptive technology support and personalization within the PBL ecosystem play a crucial role in fostering active engagement and stimulating higher-order reasoning skills in students. Conceptually, this differentiation feature enables students to trace problems logically ranging from identifying problem symptoms (*Current Reality Tree*), analyzing configuration conflicts (*Evaporating Cloud*), to testing solution simulations (*Future Reality Tree*) using the Wireshark forensic tool. These results simultaneously fill the research gap left by Chen et al. (2021), who implemented a collaborative spiral model but overlooked individual learning paces, and complement the work of Islam (2025), which relied on PBL gamification with a uniform difficulty scale. Through differentiation within the CSCL ecosystem, individualistic competition can be minimized and replaced by the establishment of a solid foundation for deductive reasoning in every individual.

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Media Practicality and Student Acceptance (UTAUT2)

The practicality and student acceptance of the CSCL-based differentiated Moodle LMS were evaluated using a questionnaire adapted from the eight constructs of the Unified Theory of Acceptance and Use of Technology 2 (UTAUT2) (Venkatesh et al., 2012). Data collected using a 7-point Likert scale were analyzed by calculating the percentage of actual scores relative to ideal scores. A summary of the student responses from both the experimental and control classes is presented in Figure 1.

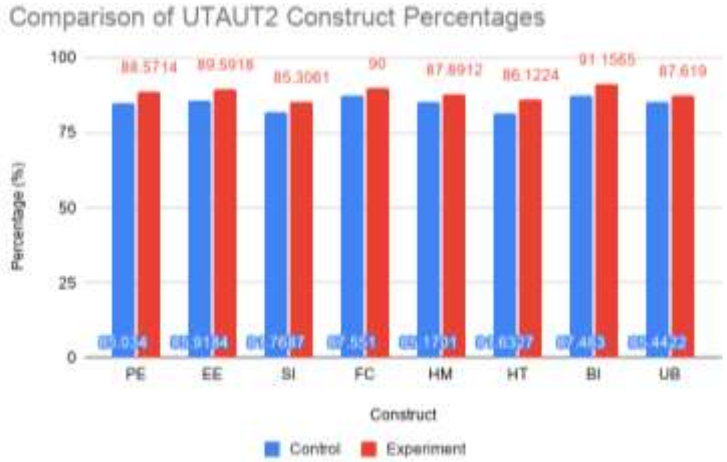

Figure 1. Summary of Student Responses Based on the UTAUT2 Model

Based on Figure 1, all UTAUT2 constructs across both groups achieved a high percentage of acceptance and consistently fell into the "Excellent" category. The experimental class recorded an overall average acceptance percentage of 88%, higher than the control class at 85%. These empirical findings are crucial, considering that CSCL implementation is often overshadowed by technical challenges, such as limited digital literacy and student reluctance to collaborate online. The high acceptance score in the experimental class indicates that the addition of differentiation features (such as tiered material access and task format flexibility) did not confuse or complicate LMS navigation; rather, it demonstrated a high perceived acceptance regarding the system's convenience and usability.

The difference in the highest percentage across constructs between the two classes provides compelling psychological insights. In the control class, the highest percentage was achieved by the *Facilitating Conditions* construct at 88%. This indicates that, in terms of infrastructure, students felt the hosting server and the Moodle LMS operated smoothly with minimal technical constraints. However, without autonomy and choice in learning, their intrinsic motivation did not reach its peak. Conversely, in the experimental class, the highest percentage was achieved by the *Behavioral Intention* construct at 91%. The high percentage in this construct demonstrates that when CSCL collaboration challenges are balanced with the freedom to choose material formats (*Interactive Video* or *Interactive Book*) and flexible task forms (reports or presentations), the system successfully fosters intrinsic motivation and a strong desire among students to continue using it in the future.

These empirical findings directly support the thesis of Muñoz-Carril et al. (2021), which states that the level of student satisfaction and perceived learning impact in a CSCL environment are not solely determined by technological sophistication, but rely heavily on the quality of task design and instructional support from educators. This study substantiates that perspective; although both classes utilized the same Moodle platform, the quality of the learning experience in the experimental class was vastly superior because it was supported by targeted Differentiated Instruction designed to reduce cognitive load when solving computer network problems. Overall, the integration of differentiated PBL within a CSCL environment has proven to be an approach that is not only effective in stimulating Logical Thinking skills but is also practical, inclusive, and highly satisfying for digital-generation vocational students.

CONCLUSION

Based on the research findings and discussion, it can be concluded that the integration of Differentiated Instruction within a Computer-Supported Collaborative Learning (CSCL) ecosystem using the Moodle Learning Management System (LMS) has proven to be highly feasible, practical, and effective in improving students'

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Logical Thinking skills. The system development, based on the Smart Learning Environment Establishment Guideline (SLEEG), successfully automated the differentiation of content, process, and product to accommodate the diversity of students' cognitive readiness levels. Within the context and sample limitations of this study, which involved 71 vocational students over two meetings, the implementation of this media significantly outperformed conventional learning by recording strong N-Gain and effect size scores, while simultaneously demonstrating the capacity to facilitate cognitive diversity among students. This success is supported by the system's high level of practicality based on the UTAUT2 evaluation, where the granted learning autonomy successfully maximized students' *Behavioral Intention*.

Despite yielding highly positive impacts, this study is limited by a relatively short implementation timeframe, comprising only two treatment meetings. Therefore, it is highly recommended for vocational school educators to begin continuously adopting the conditional access feature (*Restricted Access*) in the LMS to alleviate administrative burdens when facilitating heterogeneous classes. For future researchers, it is recommended to extend the implementation duration so that collaborative habits through digital forums (peer-scaffolding) can mature more fully. Further research is also encouraged to explore the addition of differentiation elements based on student interest profiles and to expand the scale of the trial population to comprehensively test the flexibility of this smart learning environment.

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