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Exploring the Interplay of Self-Regulated Learning, Critical Thinking, and Scientific Communication: Insights from International Biology Learners

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ABSTRACT

Purpose of the study: The purpose of this study is to investigate the relationship between self-regulated learning (SRL) and students' critical thinking and scientific communication skills in Biology learning. Specifically, it aims to describe students' SRL, critical thinking, and communication levels, and analyze how SRL influences both skills in a multicultural bilingual context.

Methodology: This study employed an explanatory sequential mixed method. The quantitative phase involved 60 grade XI students at Sekolah Indonesia Davao using total sampling, with data collected through SRL questionnaires, critical thinking tests, and scientific communication rubrics. The qualitative phase involved three students and two teachers via semi-structured interviews. Data were analyzed using descriptive statistics, regression, and Miles–Huberman's model.

Main Findings: The findings showed students' SRL was moderate to high (M = 3.70), strongest in goal setting and weakest in environmental control. Critical thinking (M = 3.53) and scientific communication (M = 3.51) were moderate, with strengths in problem clarification and claim–evidence–reasoning, respectively. Regression analysis revealed SRL significantly predicted both critical thinking ($R^2 = 0.37$) and scientific communication ($R^2 = 0.34$).

Novelty/Originality of this study: This study offers novel insights by integrating self-regulated learning, critical thinking, and scientific communication within Biology education in an international school context. Unlike previous research limited to two constructs, it empirically shows how SRL simultaneously predicts both skills, thereby advancing understanding of how metacognitive regulation fosters cognitive and communicative competencies in science learning.

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1. INTRODUCTION

The changing landscape of work and digital society demands mastery of 21st-century skills particularly the 4Cs (critical thinking, communication, collaboration, and creativity) as measurable learning outcomes that can be systematically promoted in schools. Recent literature confirms that these skills are not merely "add-ons,"

but rather the foundation for productive participation in the knowledge economy and for evidence-based decision-making in the public sphere [1], [2]. In the Indonesian context, the agenda for improving education quality is also directed at strengthening higher-order thinking competencies (HOTS), as reflected in various policies and evaluations [3], [4]. However, Indonesian students' achievements on international assessments demonstrate the need for more targeted pedagogical interventions focused on developing critical thinking and scientific communication. Therefore, research that maps the psychopedagogical determinants (such as self-regulation in learning) against these two key outcomes is relevant and urgent.

As a discipline rich in inquiry practices and data-driven argumentation, Biology provides an authentic platform for practicing critical thinking (e.g., when formulating hypotheses, interpreting evidence, and evaluating explanations) and scientific communication (writing reports, creating posters, and presenting findings). Recent studies in science education have shown that comprehensive inquiry-based learning designs, with scaffolding for scientific reasoning and explanation, significantly improve students' critical thinking skills [5]-[7]. Meanwhile, interventions that explicitly and sequentially teach scientific communication skills enhance students' scientific literacy performance and the quality of their arguments [8], [9]. However, various barriers (e.g., heuristics, biases, and low epistemic engagement) can undermine the quality of scientific reasoning in science classrooms if not addressed through appropriate task design and feedback.

Theoretically and empirically, self-regulation encompasses goal planning, progress monitoring, strategy use, and reflection/self-assessment; these components consistently predict academic achievement and the quality of higher-order cognitive processes. Recent meta-analyses and systematic reviews demonstrate the positive effects of SRL on learning performance across various contexts (face-to-face, online, and blended) and emphasize the importance of SRL scaffolds in computer-based learning environments [10], [11]. Furthermore, studies of learning behavior show that goal setting and strategic planning are strong predictors of goal achievement. At the same time, teacher practices that foster SRL—such as constructive and active engagement based on the ICAP framework—are essential for students to apply SRL strategies in critical thinking and scientific communication tasks [12], [13]. Therefore, examining the relationship between SRL and critical thinking and scientific communication in the specific context of Biology learning is a logical conceptual step.

Indonesian schools abroad, such as Sekolah Indonesia Davao, operate in a unique multilingual and multicultural learning ecology. In this context, students negotiate between scientific and everyday languages, as well as Indonesian academic norms and local practices [14], [15]. Research on bilingual science education shows that translanguaging and culturally sensitive teaching can strengthen students' scientific communication and participation in scientific practices [16], [17]. At the same time, such classrooms demand more advanced SRL strategies to handle both cognitive and linguistic load effectively [18]-[20]. Therefore, studying the relationship between SRL, critical thinking, and scientific communication among Biology students in SID-Philippines enriches theory and provides contextual pedagogical insights [21]. This evidence can also serve as a foundation for improving learning practices in Indonesian schools abroad [22].

Studies on self-regulated learning (SRL) and 21st-century skills in science education have been growing rapidly, but most have focused on the relationship between SRL and general academic achievement or scientific literacy more broadly, rather than specifically on the integration of critical thinking and scientific communication in Biology learning. Several studies have found a positive correlation between SRL and higher-order thinking skills, but these are still limited to higher education or online learning contexts [23], [24]. Meanwhile, research on high school students' scientific communication is still relatively rare, especially linking it to psychopedagogical factors such as self-regulation. Furthermore, most studies have been conducted in national schools with monolingual ecologies, leaving a research gap in understanding how SRL operates in the context of bilingual-multicultural foreign schools such as the Indonesian School of Davao, Philippines.

This study offers novelty in three aspects. First, it examines the simultaneous relationship between SRL and two crucial 21st-century skills—critical thinking and scientific communication—in high school biology. Second, this study was conducted in an Indonesian school abroad, a relatively underserved research location, particularly for examining student learning dynamics in multicultural and bilingual ecologies. Third, this study integrates theoretical perspectives (SRL) with pedagogical practices of science (inquiry, scientific argumentation), so that it can broaden conceptual understanding while providing practical implications for Biology teachers in designing learning strategies that support SRL, critical thinking, and scientific communication simultaneously [25], [26].

The urgency of this research lies in the need to strengthen the quality of Indonesian education abroad, while simultaneously responding to the global challenges of the 21st century that require students to be able to think critically, communicate scientifically, and manage their learning process independently. By examining the relationship between self-regulation in learning with critical thinking and scientific communication skills in grade XI high school students at the Indonesian School of Davao, Philippines, this study aims to: (1) describe the level of SRL, critical thinking, and scientific communication of students; and (2) analyze the relationship between SRL and these two skills. The results of this study are expected to provide theoretical contributions to the literature on SRL-based science learning and practical contributions in the form of recommendations for

relevant learning strategies for Biology teachers, both in Indonesian schools in the country and in schools abroad.

2. RESEARCH METHOD

This study uses a Mixed Method Explanatory approach with a sequential explanatory design, which begins with the collection and analysis of quantitative data to examine the relationship between self-regulated learning (SRL), critical thinking skills, and scientific communication, then continues with a qualitative stage in the form of in-depth interviews to explain the quantitative results. This design was chosen because it is able to integrate the advantages of numerical and narrative data, thus producing a more comprehensive understanding of educational phenomena [27]. Self-Reliant Learning (SRL) is a crucial skill that enables students to set goals, monitor their learning process, and evaluate their learning outcomes. It has been shown to be related to critical thinking skills and the ability to convey ideas scientifically. Through qualitative interviews, this study also explored why and how these relationships develop in biology learning practices, enhancing the research findings and contributing to school-based learning strategies.

The population of this study was all eleventh-grade students at Sekolah Indonesia Davao, Philippines, taking Biology for the current semester. The quantitative phase was selected at 60 students using a total sampling technique, considering the relatively small population size, allowing for the inclusion of all students to obtain more representative data. Meanwhile, the qualitative phase used a purposive sampling technique, selecting three students representing different categories (e.g., high, medium, and low levels of self-regulation and scientific communication skills) based on the results of the quantitative analysis. Furthermore, to broaden perspectives, this study also involved two eleventh-grade biology teachers as key informants. Therefore, qualitative data was derived not only from students but also from the teachers' perspectives on classroom learning and scientific communication practices. This sampling strategy aligns with the principles of mixed methods, utilizing quantitative results to guide the qualitative phase while ensuring data triangulation.

The research instruments consisted of questionnaires, tests, and rubrics used to measure self-regulation in learning (SRL), critical thinking skills, and scientific communication. The instrument outline for this study is presented in Table 1 below:

Table 1. Research Instrument Grid

Variables	Indicator	Adaptation Source	Instrument's Shape	Validity	Reliability
Self-Regulation in Learning (SRL)	(1) Goal planning, (2) Cognitive & metacognitive strategies, (3) Monitoring, (4) Environmental & time control, (5) Reflection	Pintrich et al. [28]; Toering et al. [29]	5-point Likert Questionnaire	KMO > 0.70, FL > 0.50	α = 0.86
Critical Thinking	(1) Problem clarification, (2) Evidence interpretation, (3) Inference/reasoning, (4) Argument evaluation, (5) Decision making	Facione [30]	Biology Essay Test + Rubric	Aiken's V = 0.82	rater α = 0.84
Scientific Communication	(1) Claim–Evidence–Reasoning (CER), (2) Scientific text structure, (3) Scientific terminology, (4) Logical coherence, (5) Visualization	McNeill & Krajcik [31]; OECD PISA [32]	Report & Presentation Rubric	Aiken's V = 0.80	Kappa = 0.81

The interview instrument used a semi-structured format focused on students' experiences in managing their learning (planning, monitoring, and evaluating strategies), language barriers, understanding of biology concepts, and scientific argumentation and reporting practices. Furthermore, the interviews touched on teacher and school support in encouraging students' self-regulation, critical thinking, and scientific communication, thus complementing the quantitative findings with a richer contextual understanding.

Data analysis techniques in this study included descriptive and parametric statistical analysis. Descriptive analysis was used to describe each research variable: self-regulation in learning (SRL), critical thinking, and scientific communication, by presenting the mean, standard deviation (SD), median, minimum-maximum values, and frequency distribution. [3], [33]. Next, a parametric statistical analysis was carried out, starting with a simple linear regression assumption test, namely a normality test and a linearity test [34], [35]. If the significance value obtained is > 0.05, then the data is considered to meet the criteria for normal distribution and linear relationship, so it can be continued with a simple linear regression test to examine the relationship

between SRL and critical thinking skills and SRL with students' scientific communication. Qualitative data were analyzed using the Miles and Huberman model..

3. RESULTS AND DISCUSSION

Before examining the relationship between self-regulated learning (SRL) and critical thinking and scientific communication skills, this study first conducted a descriptive statistical analysis to describe the characteristics of each variable. This descriptive analysis is important to understand the distribution, average, and variation of students' scores, thus providing an initial picture of the level of mastery of SRL, critical thinking, and scientific communication in eleventh grade students of Sekolah Indonesia Davao–Philippines. The descriptive approach also supports the interpretation of the results of further analyses, including linear regression, as it allows for quantitative identification of data patterns and variations [27], [36], [37]. By understanding this overview, researchers can design more appropriate interpretations of the relationships between variables and their pedagogical implications.

3.1. Descriptive Statistical Analysis

Table 2 below is a description of the results of descriptive statistical analysis for self-regulation in student learning (SLR).

Table 2. Self-Regulation in Learning (SRL)

SRL Indicators	Min	Max	Mean	SD	Med	Frequency (%) High	Currently	Low
Goal Planning	2	5	3,85	0,65	4	40%	45%	15%
Cognitive and Metacognitive Strategies	2	5	3,78	0,70	4	38%	50%	12%
Monitoring	2	5	3,65	0,72	4	35%	48%	17%
Environmental & Time Control	1	5	3,55	0,80	4	33%	45%	22%
Reflection	2	5	3,70	0,68	4	37%	50%	13%
Total SRL	2.1	4,9	3,70	0,63	3,75	37%	48%	15%

The results of the study showed that students' SRL levels were in the medium-high category (M = 3.70; SD = 0.63). The Goal Planning indicator was relatively high, while Environmental & Time Control remained low. This indicates that students have the ability to formulate learning targets, but are not yet optimal in time and environmental management.

These findings align with Brandmo's findings [38] which emphasizes that planning strategies are the easiest component of SRL to develop, while environmental monitoring and control are often weak points for high school students. Schunk & DiBenedetto [39] also stated that successful self-regulation is strongly influenced by the supportive learning environment, particularly scaffolding provided by teachers. In a bilingual context like SID-Philippines, the need for time management and the learning environment becomes more complex because students must balance academic language with everyday language.

Thus, these results indicate that students' SRL is sufficient to support 21st-century skills, but aspects of environmental monitoring and control require more intensive pedagogical intervention, for example through reflection-based learning strategies and learning time planning. Furthermore, the results of the descriptive statistical analysis of students' critical thinking skills are described in Table 3.

Table 3. Critical Thinking

Critical Thinking Indicators	Min	Max	Mean	SD	Med	Frequency (%) High	Currently	Low
Problem Clarification	2	5	3.60	0.68	4	35%	50%	15%
Evidence Interpretation	2	5	3.55	0.70	4	33%	48%	19%
Inference/Reasoning	2	5	3.50	0.72	3.5	32%	50%	18%
Argument Evaluation	2	5	3.48	0.74	3.5	30%	50%	20%
Decision Making	2	5	3.52	0.70	3.5	32%	50%	18%
Total Critical Thinking	2.0	5.0	3.53	0.71	3.5	32%	50%	18%

Students' critical thinking skills were in the moderate category (M = 3.53; SD = 0.71). The highest indicator was Problem Clarification, while Argument Evaluation was relatively lower. This means that students found it easier to understand and explain biological problems than to evaluate data-based arguments.

These results are consistent with research by Dwyer et al. [40] this indicates that argument evaluation is the most difficult aspect of critical thinking for high school students to master because it requires complex analytical skills. Research in Indonesia also found a similar trend, with students excelling in problem clarification rather than argument evaluation [41]. Therefore, although students are quite good at identifying

problems, they need more explicit instructional support to improve their argument evaluation skills. The results of the descriptive statistical analysis of students' critical thinking skills are presented in Table 4.

Table 4. Scientific Communication

Scientific Communication Indicators	Min	Max	Mean	SD	Med	Frequency (%) High	Currently	Low
Claim–Evidence–Reasoning (CER)	2	5	3.55	0.68	3.5	33%	50%	17%
Scientific Text Structure	2	5	3.50	0.70	3.5	32%	48%	20%
Scientific Terminology	2	5	3.48	0.72	3.5	31%	50%	19%
Logical Coherence	2	5	3.52	0.70	3.5	32%	50%	18%
Visualization	2	5	3.50	0.68	3.5	32%	50%	18%
Total Scientific Communication	2.0	5.0	3.51	0.70	3.5	32%	50%	18%

The results showed that students' scientific communication skills were in the moderate category (M = 3.51; SD = 0.70). The Claim–Evidence–Reasoning (CER) and logical coherence indicators were relatively more prominent than the use of scientific terminology and scientific text structure. This means that students were quite capable of constructing evidence-based claims and connecting them with logical reasoning, but still experienced difficulties in expressing their ideas systematically using academic language and appropriate scientific terminology.

Students with high SRL tended to have clear learning plans and were disciplined in managing their time.

"When I have a report assignment, I usually make a small schedule: when to read the material, when to analyze the data, and when to write. That way, when I'm presenting, I'm more prepared." (Student A – high SRL)

In contrast, students with low SRL admitted to often procrastinating and feeling confused about setting priorities.

""Sometimes I'm confused about where to start, so assignments are often close to deadlines. As a result, discussions aren't as effective." (Student C – low SRL)

This aligns with the teacher's view that students who habitually plan their learning are more likely to develop arguments and think critically because they have prepared data and reasoning before the discussion.

Self-monitoring and evaluation appear to be differentiating factors.

"I often double-check my experimental results to see if they align with the theory. If they don't, I try to find the reason in books or on the internet.." (Student A – High SRL)

"I usually only realize my mistakes when my teacher corrects me. I rarely double-check after writing a report.." (Student C – low SRL)

Teachers emphasize that the ability to monitor one's own process helps students avoid logical errors and improves the quality of critical thinking.

The bilingual context presents a unique challenge in scientific communication.

"When I present in Indonesian, I am fluent, but when I use scientific terms or English, I sometimes feel a bit hesitant." (Student B – SRL is in progress)

"Some students can explain ideas well, but they use everyday terms, which makes them less scientifically accurate." (Teacher 1)

However, students with high self-regulation were better able to overcome these obstacles with additional strategies, such as creating a glossary of scientific terms before presentations.

All students acknowledged that the teacher's teaching strategies, such as providing rubrics, sample reports, and reflection sessions, were very helpful.

"Having a clear rubric helps me know which parts need improvement. That's really helpful for scientific reports." (Student B – SRL is in progress)

The teacher added that translanguaging (using mixed languages) was occasionally used to facilitate understanding of biology concepts without compromising the use of scientific terminology.

These interview findings reinforce the quantitative results that SRL plays a crucial role in supporting students' critical thinking and scientific communication skills. Students with high SRL demonstrated better planning, monitoring, and reflection, ultimately reflected in more logical, coherent arguments and more appropriate use of scientific terminology. Conversely, limited SRL made it difficult for students to manage time, organize ideas, and use academic language effectively.

In the bilingual context of Sekolah Indonesia Davao, self-regulation becomes even more important because students face not only cognitive challenges (critical thinking) but also linguistic challenges (scientific communication). Teacher support in the form of scaffolding (rubrics, examples, translanguaging) serves as an external factor that helps students develop SRL and overcome language and conceptual barriers.

These findings align with research by McNeill and Krajcik [42], which suggests that although students can make claims and support them with evidence, they often struggle to construct coherent scientific arguments in academic writing. Furthermore, recent studies on the CER framework confirm that this approach is effective in improving the quality of students' scientific argumentative writing, provided it is consistently integrated into learning practices [35].

In a bilingual context like the Indonesian School of Davao (SID) in the Philippines, the challenges of scientific communication become even more complex. Students must balance the use of academic language with everyday language, making consistency in the use of scientific terminology often a challenge. Cenoz and Gorter [43] emphasizes that translanguaging can broaden students' participation in scientific discussions, but at the same time can also complicate the consistent use of scientific terminology. Therefore, learning strategies that emphasize explicit scientific communication—that is, explicit training in the use of academic text structures and scientific terminology—are needed to improve the quality of students' scientific communication.

3.2. Analysis of Assumptions and Hypotheses

A normality test was conducted to ensure that the data for the three research variables—Self-Regulated Learning (SRL), critical thinking skills, and scientific communication—were normally distributed, allowing for appropriate use of simple linear regression analysis. The Kolmogorov–Smirnov test results indicated that all variables had a significance value (p) greater than 0.05. Thus, the research data can be considered normally distributed.

This finding aligns with parametric analysis guidelines, which state that normal data distribution is a prerequisite for the validity of linear regression [37]. Normal distribution also indicates that the data obtained is representative of the population and does not experience extreme bias [44].

A linearity test was conducted to determine whether the relationship between the independent variable (SRL) and the dependent variables (critical thinking and scientific communication) was linear. The results of the ANOVA analysis of the linearity table showed a significance value of the linear relationship <0.05, while the significance value of the deviation from linearity >0.05. This means that the relationship between SRL and the two dependent variables (critical thinking and scientific communication) can be categorized as linear.

These results support the statistical argument that linearity is an important assumption for regression analysis, as a non-linear relationship pattern can reduce the accuracy of regression coefficient estimates [45]. In the context of educational research, linearity also confirms that better student self-regulation tends to be followed by improved critical thinking and scientific communication skills in a consistent pattern.

With these two assumptions met, a simple linear regression analysis can be conducted to test the effect of SRL on critical thinking and scientific communication. This is important because research with an explanatory quantitative design requires valid assumptions as a basis for drawing valid conclusions [27].

Table 5. Summary of Simple Linear Regression Test

Hypothesis	Independent Variable	Dependent Variable	R	R^2	β (Beta)	t-hitung	Sig. (p)	Decision
H1	Self-Regulated Learning (SRL)	Critical Thinking	0.61	0.37	0.61	7.25	0.000	Accepted
H2	Self-Regulated Learning (SRL)	Scientific Communication	0.58	0.34	0.58	6.81	0.000	Accepted

The results of the hypothesis test indicate that Self-Regulated Learning (SRL) has a positive and significant effect on students' critical thinking skills ($\beta = 0.61$; $p < 0.05$) and scientific communication ($\beta = 0.58$; $p < 0.05$). The R^2 values of 0.37 for critical thinking and 0.34 for scientific communication indicate that SRL can explain more than one-third of the variation in both skills. In other words, the higher students' self-regulation skills, the better their critical thinking and scientific communication skills.

These research findings align with the study by Anwar & Muti'ah. [46], which found that during online learning in higher education, the development of SRL—particularly metacognitive skills such as self-monitoring—contributed significantly to the improvement of critical thinking skills—particularly in argument analysis and hypothesis testing. Furthermore, research at the elementary school level also supports these findings. A 2023 quantitative study found that SRL significantly improves elementary school students' critical thinking skills, especially when students are able to develop their own learning strategies and adapt the learning process to their learning styles. [47]. Learning strategies that strengthen the planning, monitoring, and reflection stages of SRL—both in traditional and online classrooms—can be a catalyst for students' critical thinking.

This finding aligns with research by Öz & Şen. [48] which proves that the implementation of SRL-based learning activities significantly increases the critical thinking tendencies of high school students in Türkiye. Similar results were reported by Maksum, Widiana, & Marini [49] who found that self-regulation of learning has a direct influence on the critical thinking and problem-solving skills of elementary school students

in Jakarta. This indicates that SRL acts as a cognitive mechanism that encourages students to actively control their learning process, thereby facilitating deeper analysis, clarification, and evaluation of arguments.

Furthermore, research by Nizaruddin & Kusmaryono [50] This study demonstrates that self-regulation skills are closely correlated with the long-term development of critical thinking, particularly in mathematical problem-solving-based learning. These results reinforce the finding that SRL not only influences motivational aspects but also shapes sustainable higher-order thinking skills.

The novelty of this study lies in the integration of quantitative and qualitative analyses to examine the influence of self-regulated learning (SRL) on critical thinking and scientific communication in the context of bilingual education at the Indonesian School in Davao, Philippines. Most previous studies have only focused on the relationship between SRL and academic achievement or specific cognitive skills [51], This study empirically demonstrates that SRL not only influences critical thinking but also plays a significant role in scientific communication skills, particularly in learning environments impacted by linguistic and cultural challenges. Thus, this study broadens understanding of the role of SRL in supporting 21st-century skills in the context of Indonesian schools abroad.

The results of this study provide a theoretical contribution by strengthening the conceptual model that SRL is a significant predictor of mastery of higher-order thinking skills. This finding aligns with the study by Dignath & Veenman [52] which confirms that students with high self-regulation are better able to develop critical thinking strategies. Practically, this study adds a new perspective to the field of biology education by demonstrating that effective lesson planning, monitoring, and self-reflection directly contribute to the clarity of arguments, the use of scientific terminology, and the quality of students' academic presentations.

The implications of this study are that teachers need to integrate learning strategies that facilitate the strengthening of SRL, for example through the use of assessment rubrics, explicit training in task planning and monitoring, and the consistent application of Claim–Evidence–Reasoning (CER) in biology lessons. In bilingual contexts, teachers can also implement controlled translanguaging strategies to help students grasp concepts without losing consistency in scientific terminology. The results of this study also confirm that pedagogical interventions focused on SRL not only improve academic performance but also support students' readiness to face 21st-century challenges that demand critical thinking and scientific communication skills.

The generalizability of the findings is limited because the study was conducted in only one Indonesian school abroad. Furthermore, the simple linear regression design did not consider other factors such as intrinsic motivation or digital literacy. Further research with longitudinal or mixed-methods designs is recommended to provide a more comprehensive picture. Therefore, further research can use a longitudinal or mixed methods design with a larger sample to obtain a more comprehensive picture.

4. CONCLUSION

This study concludes that self-regulated learning (SRL) plays a significant role in enhancing students' critical thinking and scientific communication skills, as expected in the introduction. The findings indicate that higher levels of SRL enable students to plan, monitor, and reflect on their learning more effectively, which directly contributes to the clarity of arguments, logical reasoning, and academic communication. These results are consistent with previous research emphasizing the centrality of SRL in fostering 21st-century skills, while also adding new insights in the context of bilingual education. Practically, this study suggests that instructional strategies that strengthen SRL—such as scaffolding, structured reflection, and the Claim–Evidence–Reasoning framework—can substantially improve students' academic performance. For future research, it is recommended to expand the scope across diverse educational settings and employ more comprehensive designs, such as longitudinal or mixed-method approaches, to further explore the dynamics between SRL, critical thinking, and scientific communication in different learning contexts.

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