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# Enhancing self-regulated learning through artificial intelligence: experimental evidence from high school students

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**Abstract**

Self-regulated learning is a critical competency for supporting students' academic success, yet its development remains limited by outdated, inflexible teaching approaches. Meanwhile, the potential of artificial intelligence in education continues to grow, but empirical evidence regarding its effectiveness in enhancing self-regulated learning among secondary school students in Indonesia remains limited. This study aims to test the effectiveness of using an artificial intelligence application in enhancing students' self-regulated learning. The research method employed a quantitative approach using an experimental design with a pretest-posttest control group, involving 64 students divided into experimental and control groups via cluster random sampling. Data were collected using a self-regulated learning scale that had been validated for validity and reliability, then analyzed using an ANCOVA test with JAMOVI software. The results indicate that the experimental group demonstrated a significant increase in self-regulated learning compared to the control group ($p < 0.05$). These findings confirm that the use of artificial intelligence applications is highly effective in enhancing self-regulated learning among secondary school students and provide practical implications for technology-based development within school.

## Introduction

Self-regulated learning (SRL) skills are fundamental competencies that play a crucial role in students' academic success and their readiness to face increasingly complex learning challenges. Self-regulated learning refers to an individual's active process of systematically regulating thoughts, feelings, and actions to achieve learning goals (Zimmerman & Schunk, 1989). Students with strong SRL skills tend to demonstrate better academic performance, higher learning autonomy, and greater perseverance when facing learning challenges (Caixia et al., 2025). However, empirical evidence indicates that students' SRL levels remain suboptimal, particularly within the context of secondary education, which is still dominated by teacher-centered approaches and limited opportunities for student autonomy (Kismihók et al., 2020; Du et al., 2025; Jaarsveld et al., 2025).

Conventional learning approaches, such as group-based and project-based learning, often face structural limitations in fostering students' self-regulated learning (Baluarte-Araya &

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Ramirez-Valde, 2022). These approaches tend to fail to accommodate individual differences, provide inconsistent feedback, and limit students' opportunities to engage in goal-setting, self-monitoring, and self-evaluation (Lindner et al., 2021; Zheng et al., 2023; Taş & Minaz, 2024; Žerovnik, 2024). Consequently, many students remain dependent on external guidance and struggle to develop self-regulated learning effectively (Rone et al., 2023).

In the context of developing countries, including Indonesia, these challenges are further exacerbated by limited integration of technology into pedagogical practices, a lack of institutional support, and disparities in digital readiness (Santoso et al., 2022; Mali et al., 2023). Although digital technology is increasingly available in educational settings, its use is often limited to facilitating access to information rather than supporting deeper learning processes such as planning, monitoring, and evaluation of learning (Bala et al., 2020). Consequently, the potential of technology to promote learning remains limited.

Artificial intelligence (AI) has emerged as a promising approach to address these limitations by enabling adaptive, personalized, and real-time learning support (Akintola et al., 2025; Yarlagadda, 2025). AI-based applications can help students set learning goals, monitor their progress, and evaluate their performance, thereby directly supporting the improvement of students' SRL (Huang et al., 2022; S.-H. Jin et al., 2023). Furthermore, AI can serve as an external regulatory framework that gradually enhances students' metacognitive awareness and self-regulated learning.

In addition to its adaptive capabilities, artificial intelligence enables continuous formative feedback and data-driven learning support, which are essential for strengthening self-regulated learning (Žerovnik, 2024). Unlike conventional learning environments that rely on delayed teacher feedback, AI systems provide immediate responses to students' questions, allowing them to identify errors, adjust strategies, and refine their understanding in real-time (Calatayud et al., 2021). This immediacy supports the development of metacognitive awareness, as students become more actively engaged in monitoring and evaluating their own learning processes. Furthermore, AI applications can personalize learning pathways by adjusting content difficulty, recommendations, and feedback based on individual performance, thereby addressing the limitations of one-size-fits-all instructional approaches (Bognár et al., 2024).

From a motivational perspective, artificial intelligence can enhance student engagement through interactive and responsive learning experiences, which can boost perseverance and learning outcomes (Wu et al., 2024). However, despite these advantages, concerns remain regarding the potential for excessive reliance on artificial intelligence, which can diminish independent critical thinking if not properly guided (Sardi et al., 2025). Therefore, the integration of AI in education must be positioned not merely as a technological innovation, but as a pedagogical strategy that must be carefully designed to effectively enhance students' self-regulated learning.

Despite its potential, empirical evidence examining the effectiveness of artificial intelligence in enhancing self-regulated learning remains limited, particularly in the context of secondary education and in developing countries such as Indonesia. Most existing studies focus only on higher education settings or employ non-experimental designs, resulting in a lack of in-depth evidence regarding the impact of artificial intelligence on secondary school students' self-regulated learning. This gap highlights the need for rigorous experimental research to provide stronger evidence regarding how artificial intelligence can effectively support students' self-regulated learning.

Therefore, this study aims to examine the effectiveness of artificial intelligence-based learning interventions in enhancing students' self-regulated learning. The significance of this study lies in its contribution to providing empirical evidence regarding the role of artificial intelligence in supporting students' self-regulated learning in the context of high school education.

This study examines the use of an artificial intelligence application as the independent variable and students' self-regulated learning as the dependent variable. A quantitative experimental design with a pretest-posttest control group approach was used to evaluate the effectiveness of the intervention. The research hypothesis is that there will be an increase in the self-regulated learning abilities of high school students following the intervention using the artificial intelligence application compared to students who did not receive the artificial intelligence-based intervention.

## Methods

### Design

This study design which uses a quantitative experimental approach to test the effectiveness of using an artificial intelligence (AI) application in enhancing self-regulated learning (SRL) among high school students. The experimental design was chosen because it allows researchers to directly evaluate the causal relationship between the intervention administered and changes in the variables under study. This research design employs a pretest-posttest control group design, in which participants are divided into two groups: the experimental group, which receives an intervention involving the use of an AI application in the learning process, and the control group, which follows conventional learning without receiving the AI application intervention. SRL measurements were taken before and after the intervention to assess the changes occurring in both groups. This design is most suitable for answering the research question regarding the effectiveness of AI applications in improving the SRL abilities of high school students, as it allows for systematic comparison and control of external variables that could potentially influence the research results. See the table below for more details:

**Table 1.** Research Design

| Group | Pretest | Treatment | Posttest |
|---|---|---|---|
| Experimental R | O1 | X | O2 |
| Control R | O1 | - | O2 |

Note:
R : The group was selected at random
O1 : Pretest (an initial test administered before the intervention)
O2 : Posttest (final test administered after the treatment)
X : Treatment
- : Without treatment

### Participants

The participants in this study were 64 high school students from State High School 7 in Banjarmasin, Indonesia, during the 2025/2026 school year. The sampling technique employed was cluster random sampling, with the sampling units being classes selected at random from the available population. The selected classes were then designated as the experimental group (Class XI-11) and the control group (Class XI-10). This approach was chosen because it aligns with the context of educational research involving natural learning groups and to minimize disruption to the learning process at school. All participants were within the adolescent age range (15-17 years) and had basic experience in using digital technology. Participation was voluntary with the consent of the participants, using a Google Form to complete the instruments, a letter of authorization addressed to the school, and informed consent from the participants; all research procedures were conducted in accordance with research ethics principles. See the table below for more details:

**Table 2.** Demographic characteristics of the participant

| Demographics | Category | Groups | n | % |
|---|---|---|---|---|
| Gender | Male | Control | 12 | 18.8% |
| | | Experimental | 16 | 25% |
| | Female | Control | 19 | 29.7% |
| | | Experimental | 17 | 26.6% |
| Age | 15 years | Control | 0 | 0% |
| | | Experimental | 1 | 1.6% |
| | 16 years | Control | 19 | 29.7% |
| | | Experimental | 22 | 34.4% |
| | 17 years | Control | 12 | 18.8% |
| | | Experimental | 10 | 15.6% |
| **Total** | | | **64** | **100%** |

## Instruments

The measurement of self-regulated learning (SRL) in this study is based on Zimmerman's theory, which has been further developed according to the model proposed by Xin et al. (2024), and encompasses four main dimensions: motivation and action toward learning, planning and goal setting, strategies for learning and assessment, and lack of self-directedness. Examples of instrument statements from the planning and goal-setting dimension, such as "I learn according to my interests"; the strategies for learning and assessment dimension, such as "I make a plan on how I will carry out the learning process"; the strategies for learning and assessment dimension, such as "I evaluate whether my goals are accomplished or not" and the lack of self-directedness dimension, such as "I wait for people to tell me what to do in learning". The instrument was designed as a five-point Likert scale that reflects the respondents' level of agreement with each statement. Before being used in the study, this scale underwent a content validation process through expert judgment. The assessment results were analyzed using Gregory's validity, which yielded a value of 1.00, indicating a very high level of agreement among validators following several revisions and confirming that all items in the instrument possess strong content validity and are suitable for measurement.

In addition, the reliability test used composite reliability because it changed from a multidimensional construct to a unidimensional one, yielding a high reliability coefficient of 0.959; thus, the instrument was deemed to have good internal consistency. In addition to the measurement instrument, this study also developed an experimental module as a guide for implementing interventions using artificial intelligence (AI) applications, specifically Perplexity AI, in the learning process. The module was designed to facilitate the development of students' SRL through stages aligned with the dimensions of SRL. The experimental module includes learning objectives, activity steps, guidelines for using the AI application, student worksheets, and evaluation mechanisms.

To ensure the quality and suitability of the implementation, the experimental module also underwent an expert judgment process involving experts in the fields of educational psychology and learning technology. The assessment focused on the appropriateness of the content, the clarity of the instructions, the relevance to the SRL construct, and pedagogical suitability. The results of the evaluation, following several revisions, indicated that the module demonstrated a very high level of appropriateness and was deemed suitable for use in the experimental study. Thus, both the measurement instruments and the intervention module in this study have met the validity and reliability standards required to produce credible research findings.

### Procedure

This research procedure began with an opening session and the administration of a pretest to both groups (experimental and control) to measure students' initial levels of self-regulated learning. Subsequently, the experimental group received an intervention involving the use of an AI application based on perplexity, designed to support the process of planning, monitoring, and evaluating student learning. The control group followed conventional learning as usual without the use of an AI application. The intervention was carried out during a learning period that had been adjusted to the school's academic schedule after obtaining a research permission letter. After the intervention was completed, both groups were given a posttest using the same instrument to assess changes in students' SRL levels. The entire research process was carried out in coordination with the school and teachers to ensure consistent implementation and adherence to applicable research ethics. See the table below for more details:

**Table 3.** Research procedure

| Meeting | Control Group | Details | Experimental Group | Details |
|---|---|---|---|---|
| First | Opening and SRL Pretest | Description of research objectives and activities | Opening, SRL Pretest, and Introduction to the AI Application | Description of the objectives, how the AI application is used, and the focus on the dimensions of motivation and planning |
| Second | Conventional learning without intervention | Discussion of materials and exercises | Learning using an AI application | AI support for self-regulation, assessment, and monitoring of learning progress |
| Third | SRL Posttest and Closing | Final SRL assessment and acknowledgments | SRL Posttest, Reflection Using AI Applications, and Closing | Final SRL assessment and acknowledgments |

### Data Analysis

The data were analyzed using an inferential statistical approach with the aid of JAMOVI software. Descriptive analysis was used to describe the participants' characteristics and the distribution of students' SRL scores. Prior to hypothesis testing, classical assumption testing was conducted, such as tests for normality and homogeneity, to ensure the validity of further analysis. To evaluate the effectiveness of the intervention, an Analysis of Covariance (ANCOVA) test was used to test for differences in the mean of the dependent variable between two or more groups, while controlling for the influence of one or more additional continuous variables called covariates. Additionally, a paired-sample t-test was used to assess changes in SRL within each group.

## Results

The descriptive statistical analysis presented shows an increase in the mean scores for both groups. In the control group, the mean SRL score increased from 69.5 on the pretest to 70.4 on the posttest. Meanwhile, the experimental group showed a greater increase, from 64.8 on the pretest to 77.6 on the posttest. This increase indicates that, in general, there was a

development in students' Self-Regulated Learning (SRL) abilities, particularly in the group that received the AI application intervention. In terms of standard deviation, the control group showed an increase from 7.77 on the pretest to 8.74 on the posttest, indicating relatively greater variation in scores. Conversely, in the experimental group, the standard deviation decreased from 9.61 on the pretest to 2.73 on the posttest. This decrease indicates that after the intervention was administered, the students' scores in the experimental group became more consistent and uniform. See the table below for more details:

**Table 4.** Descriptive Statistic

| Category | Groups | N | *Mean* | *Min.* | *Max.* | *Std. Deviation* |
|---|---|---|---|---|---|---|
| Pretest | Control | 31 | 69.5 | 58 | 90 | 7.77 |
| | Experimental | 33 | 64.8 | 53 | 88 | 9.61 |
| posttest | Control | 31 | 70.4 | 57 | 91 | 8.74 |
| | Experimental | 33 | 77.6 | 73 | 84 | 2.73 |

The categorization of pretest and posttest results showed that the pretest scores in the very high category, the control group consisted of 6 students (9.4%), while the experimental group had 7 students (10.9%). In the high category, the control group had a larger number of students, namely 17 students (26.6%), while the experimental group had 7 students (10.9%). Meanwhile, in the moderate category, the control group had 8 students (12.5%) and the experimental group had 19 students (29.7%). This indicates that the initial SRL ability of students in the control group was higher than that of the experimental group. After the experimental group was treated with the use of an AI application, a change in the distribution of SRL categories was observed in the posttest results. In the very high category, the number of students in the experimental group increased to 18 students (28.1%), while in the control group there were 7 students (10.4%). In the high category, the control group consisted of 16 students (25.0%) and the experimental group had 15 students (23.4%). Meanwhile, in the moderate category, the control group had 8 students (12.5%), and in the experimental group, there were no students remaining in that category (0%). These changes indicate a greater increase in the level of Self-Regulated Learning (SRL) in the experimental group following the implementation of the AI application compared to the control group. See the table below for more details:

**Table 5.** Classification of Pretests and Posttests

| Category | Groups | Range Score | Frequency | | % | |
|---|---|---|---|---|---|---|
| | | | Pretest | Posttest | Pretest | Posttest |
| Very High | Control | $76.5 \leq X$ | 6 | 7 | 9.4% | 10.4% |
| | Experimental | | 7 | 18 | 10.9% | 28.1% |
| High | Control | $63.35 < X \leq$ | 17 | 16 | 26.6% | 25% |
| | Experimental | 76.5 | 7 | 15 | 10.9% | 23.4% |
| Moderate | Control | $50.65 \leq X <$ | 8 | 8 | 12.5% | 12.5% |
| | Experimental | 63.35 | 19 | 0 | 29.7% | 0% |
| Low | Control | $37.95 < X \leq$ | 0 | 0 | 0% | 0% |
| | Experimental | 50.65 | 0 | 0 | 0% | 0% |
| Very Low | Control | $X < 37.95$ | 0 | 0 | 0% | 0% |
| | Experimental | | 0 | 0 | 0% | 0% |

The paired-samples t-test was conducted prior to hypothesis testing using ANCOVA, as a preliminary analysis was first performed to examine changes in learning outcomes within the experimental group. The results of the paired samples t-test yielded a t-value of -7.45, df = 32, and $p < 0.001$. This indicates a significant difference between the pretest and posttest scores in the experimental group, with a Cohen's d value of -1.30, indicating that the

intervention had a very large effect size on the improvement in posttest scores. It can be concluded that there was a significant improvement between the pretest and posttest scores in the experimental group. See the table below for more details:

**Table 6.** Paired Samples T-Test

| | | Statistic | df | p | | Effect Size |
|---|---|---|---|---|---|---|
| Pretest | Posttest | Students | -7.45 | <.001 | Cohen's d | -1.30 |
| | | Wilcoxon | 28.0 | <.001 | Rank biserial correlation | -0.900 |

The ANCOVA test revealed that the overall model was statistically significant (F value = 26.0, $p < 0.001$). Furthermore, the analysis indicates that the application of different treatments across groups had a significant effect on students' posttest SRL scores (F value = 40.9, $p < 0.001$, and partial eta-squared $\eta^2 = 0.401$). The partial eta-squared value of 0.401 confirms that the use of the AI application provides a significant boost or effect in improving students' SRL. These results indicate that the use of the AI application in the learning process has a positive and significant ($p < 0.05$) influence on the improvement of students' Self-Regulated Learning. See the table below for more details:

**Table 7.** ANCOVA test

| | Sum of square | df | Mean suqare | F | p | $\eta^2$ | $\eta^2p$ |
|---|---|---|---|---|---|---|---|
| Overall model | 1931 | 2 | 965.4 | 26.0 | <.001 | | |
| Group | 1216 | 1 | 1215.8 | 40.9 | <.001 | 0.325 | 0.401 |
| Pretest | 715 | 1 | 715.0 | 24.0 | <.001 | 0.191 | 0.283 |
| Residuals | 1814 | 61 | 29.7 | | | | |

## Discussion

The findings of this study indicate that the use of artificial intelligence significantly enhances self-regulated learning among high school students, as evidenced by higher posttest scores in the experimental group compared to the control group. Further ANCOVA analysis confirms that the intervention produced a statistically significant effect with a large effect size. These findings provide empirical evidence that artificial intelligence can function not only as a technological tool for accessing information, but also as a learning support system capable of facilitating students' active engagement in the learning process at school.

The increase in self-regulated learning observed in this study can be understood through the way artificial intelligence reshapes the learning experience. In conventional classroom settings, students often rely on teachers for feedback, guidance, and learning direction, which can limit opportunities for students to engage in self-regulated learning (Sulla et al., 2023). In contrast, the use of artificial intelligence provides immediate and personalized feedback that allows students to evaluate their understanding and adjust their learning strategies in real-time (Calatayud et al., 2021). This mechanism of immediate feedback is crucial because delays in feedback within traditional learning environments have been shown to reduce students' ability to effectively monitor their learning progress (Zheng et al., 2023). Therefore, the presence of AI-assisted feedback can strengthen students' metacognitive awareness and encourage them to engage in more reflective learning.

From a theoretical perspective, these findings align with Zimmerman and Schunk (1989) conceptualization of self-regulated learning, which emphasizes the active regulation of cognition, motivation, and behavior during the learning process. These findings are also consistent with the self-regulated learning framework developed by Xin et al. (2024), which highlights the dimensions of motivation and action to learning, planning and goal setting,

strategies for learning and assessment, and lack of self-directedness. In this study, artificial intelligence supports these dimensions simultaneously by encouraging students to set learning goals, monitor task completion, independently seek relevant information, and evaluate their own performance throughout the intervention process. This suggests that artificial intelligence can function as an external factor that gradually supports the internalization of students' self-regulated learning.

The findings of this study are consistent with previous empirical evidence indicating the positive role of artificial intelligence in supporting self-regulated learning. Jin et al. (2023) found that artificial intelligence-based learning systems significantly support students' metacognitive, cognitive, and behavioral regulation in the learning environment. Similarly, Chang et al. (2023) explains that AI chatbots designed with goal-setting and feedback features are effective in improving students' ability to manage their own learning processes. These findings suggest that the use of artificial intelligence can facilitate students' self-directed learning behavior through adaptive feedback and personalized guice.

Furthermore, the findings of this study support the results of research by Molenaar (2022), who argues that artificial intelligence serves as a supportive tool in the learning process by helping students monitor their learning progress, adjust their strategies, and manage the learning process to make it more focused and self-directed. Consistent with these findings, students in the experimental group demonstrated greater consistency in learning outcomes after receiving the intervention. This indicates that artificial intelligence can not only improve learning outcomes but also help foster more stable and structured learning behaviors in students.

The current findings are also consistent with systematic review studies examining the relationship between artificial intelligence and self-regulated learning. Chang and Sun (2024), in their systematic review, demonstrated that artificial intelligence positively influences self-regulated language learning by supporting independent learning behaviors and reflective thinking processes. In line with this, Ren et al. (2025) demonstrates that artificial intelligence plays a crucial role in enhancing self-monitoring, self-assessment, and adaptive learning strategies across various educational contexts. Lan and Zhou (2025) further emphasize that artificial intelligence-assisted learning environments support students by enabling personalized learning experiences and adaptive regulation processes.

Furthermore, the findings of this study support research highlighting the role of artificial intelligence in enhancing student motivation and engagement during the learning process. Huang et al. (2022) found that artificial intelligence-supported learning environments enhance learning satisfaction, self-efficacy, and motivation by helping students manage learning goals and evaluate their progress more effectively. Zhai and Nezakatgoo (2025) also reported that artificial intelligence positively influences students' metacognitive strategies, self-determined motivation, and social learning experiences. These findings may explain why students in the experimental group demonstrated stronger participation and more active engagement during the intervention process.

Other important findings in this study indicate that learning using artificial intelligence appears to reduce students' reliance on teachers during learning activities. This finding is highly relevant in the context of Indonesian education, as previous studies have shown limited results regarding self-regulated learning (Santoso et al., 2022; Saptopramono et al., 2019). Through artificial intelligence-based learning, students are encouraged to independently explore information, evaluate responses, and determine appropriate learning strategies.

However, the findings of this study should also be interpreted critically. One possible explanation for the observed increase is the novelty effect; students may initially demonstrate higher motivation and engagement simply because they are exposed to new technology. This possibility is supported by previous studies showing that innovative digital learning environments can temporarily boost student enthusiasm and participation (Bognár et al.,

2024). Although the experimental design controlled for baseline differences, variations in students' prior digital literacy, motivation, or learning preferences may still have influenced the intervention outcomes.

Another important issue concerns the potential risks of overreliance on artificial intelligence. Although artificial intelligence can support the development of self-regulated learning, overreliance on automated systems may reduce opportunities for independent critical thinking and deep cognitive processing if students become too dependent on AI-generated responses (Sardi et al., 2025). Dai et al. (2025) also warns that excessive use of artificial intelligence in learning environments can weaken students' sense of academic responsibility and reduce meaningful social interaction during learning activities. Therefore, the use of artificial intelligence should not replace the role of teachers, but rather complement pedagogical practices that encourage students' critical reflection and independent thinking.

Overall, this study contributes to the growing literature on technology-enhanced learning by providing experimental evidence that the use of artificial intelligence can effectively enhance self-regulated learning among high school students. More importantly, these findings suggest that artificial intelligence should be understood not merely as a technological innovation, but as a pedagogical tool capable of reshaping how students manage, monitor, and engage in their learning processes. When implemented appropriately and supported by effective pedagogical guidance, AI-enhanced learning has the potential to bridge the gap between students' learning needs and the limitations of traditional teaching.

### Implications

These findings indicate that the use of AI applications can enhance students' self-regulated learning (SRL) by providing quick, relevant, and responsive access to information tailored to students' learning needs, thereby helping them plan their learning, set learning goals, and select appropriate learning strategies. Thus, AI applications can serve as effective learning tools to enhance SRL among high school students, provided their use is appropriately guided and supported by teachers.

### Limitations and future directions

This study has several limitations that should be considered when interpreting its results, such as: the fact that participant involvement was limited to a single school restricts the generalizability of the findings to a broader educational context; the use of class-based random cluster sampling allowed for differences in baseline characteristics among groups that could not be fully controlled; and the relatively short duration of the intervention may not yet be sufficient to capture the long-term impact of using artificial intelligence applications on the development of students' self-regulated learning. Additionally, measurements relying on self-report instruments have the potential to introduce subjective bias. Therefore, future researchers are advised to include a diverse sample, employ a longitudinal design, and combine quantitative and qualitative approaches to gain a deeper understanding of the effectiveness of AI applications in enhancing students' SRL

## Conclusion

Self-regulated learning (SRL) skills are a key competency for the academic success of high school students, yet their development still faces limitations due to learning approaches that lack adaptability. The findings of this study indicate a significant difference in SRL between the experimental and control groups, with the experimental group using the AI application demonstrating a higher average SRL score compared to the control group. Thus, it can be concluded that the use of AI applications has a significant impact on improving students' SRL. Practically, these findings provide a basis for schools and educators to adopt AI technology as an innovative strategy for enhancing students' SRL. These research results

can enrich our understanding of the role of digital technology in supporting the development of students' SRL, while also affirming that AI-based learning approaches can be an effective solution to bridge the gap between learning needs and the limitations of traditional methods.

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## Author Contribution Statement

We would like to express our gratitude to all the authors for their contributions to this study. First, MR was responsible for designing the research concept, developing the modules and instruments, coordinating the data collection process, and drafting the initial manuscript. Second, YA contributed to the development of the methodological design, data analysis and interpretation, and provided critical review of the manuscript. Both authors reviewed and approved the final version of the manuscript for publication.

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