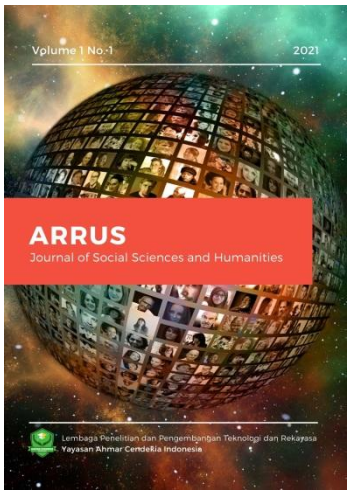
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RESEARCH ARTICLE

Self-Regulated Learning Predicting Scientific Literacy Amid Low Information Literacy CHEM-SSI

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Abstract: This study examined information literacy profiles among secondary school students and investigated whether self-regulated learning (SRL) predicted scientific literacy among students with very low information literacy. It also evaluated scientific literacy outcomes after socioscientific chemistry learning supported by an E-Bulletin on atomic structure. A sequential explanatory correlational design with an embedded intervention component was employed. A total of 131 students from six secondary schools completed an Information Literacy Questionnaire. Of these, 28 students classified as having very low information literacy completed a Self-Regulated Learning Scale and a Three-Tier Scientific Literacy Test after the E-Bulletin-based socioscientific chemistry intervention. Data were analysed using descriptive statistics, Pearson correlation, multiple regression, and effect size analysis. Information literacy was predominantly moderate, while 21.37% of students were categorised as very low. This subgroup demonstrated moderate SRL and high scientific literacy after the intervention. SRL was strongly associated with scientific literacy ($r = .742$, $p < .001$), with self-evaluation emerging as the strongest predictor ($\beta = .334$, $p = .004$). Large to very large effect sizes were observed. These findings indicate that SRL significantly predicts scientific literacy and that socioscientific E-Bulletin chemistry learning can support students with limited information literacy.

Keywords: Self-Regulated Learning, Scientific Literacy, Low Information Literacy, Socioscientific Issues, Chemistry Learning

1. Introduction

The swift proliferation of digital technologies has fundamentally altered the modalities through which students access, assess, and apply information within educational contexts (Haleem et al., 2022). Although digital environments afford unparalleled learning opportunities, they concurrently necessitate that learners cultivate robust information literacy competencies to discern credible information from misinformation, critically analyse sources, and effectively employ knowledge in academic scenarios (Azzajjad et al., 2026). As a result, information literacy has ascended to a vital competency for lifelong learning and effective engagement in knowledge-driven societies.

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Information literacy assumes particular significance within the realm of secondary education, as students increasingly depend on digital platforms, search engines, online resources, and artificial intelligence tools to facilitate their learning (Rahmawati et al., 2024; Sakkir et al., 2025). Recent investigations have indicated that a considerable number of secondary school students encounter challenges in assessing the credibility of information, identifying trustworthy sources, and synthesising information into a coherent understanding (Svedholm-Häkkinen et al., 2025). Despite the substantial increase in access to digital resources, the progression of information literacy often remains inconsistent across various educational institutions and student demographics (Gnambs & Schwaß, 2025). These obstacles are particularly alarming in the domain of science education, where students are required to interpret evidence, evaluate claims, and make informed decisions predicated on scientific information (García-Carmona, 2025; Anggreni et al., 2026).

Self-regulated learning (SRL) has garnered widespread recognition as a pivotal factor influencing academic achievement in digital learning contexts. As posited by Zimmerman, SRL pertains to learners' capacity to proactively plan, monitor, regulate, and appraise their own learning processes (Zimmerman, 2000). In a similar vein, Pintrich (2004) underscored that effective learners utilise cognitive, metacognitive, motivational, and behavioural strategies to fulfil their academic objectives (Pintrich, 2004). Recent scholarly inquiries have consistently illustrated that students displaying enhanced SRL capabilities demonstrate elevated levels of engagement, persistence, academic performance, and success in digital learning environments. Within technology-mediated learning contexts, SRL empowers learners to navigate information overload, sustain learning motivation, and autonomously regulate their learning behaviours (Fan et al., 2025).

Scientific literacy has emerged as another critical educational outcome in the contemporary era. The OECD-PISA framework conceptualises scientific literacy as the capacity to elucidate scientific phenomena, evaluate and design scientific inquiries, and interpret scientific data and evidence (Tytler et al., 2025). Beyond mere factual knowledge, scientific literacy necessitates that students apply scientific reasoning, critically evaluate evidence, and make informed decisions concerning socio-scientific issues.

While prior research has examined information literacy, self-regulated learning, and scientific literacy in isolation, there exists a paucity of studies investigating the interplay of these constructs within a cohesive framework. Current literature predominantly concentrates on general student populations, while scant attention has been directed towards students exhibiting markedly low information literacy who may be particularly susceptible in digital learning contexts. Moreover, empirical data remain limited regarding the degree to which self-regulated learning serves as a predictor of scientific literacy among students with deficient information literacy profiles after digital learning interventions. To address the identified research gaps and achieve the objectives of this study, the following research questions were formulated:

RQ1. What are the information literacy profiles of secondary school students across different school contexts?

RQ2. What are the self-regulated learning profiles of students identified as having very low information literacy?

RQ3. What is the level of scientific literacy among students with very low information literacy following participation in an E-Bulletin-supported chemistry learning intervention?

RQ4. Is there a significant relationship between self-regulated learning and scientific literacy among students with very low information literacy?

RQ5. Which dimensions of self-regulated learning significantly predict scientific literacy among students with very low information literacy?

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RQ6. What is the magnitude of the effects of the E-Bulletin intervention and self-regulated learning on scientific literacy outcomes among students with very low information literacy?

2. Literature Review

2.1. *Information Literacy*

Information literacy has emerged as an essential competency within the modern digital learning milieu, wherein students are incessantly subjected to substantial quantities of information derived from a multitude of digital origins (Audrin & Audrin, 2022). The Association of College and Research Libraries (ACRL) delineates information literacy as the capacity to identify informational requirements, locate pertinent data, critically assess information, and utilise information in a manner that is both effective and ethical (Fekete & Győrffy, 2025).

Contemporary investigations have underscored the escalating significance of information literacy within digital learning ecosystems (Jang et al., 2021). Empirical studies conducted in Indonesia, Malaysia, and South Korea from 2021 to 2025 revealed that students frequently encounter challenges in evaluating online information, discerning misinformation, and assimilating information into the construction of meaningful knowledge (Marten et al., 2025; Nygren & Efimova, 2025; Pimentel, 2025). Moreover, research conducted in Finland and Singapore has illustrated a positive correlation between information literacy and academic performance, digital competence, and higher-order cognitive skills (Li et al., 2025; Ravikumar et al., 2024; Vodă et al., 2022). These outcomes imply that information literacy constitutes a foundational competency that empowers students to engage proficiently with digital learning resources.

2.2. *Self-Regulated Learning*

Self-regulated learning (SRL) serves as the conceptual framework for comprehending how learners proactively oversee and manipulate their educational processes (Ahmar & Azzajjad, 2025; Huggahalli & Gupta, 2025). Zimmerman's Social Cognitive Theory delineates SRL as a recursive process comprising the phases of forethought, performance, and self-reflection (W. L. Chang & Sun, 2024; dos Santos Silva & Marinho, 2025). In the forethought phase, learners delineate objectives and formulate strategic plans; in the performance phase, they engage in the monitoring and regulation of their learning behaviours; and in the self-reflection phase, they assess outcomes and refine future learning strategies. This cyclical framework underscores the proactive involvement of learners in orchestrating their own educational experiences.

In a similar vein, Pintrich's theoretical model conceptualises SRL as the regulation of cognitive, motivational, behavioural, and contextual learning elements (Shen & Bai, 2024). Pintrich posits that proficient learners consistently evaluate their advancement, manage available resources, modulate effort, and adapt strategies to fulfil academic objectives (Feng et al., 2025). Recent empirical investigations conducted in China, Australia, and the United States have uniformly indicated that SRL serves as a substantial predictor of academic success, engagement, and efficacy in digital learning contexts (DAI et al., 2022; Romanova et al., 2024; Zhao et al., 2023). A contemporary meta-analysis of online and blended educational environments has further determined that students exhibiting enhanced self-regulatory skills manifest elevated levels of persistence, academic performance, and retention of knowledge (Apridayani et al., 2023). Consequently, SRL holds particular significance in technology-mediated learning environments where learners must navigate digital resources and educational activities autonomously.

2.3. *Scientific Literacy*

Scientific literacy is widely recognised as one of the most important educational outcomes in the twenty-first century (Sjöström, 2025). According to the Organisation for Economic Co-operation and Development (OECD), scientific literacy refers to an individual's ability to

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engage with science-related issues, explain scientific phenomena, evaluate and design scientific inquiry, and interpret scientific evidence for informed decision-making (Noor, 2021). The OECD-PISA framework emphasises that scientific literacy involves not only scientific knowledge but also scientific reasoning, critical thinking, and evidence-based judgment (Suárez-Mesa & Gómez, 2024).

The PISA 2025 Science Framework further highlights the importance of scientific literacy in addressing global challenges such as climate change, sustainability, health, and technological development (Tasquier et al., 2022). Contemporary perspectives classify scientific literacy into several interconnected dimensions, including nominal, functional, conceptual, and multidimensional literacy (Valladares, 2021). These dimensions represent progressively higher levels of understanding, ranging from recognition of scientific terminology to the application of scientific knowledge in complex real-world contexts (Alé et al., 2025). Recent studies conducted in Germany, Canada, and Japan have shown that scientific literacy is strongly influenced by students' abilities to access, evaluate, and utilise information as well as their capacity to regulate learning independently (Faza & Lestari, 2025; Podgornik et al., 2017; Rusdi et al., 2023; Sun & Chan, 2025). Consequently, scientific literacy can be viewed as a multidimensional outcome that emerges from the interaction between information-processing competencies and self-regulatory learning processes.

2.4. *Conceptual Framework*

Figure 1 the hypothesised relationships among information literacy, self-regulated learning, and scientific literacy.

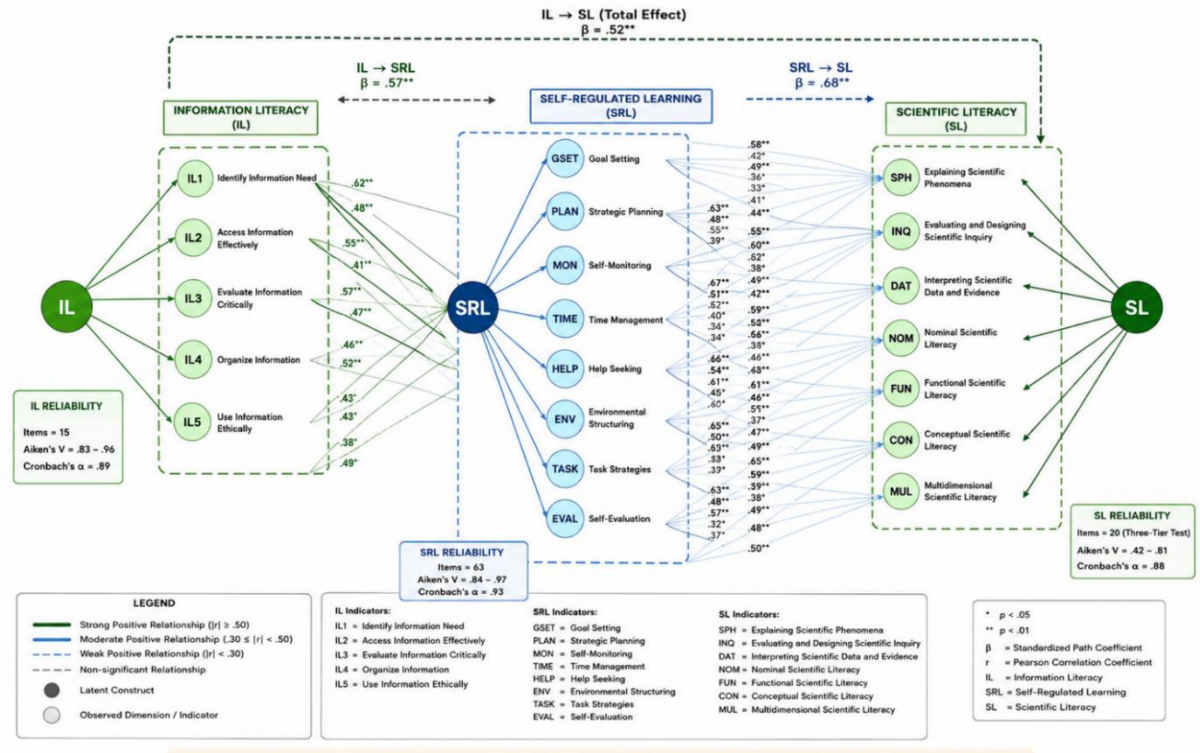


Figure 1. Conceptual Relationship Network Between Information Literacy, Self-Regulated Learning, and Scientific Literacy

Figure 1 presents the conceptual relationships among information literacy, self-regulated learning, and scientific literacy that guided the study.

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3. Research Method And Materials

3.1. *Research Design*

This study uses a sequential explanatory correlational design with an embedded intervention component. A total of 131 secondary school students completed an information literacy assessment, and their scores were subsequently classified into five categories: very low, low, moderate, high, and very high. The cross-sectional approach enabled the identification of students' literacy profiles and the examination of relationships among variables without manipulating participants or observing changes over time.

Following the initial classification, 28 students identified as having very low information literacy were selected for further analysis. These students completed a self-regulated learning questionnaire and subsequently participated in a scientific literacy assessment using a three-tier diagnostic test after engaging with an E-Bulletin-based chemistry learning intervention on atomic structure. The correlational component of the design was used to determine whether variations in self-regulated learning were associated with differences in scientific literacy performance and to identify the extent to which self-regulated learning dimensions predicted scientific literacy outcomes.

The very low information literacy group was purposively selected because these students represented the most educationally vulnerable subgroup and therefore provided an appropriate population for investigating whether self-regulated learning could support scientific literacy development following targeted instructional support.

3.2. *Participants*

Participants were recruited from six secondary schools representing diverse educational contexts, including urban public schools and an integrated model school. Among students with initially limited information literacy skills. Participant characteristics are presented in Table 1.

Table 1: Participant Characteristics Across Research Stages

Research Stage	Measurement	n	Gender		Dichotomous	
			Male, n (%)	Female, n (%)	Urban, n (%)	Rural, n (%)
Stage 1	Information Literacy Assessment	131	57 (43.51)	74 (56.49)	109 (83.21)	22 (16.79)
Stage 2	Self-Regulated Learning Assessment (Very Low Information Literacy Group)	28	12 (42.86)	16 (57.14)	23 (82.14)	5 (17.86)
Stage 3	Three-Tier Scientific Literacy Assessment (Post E-Bulletin Intervention)	28	12 (42.86)	16 (57.14)	23 (82.14)	5 (17.86)

Table 1 shows that 131 students participated in the initial information literacy assessment, with female students representing the majority of the sample (56.49%). Following the classification process, 28 students identified as having very low information literacy were selected for subsequent assessments of self-regulated learning and scientific literacy.

3.3. *Instruments*

Three instruments were employed to collect data on information literacy, self-regulated learning, and scientific literacy. All instruments underwent psychometric evaluation before implementation, including content validation by experts and internal consistency reliability testing (Jansen et al., 2021). Before data collection, all instruments underwent psychometric evaluation to establish their validity and reliability. The overall psychometric characteristics are summarised in Table 2, whereas Figure 2 shows the distribution of item-level validity and reliability indices across the three research instruments.

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Table 2: Instrument Psychometric Properties

Instrument	Items	Aiken's V	Reliability
Information Literacy	15	.83-.96	.89
SRL	63	.84-.97	.93
Scientific Literacy	20	.42-.81	.88

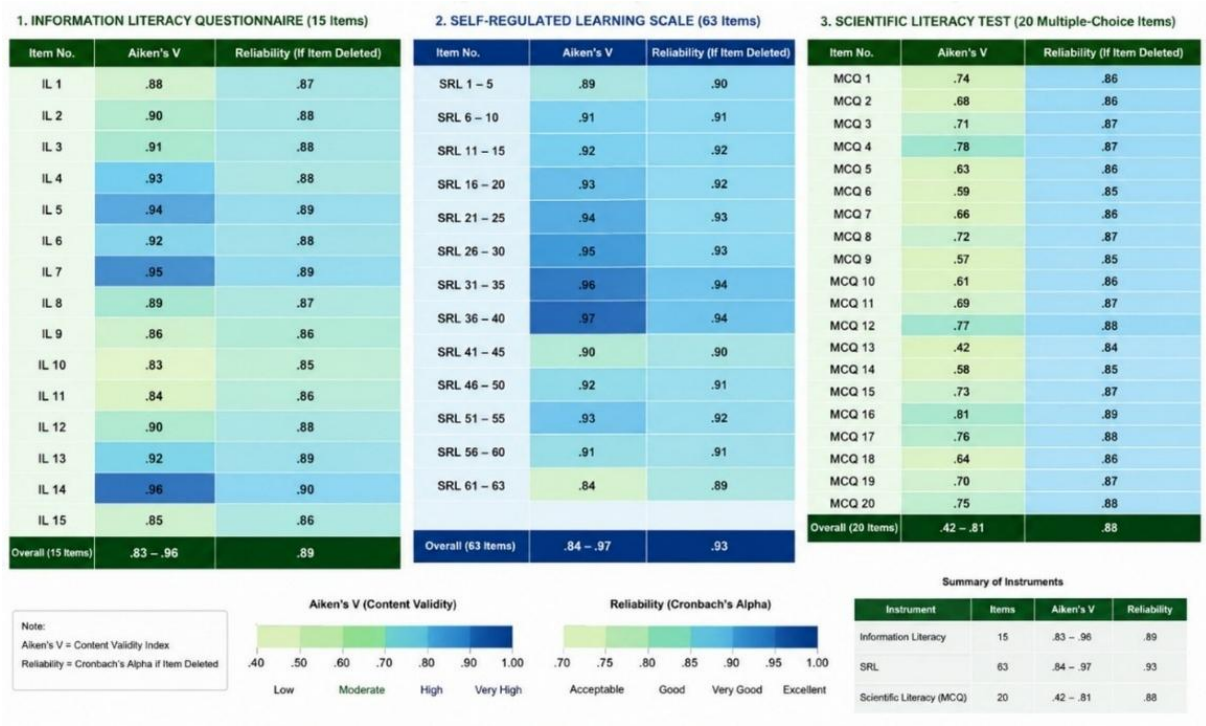


Figure 2: Item-Level Psychometric Properties of the Research Instruments

Interpreting scientific data and evidence together with nominal, functional, conceptual, and multidimensional literacy levels and confidence judgments (Tier 3) (Osborne & Allchin, 2025). The three instruments demonstrated satisfactory validity and reliability (Table 2; Figure 2).

3.4. *Data Collection Procedures*

Data collection was conducted in three sequential stages following approval from the school administrations and informed consent obtained from all participants and their parents or guardians. Participation was voluntary, and students were informed that their responses would be treated confidentially and used solely for research purposes. In the first stage, 131 students completed the Information Literacy Questionnaire to identify their literacy profiles and classify them into predefined categories. Based on the classification results, 28 students categorised as having very low information literacy were selected for the second stage, which involved administering the Self-Regulated Learning Scale. Subsequently, these students participated in E-Bulletin-supported chemistry learning activities on atomic structure before completing the Three-Tier Scientific Literacy Test in the final stage.

3.5. *Data Analysis*

Descriptive statistical analyses were initially conducted to summarise participants' information literacy, self-regulated learning, and scientific literacy scores. Measures of central tendency and dispersion, including mean, standard deviation, standard error, confidence intervals, minimum and maximum scores, coefficient of variation, skewness, and kurtosis, were calculated to provide a comprehensive overview of data distribution and participant

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characteristics. Information literacy scores were further classified into five categories: very low, low, moderate, high, and very high (Liu et al., 2025).

Prior to inferential analyses, normality testing was performed using the Shapiro–Wilk test and supported by the examination of skewness and kurtosis values. Pearson product-moment correlation analysis was then employed to examine the relationships between self-regulated learning dimensions and scientific literacy outcomes. Correlation coefficients (r), significance levels (p-values), confidence intervals, and coefficients of determination (r^2) were calculated to determine the strength and direction of the relationships among variables (Alsaqr, 2021).

To identify the predictive contribution of self-regulated learning dimensions, multiple regression analysis using the enter method was conducted with scientific literacy as the dependent variable. Regression coefficients, standardised beta values (β), tolerance, variance inflation factor (VIF), and relative contribution percentages were examined to evaluate the influence of each predictor and assess multicollinearity (Mizumoto, 2023). Furthermore, effect size analyses were performed to determine the practical significance of the findings, including Cohen's d for pretest–posttest comparisons, Cohen's f^2 for regression models, and partial eta squared (η^2) for variance explained by the overall model (Lovakov & Agadullina, 2021). All statistical analyses were conducted using IBM SPSS Statistics Version 20, with statistical significance established at $p < .05$.

4. Results and Discussion

4.1. Results

To identify the distribution of information literacy among secondary school students, descriptive statistical analyses were conducted across six participating schools. The analysis focused on students' information literacy categories, central tendency, and score variability to provide a comprehensive overview of literacy conditions across different school contexts. The findings are presented in Table 3.

4.1.1. RQ1: What are the information literacy profiles of secondary school students?

Table 3: Distribution of Information Literacy Categories

School Code	School Accreditation	Very Low n (%)	Low n (%)	Moderate n (%)	High n (%)	Very High n (%)
School 1	A	4 (18.18)	5 (22.73)	7 (31.82)	4 (18.18)	2 (9.09)
School 2	A	5 (22.73)	4 (18.18)	8 (36.36)	3 (13.64)	2 (9.09)
School 3	A	5 (22.73)	5 (22.73)	7 (31.82)	4 (18.18)	1 (4.55)
School 4	A	4 (18.18)	6 (27.27)	7 (31.82)	4 (18.18)	1 (4.55)
School 5	A	5 (22.73)	6 (27.27)	6 (27.27)	4 (18.18)	1 (4.55)
School 6	A	5 (23.81)	4 (19.05)	6 (28.57)	4 (19.05)	2 (9.52)
Total	—	28 (21.37)	30 (22.90)	41 (31.30)	23 (17.56)	9 (6.87)

Table 3 shows that the overall information literacy performance of secondary school students was classified as moderate (M = 66.15, SD = 8.17). Moderate literacy represented the largest proportion of students (31.30%), followed by low literacy (22.90%) and very low literacy (21.37%), indicating that nearly half of the participants demonstrated limited information literacy competencies. School-level comparisons revealed that School 1 achieved the highest mean score (M = 68.91, SD = 8.34), whereas School 5 recorded the lowest average performance (M = 63.77, SD = 8.73). Figure 3 presents the distribution of information literacy scores and category patterns across the six participating schools.

RQ2: What are the self-regulated learning profiles of students with very low information literacy?

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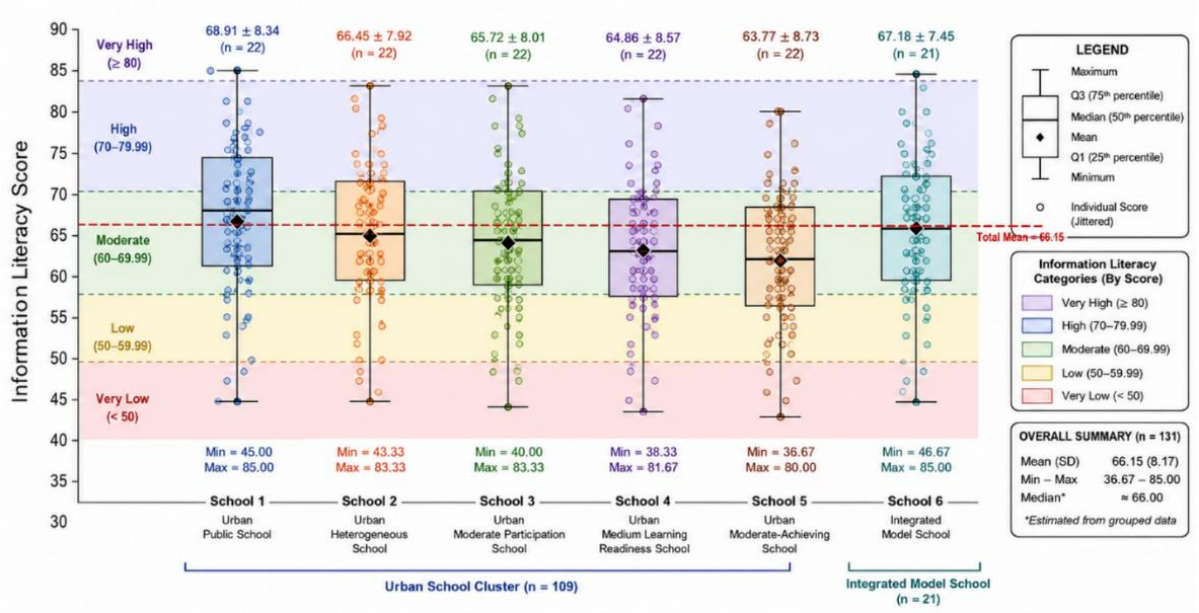


Figure 3: Distribution of Information Literacy Scores Across School Contexts

Figure 3 demonstrates that information literacy scores were predominantly concentrated within the moderate category across all participating schools, although considerable variability was observed among individual students. The distribution further revealed that 28 students (21.37%) were classified as having very low information literacy and were subsequently selected for further analyses examining self-regulated learning and scientific literacy outcomes. The descriptive statistics presented in Table 4 provide an overview of the SRL profiles of students who were selected for further intervention and scientific literacy assessment.

RQ3: What are the self-regulated learning profiles of students with very low information literacy?

Table 4: Descriptive Statistics of Self-Regulated Learning Among Students With Very Low Information Literacy (n = 28)

SRL Dimension	Mean	SD	95% CI	Min–Max	Interpretation
Goal Setting	3.18	0.52	2.98–3.38	2.10–4.25	Moderate
Strategic Planning	3.24	0.49	3.05–3.43	2.20–4.30	Moderate
Self-Monitoring	3.05	0.58	2.82–3.28	1.95–4.20	Moderate
Time Management	2.94	0.61	2.70–3.18	1.80–4.15	Moderate
Help Seeking	3.31	0.56	3.09–3.53	2.05–4.40	Moderate–High
Environmental Structuring	3.22	0.53	3.01–3.43	2.10–4.35	Moderate
Task Strategies	3.08	0.57	2.86–3.30	1.95–4.25	Moderate
Self-Evaluation	3.14	0.55	2.93–3.35	2.00–4.30	Moderate
Overall SRL	**3.15**	**0.48**	**2.96–3.34**	**2.10–4.28**	**Moderate**

Table 4 indicates that students with very low information literacy demonstrated an overall moderate level of self-regulated learning (M = 3.15, SD = 0.48). Among the SRL dimensions, Help Seeking showed the highest mean score (M = 3.31, SD = 0.56), whereas Time Management recorded the lowest score (M = 2.94, SD = 0.61), suggesting that students were generally willing to seek assistance but experienced difficulties in effectively managing their learning time. The descriptive statistics presented in Table 5 provide an overview of students' scientific literacy performance following participation in the E-Bulletin-supported chemistry learning activities.

RQ4: What is the level of scientific literacy among students with very low information literacy after participating in the E-Bulletin intervention?

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Table 5: Descriptive Statistics of Scientific Literacy Among Students With Very Low Information Literacy After E-Bulletin Intervention (n = 28)

Scientific Literacy Dimension	Mean	SD	95% CI	Min–Max	Interpretation
Explaining Scientific Phenomena	72.86	9.15	69.31–76.41	55–90	High
Evaluating and Designing Scientific Inquiry	69.43	10.27	65.45–73.41	50–88	Moderate–High
Interpreting Scientific Data and Evidence	74.11	8.84	70.68–77.54	58–92	High
Nominal Scientific Literacy	76.18	8.52	72.88–79.48	60–94	High
Functional Scientific Literacy	72.57	9.26	68.98–76.16	54–90	High
Conceptual Scientific Literacy	68.89	10.83	64.69–73.09	48–88	Moderate–High
Multidimensional Scientific Literacy	66.71	11.24	62.35–71.07	45–86	Moderate–High
Confidence Level (Tier 3)	73.04	8.79	69.63–76.45	58–90	High
Overall Scientific Literacy	**71.22**	**8.41**	**68.14–74.30**	**52–90**	**High**

Table 5 indicates that students achieved an overall high level of scientific literacy following the E-Bulletin intervention (M = 71.22, SD = 8.41). The highest performance was observed in Nominal Scientific Literacy (M = 76.18, SD = 8.52) and Interpreting Scientific Data and Evidence (M = 74.11, SD = 8.84), whereas Multidimensional Scientific Literacy recorded the lowest mean score (M = 66.71, SD = 11.24), suggesting that higher-order integration of scientific concepts remained relatively more challenging for students. The correlation results presented in Figure 4 and Table 6 provide evidence regarding the strength and direction of associations between self-regulated learning and scientific literacy among students with very low information literacy.

RQ5: Which dimensions of self-regulated learning significantly predict scientific literacy among students with very low information literacy?

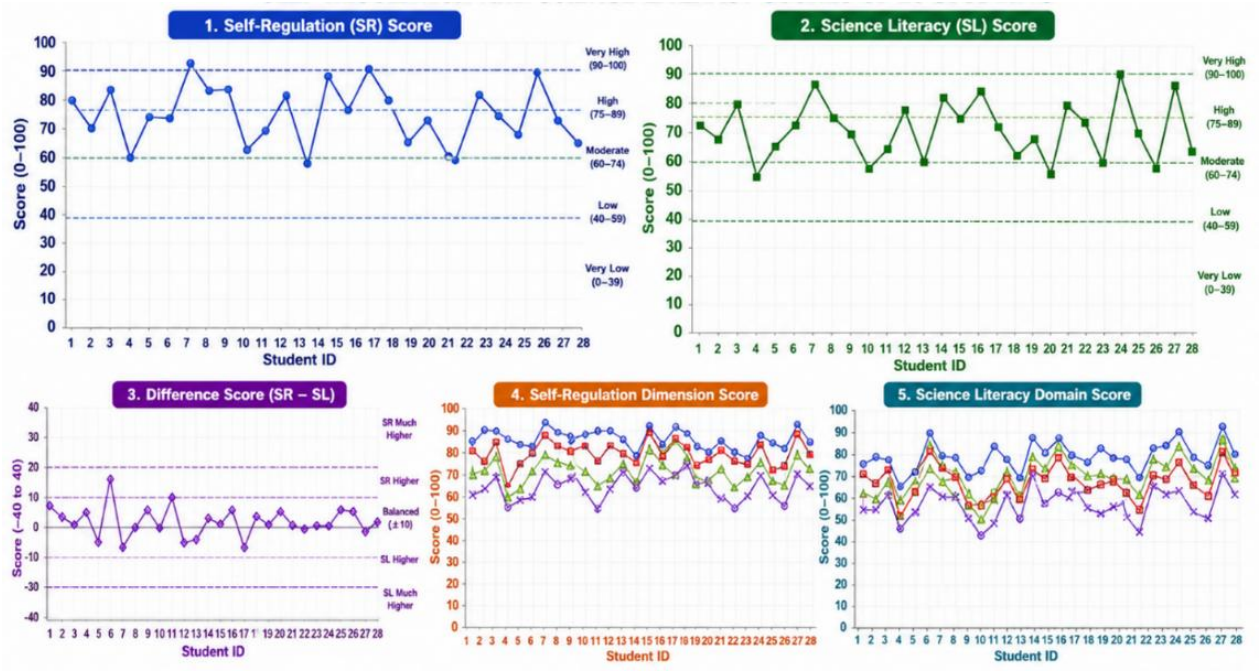


Figure 4: Multidimensional Learning Profiles Across Self-Regulated Learning, Information Literacy, and Scientific Literacy

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Table 6: Relationship Between Self-Regulated Learning and Scientific Literacy Among Students With Very Low Information Literacy (n = 28)

Variable	Scientific Literacy (r)	p-value	95% CI Lower	95% CI Upper	r^2	Effect Size (%)	Strength
Goal Setting	.621	.000	.331	.806	.386	38.6	Strong
Strategic Planning	.653	.000	.378	.826	.426	42.6	Strong
Self-Monitoring	.598	.001	.294	.793	.358	35.8	Strong
Time Management	.541	.003	.205	.761	.293	29.3	Moderate–Strong
Help Seeking	.483	.009	.127	.726	.233	23.3	Moderate
Environmental Structuring	.567	.002	.244	.778	.321	32.1	Moderate–Strong
Task Strategies	.615	.001	.321	.803	.378	37.8	Strong
Self-Evaluation	.684	.000	.424	.843	.468	46.8	Strong
Overall SRL	**.742**	**< .001**	**.527**	**.872**	**.551**	**55.1**	**Very Strong**

Figure 4 presents multidimensional relationships among self-regulated learning, information literacy, and scientific literacy across 28 students. Table 6 shows that all dimensions of self-regulated learning were positively and significantly correlated with scientific literacy ($p < .05$). The strongest relationship was observed between Self-Evaluation and scientific literacy ($r = .684$, $r^2 = .468$), while the overall self-regulated learning score demonstrated a very strong positive correlation with scientific literacy ($r = .742$, $r^2 = .551$), indicating that self-regulated learning accounted for approximately 55.1% of the variance in students' scientific literacy performance. The regression coefficients and model statistics are presented in Table 7.

Table 7: Multiple Regression Analysis Predicting Scientific Literacy From Self-Regulated Learning Dimensions (n = 28)

Predictor	B	SE B	β	T	p	Tolerance	VIF	Relative Contribution (%)
Goal Setting	2.184	0.947	.226	2.31	.031	.614	1.63	12.4
Strategic Planning	2.957	1.082	.287	2.73	.012	.592	1.69	15.7
Self-Monitoring	1.741	0.893	.174	1.95	.065	.678	1.47	8.9
Time Management	1.365	0.846	.143	1.61	.121	.711	1.41	6.4
Help Seeking	1.082	0.801	.118	1.35	.191	.734	1.36	5.3
Environmental Structuring	1.826	0.874	.192	2.09	.048	.655	1.53	9.7
Task Strategies	2.014	0.917	.208	2.20	.039	.621	1.61	10.6
Self-Evaluation	3.486	1.094	.334	3.19	.004	.576	1.74	18.7
Constant	**18.472**	**6.518**	—	**2.83**	**.010**	—	—	—

The regression model was statistically significant, $F(8, 19) = 17.83$, $p < .001$, explaining 66.1% of the variance in scientific literacy ($R^2 = .661$; Adjusted $R^2 = .624$). Among the self-regulated learning dimensions, Self-Evaluation emerged as the strongest predictor ($\beta = .334$, $p = .004$), followed by Strategic Planning ($\beta = .287$, $p = .012$) and Goal Setting ($\beta = .226$, $p = .031$), indicating that metacognitive regulation and learning planning contributed most substantially to students' scientific literacy performance.

RQ6: What is the magnitude of the effects of the E-Bulletin intervention and self-regulated learning on scientific literacy outcomes among students with very low information literacy?

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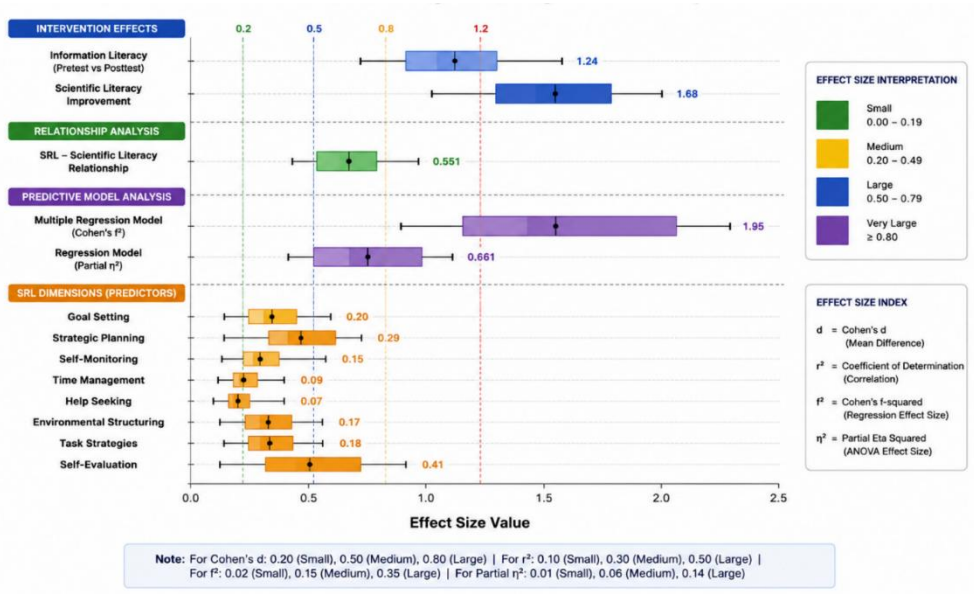


Figure 5: Comparison of Effect Sizes Across Intervention, Correlation, and Regression Analyses

Figure 5 indicates that the E-Bulletin intervention produced substantial improvements in both information literacy (d = 1.24) and scientific literacy (d = 1.68), reflecting large to very large practical effects. Furthermore, the regression model demonstrated a very large effect size (f^2 = 1.95), with Self-Evaluation (f^2 = 0.41) and Strategic Planning (f^2 = 0.29) emerging as the most influential self-regulated learning dimensions contributing to scientific literacy outcomes.

4.2. *Discussion*

4.2.1. Information Literacy Profiles

The findings in Table 3 and Figure 3 indicate that students' information literacy was generally located in the moderate category, with an overall mean score of 66.15 (SD = 8.17). However, the distribution also revealed that 28 students, or 21.37% of the sample, were classified as having very low information literacy, while another 22.90% were in the low category. This finding suggests that although the majority of students had the basic capacity to access, evaluate, and use information, a substantial proportion still experienced difficulty in managing academic information effectively.

The school-level distribution shown in Table 3 and Figure 3 further demonstrates that information literacy was not evenly distributed across school contexts. School 1 recorded the highest average information literacy performance, whereas School 5 showed the lowest average performance, indicating that school environment, access to learning resources, and students' readiness to engage with digital information may shape literacy outcomes. This finding is consistent with an Indonesian rural-school study, which found that digital literacy, learning media perception, and self-regulated learning contributed to cognitive learning outcomes in disadvantaged school contexts (Bahri et al., 2024). However, the present finding also differs from some studies in technologically advanced learning settings, such as Estonia, where digital tools are increasingly integrated into schooling, and students are encouraged to develop self-directed digital learning habits (Granström & Oppi, 2025).

4.2.2. Self-Regulated Learning Patterns

The results in Table 4 show that students with very low information literacy demonstrated an overall moderate level of self-regulated learning (M = 3.15, SD = 0.48). Among the SRL dimensions, Help Seeking showed the highest mean score (M = 3.31), while Time Management showed the lowest mean score (M = 2.94). This indicates that students were relatively willing to ask for assistance when facing learning difficulties but still struggled to

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regulate time, learning schedules, and independent study routines. In Zimmerman's self-regulated learning theory, this pattern reflects partial activation of the self-regulation cycle, where students may engage in social resource use but have not yet fully developed planning, monitoring, and self-reflection processes (D. H. Chang et al., 2023).

These results are in line with recent studies showing that SRL is essential in digital and blended learning environments. Xu et al. (2023), through a meta-analysis of online and blended learning, reported that SRL interventions had a positive and moderate effect on learning achievement (Xu, Zhao, Zhang, et al., 2023). Similarly, a Macau study by Deng et al. (2022) emphasised that SRL strategies are associated with academic achievement and that validated SRL instruments are important for understanding students' learning behaviour (Xu, Zhao, Liew, et al., 2023). Nevertheless, the moderate SRL profile in Table 4 also suggests a limitation: students with low information literacy may not automatically develop strong self-regulation simply because they receive digital learning materials. This finding challenges overly optimistic assumptions that digital learning environments alone can produce independent learners without explicit scaffolding of planning, monitoring, and reflection.

4.2.3. Relationship Between Self-Regulated Learning and Scientific Literacy

The correlation results in Table 6 demonstrate that all SRL dimensions were positively and significantly related to scientific literacy. Overall, SRL had the strongest association with scientific literacy ($r = .742$, $r^2 = .551$), suggesting that self-regulated learning explained approximately 55.1% of the variance in scientific literacy performance. Self-Evaluation also showed a strong relationship with scientific literacy ($r = .684$), indicating that students who were more capable of evaluating their learning progress tended to achieve better scientific literacy outcomes. This pattern supports social cognitive theory, which views learning as a reciprocal process involving personal regulation, behavioural strategies, and environmental support.

The strong relationship between SRL and scientific literacy is consistent with the Indonesian systematic literature review, which concluded that SRL has a positive role in overcoming scientific literacy limitations through self-efficacy, motivation, active learning, and engagement (Wang et al., 2025). The finding also aligns with OECD's PISA 2025 Learning in the Digital World framework, which identifies self-regulated learning as a central competency for students learning with digital technologies. However, the present study extends prior research by focusing specifically on students with very low information literacy rather than general student populations. This is important because the results suggest that even among academically vulnerable students, SRL remains a meaningful mechanism for improving scientific literacy when supported through structured instructional intervention.

4.2.4. Predictive Power of Self-Regulated Learning

The regression results in Table 7 show that the SRL model significantly predicted scientific literacy, explaining 66.1% of the variance in students' scientific literacy outcomes. Self-Evaluation emerged as the strongest predictor ($\beta = .334$, $p = .004$), followed by Strategic Planning ($\beta = .287$, $p = .012$) and Goal Setting ($\beta = .226$, $p = .031$). These results indicate that metacognitive regulation was more influential than purely behavioural strategies such as Help Seeking and Time Management. The finding is theoretically consistent with Zimmerman's model, which emphasises self-evaluation as a key reflective process that allows learners to judge their performance, revise strategies, and improve future learning outcomes.

The effect size results in Table 7 and Figure 5 further strengthen this interpretation. The regression model produced a very large effect size (Cohen's $f^2 = 1.95$), while Self-Evaluation ($f^2 = 0.41$) and Strategic Planning ($f^2 = 0.29$) were the most influential SRL predictors. This pattern is consistent with Bahri et al.'s Indonesian study, which found that SRL made the largest contribution to cognitive learning outcomes compared with digital literacy and students' perception of learning media. However, the relatively small effects of Time Management ($f^2 = 0.09$) and Help Seeking ($f^2 = 0.07$) suggest that not all SRL components

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contribute equally to scientific literacy. This finding refines previous SRL theory by showing that reflective and planning-oriented regulation may be more critical than support-seeking behaviors when students are required to interpret scientific evidence and solve conceptually complex problems.

4.2.5. Practical Implications for Digital Learning

The findings have important implications for digital learning design, particularly in the use of E-Bulletin-based chemistry learning. Table 5 shows that students achieved a high overall level of scientific literacy after the intervention (M = 71.22, SD = 8.41), with the highest performance in Nominal Scientific Literacy and Interpreting Scientific Data and Evidence. This suggests that the E-Bulletin intervention may have supported students in recognising scientific concepts, interpreting evidence, and building confidence in their responses. At the same time, Table 5 also shows that Multidimensional Scientific Literacy had the lowest mean score among the scientific literacy dimensions. This indicates that students still require stronger support in integrating scientific concepts, inquiry reasoning, data interpretation, and contextual decision-making. Therefore, digital learning tools such as E-Bulletins should not only provide attractive content but also embed explicit SRL prompts, reflective questions, inquiry tasks, and evidence-based reasoning activities. This implication is consistent with the OECD's Learning in the Digital World framework, which stresses that students need to monitor and control their cognitive, metacognitive, motivational, and affective processes while learning with technologies.

This study contributes theoretically, methodologically, and practically to research on information literacy, self-regulated learning, and scientific literacy in secondary education. Theoretically, the study demonstrates that SRL functions as an important learning mechanism linking information literacy vulnerability with scientific literacy performance. Methodologically, the study integrates information literacy profiling of 131 students, targeted analysis of 28 very low information literacy students, validated psychometric instruments in Table 2 and Figure 2, a three-tier scientific literacy assessment, correlation analysis, regression modelling, and effect size analysis in a single empirical framework. Practically, the findings provide evidence that E-Bulletin-supported learning can be strengthened by embedding SRL-based scaffolding, especially self-evaluation, strategic planning, and goal-setting activities, to support students who begin with weak information literacy profiles.

5. Conclusion

This study examined information literacy, self-regulated learning (SRL), and scientific literacy among secondary school students in a digital learning environment. The findings indicated that information literacy was generally moderate, although 21.37% of students were classified as having very low information literacy. Students in this subgroup demonstrated moderate SRL and achieved relatively high scientific literacy following participation in the E-Bulletin-supported chemistry learning intervention. Correlation, regression, and effect size analyses consistently showed that SRL, particularly self-evaluation, strategic planning, and goal setting, was a significant predictor of scientific literacy. The study contributes to the literature by integrating information literacy, SRL, and scientific literacy within a single empirical framework. The findings support Social Cognitive Theory and Zimmerman's SRL model, highlighting metacognitive regulation as an important mechanism underlying scientific literacy development. Practically, the results suggest that digital learning interventions should incorporate explicit SRL scaffolds, including reflection, progress monitoring, planning activities, and inquiry-based tasks. In terms of practical implications, these findings offer specific guidance for teachers, teacher professional development, and curriculum policy. First, for classroom practice, chemistry teachers working with students who exhibit low information literacy should embed explicit SRL prompts—such as goal-setting checklists and structured self-evaluation rubrics—directly within socioscientific issue-based digital materials (like E-Bulletins), rather than treating self-regulation as a separate instructional add-on. Second, at the institutional level, teacher professional development programmes must be

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upgraded to actively equip educators with pedagogical strategies for scaffolding self-regulation alongside digital content delivery. This is particularly crucial for teachers in under-resourced or rural school settings where information literacy gaps are more pronounced. Finally, regarding policy, policymakers designing digital literacy curricula should proactively integrate SRL training as a core, preventive component for students entering secondary education. Rather than addressing information literacy deficits reactively, a policy shift toward embedding metacognitive and self-regulatory skills into the national digital learning framework will better prepare students to navigate complex scientific information independently. Taken together, this study reinforces the view that scientific literacy in the digital era cannot be cultivated through content instruction alone; it requires the deliberate cultivation of learners' capacity to regulate their own cognitive and motivational processes. Several limitations should be acknowledged. The study involved a relatively small subgroup of 28 students, employed a cross-sectional correlational design, focused on a single chemistry topic, and relied partly on self-reported SRL measures. Future studies should employ longitudinal or experimental designs with larger and more diverse samples and examine the potential of learning analytics and artificial intelligence-supported learning environments to strengthen SRL and scientific literacy.

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