



## Fostering science culture as a social practice of learning: evaluating the 6SI contextual model and hyper-content platform in secondary Science Education

*Fomentar la cultura científica como práctica social del aprendizaje: evaluación del modelo contextual 6SI y la plataforma de hipercontenido en la educación secundaria de Ciencias*

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### Abstract

**Introduction:** The digital transformation of secondary science education demands instructional models that systematically integrate cognitive engagement, procedural inquiry, and self-regulated learning within digital environments. Science culture is conceptualized not merely as an individual cognitive literacy index, but as a social practice constructed through collaborative inquiry, scientific writing, and digital publication in post-digital settings. **Objective:** This study aimed to analyze the effectiveness of integrating the 6SI contextual instructional model with a digital hyper-content platform in enhancing conceptual knowledge and scientific writing performance as indicators of science culture development.

**Methodology:** A quasi-experimental pretest-posttest non-equivalent control group design was employed, involving 60 Grade 8 secondary students divided into an experimental group (n=30) utilizing the 6SI-hypercontent model and a matched control group (n=30) receiving conventional direct instruction. The intervention lasted four weeks, focusing on environmental biodiversity. Data were collected via a validated cognitive test (15 items; Cronbach's  $\alpha=.82$ ) and a rubric-based writing assessment scored by two independent evaluators (Cohen's  $\kappa=.85$ ). **Results:** Groups were equivalent at baseline ( $p>.05$ ). Post-intervention, the experimental group achieved significantly greater gains in conceptual knowledge ( $g=0.68$ ,  $SD=0.17$ ) compared to the control group ( $g=0.20$ ,  $SD=0.07$ ;  $t(58)=13.83$ ,  $p<.001$ , Cohen's  $d=3.57$ ). Similarly, scientific writing skills improved markedly in the experimental group ( $g=0.65$ ,  $SD=0.10$ ) versus the control ( $g=0.23$ ,  $SD=0.09$ ;  $t(58)=17.07$ ,  $p<.001$ , Cohen's  $d=4.41$ ).

**Conclusions:** The reconfigured social practices of the 6SI model supported by non-linear hyper-content resources effectively scaffold collaborative meaning-making and reflective evaluation foundational to active science culture formation, contributing evidence-based insights for integrated science education reform.

### Keywords

Science culture; self-regulated learning; hyper-content; 6SI instructional model; scientific inquiry; connectivism; social practice.

### Resumen

**Introducción:** La transformación digital de la educación científica en secundaria exige modelos de enseñanza que integren sistemáticamente la implicación cognitiva, la indagación procedimental y el aprendizaje autorregulado en entornos digitales. La cultura científica se conceptualiza no solo como un índice individual de alfabetización cognitiva, sino como una práctica social construida mediante la indagación colaborativa, la escritura científica y la publicación digital en contextos posdigitales. **Objetivo:** El objetivo de este estudio fue analizar la efectividad de la integración del modelo instruccional contextual 6SI y una plataforma digital de hipercontenido en la mejora del conocimiento conceptual y el rendimiento en escritura científica como indicadores del desarrollo de la cultura científica.

**Metodología:** Se empleó un diseño cuasiexperimental de pretest-posttest con grupo control no equivalente, con 60 estudiantes de educación secundaria (8.º grado) distribuidos en un grupo experimental (n=30) que utilizó el modelo 6SI-hipercontenido y un grupo control pareado (n=30) que recibió instrucción directa convencional. La intervención se desarrolló durante cuatro semanas, centrada en la biodiversidad ambiental. Los datos se recogieron mediante una prueba cognitiva validada (15 ítems;  $\alpha$  de Cronbach=.82) y una evaluación de escritura basada en rúbrica calificada por dos evaluadores independientes ( $\kappa$  de Cohen=.85).

**Resultados:** Los grupos fueron equivalentes en la línea base ( $p>.05$ ). Tras la intervención, el grupo experimental obtuvo mayores ganancias en conocimiento conceptual ( $g=0.68$ ,  $DT=0.17$ ) frente al grupo control ( $g=0.20$ ,  $DT=0.07$ ;  $t(58)=13.83$ ,  $p<.001$ ,  $d$  de Cohen=3.57). Del mismo modo, la escritura científica mejoró notablemente en el grupo experimental ( $g=0.65$ ,  $DT=0.10$ ) en comparación con el control ( $g=0.23$ ,  $DT=0.09$ ;  $t(58)=17.07$ ,  $p<.001$ ,  $d$  de Cohen=4.41). **Conclusiones:** Las prácticas sociales reconfiguradas del modelo 6SI apoyadas por recursos de hipercontenido no lineal andamian eficazmente la construcción colaborativa de significados y la evaluación reflexiva, procesos fundamentales para la formación activa de la cultura científica, ofreciendo evidencias para la reforma de la educación científica integrada.

### Palabras clave

Cultura científica; aprendizaje autorregulado; hyper-content; modelo instruccional 6SI; indagación científica; conectivismo; práctica social.



## Introduction

### ***The Paradigm Shift: Fostering Science Culture in Secondary Education***

In contemporary secondary education, the concept of science culture represents a holistic paradigm shift that moves beyond the traditional, rote-memorisation "banking model" of science education (Holbrook & Rannikmäe, 2009). While traditional scientific literacy often represents a simple threshold of factual recall, science culture represents an active disposition, an internalised set of habits of mind, and the capacity to evaluate, synthesise, and communicate evidence critically in post-digital settings (Roberts, 2007; Sjöström & Eilks, 2018), which has been shown to significantly enhance students' cognitive and motor engagement in active learning environments (Kaloka et al., 2023). In secondary schools, fostering a robust science culture is increasingly recognised as a cross-curricular necessity, enabling learners to critically evaluate evidence in both academic and everyday settings.

Global assessments like PISA (Programme for International Student Assessment) have consistently highlighted a significant gap in the ability of students to apply scientific concepts to real-world problems. This gap is particularly evident in the "Vision I" and "Vision II" distinction proposed by Roberts (2007). While Vision I focuses on the internal logic and content of science disciplines, Vision II emphasises the application of science in social, political, and personal contexts. Fostering science culture requires a "Vision III" a hybrid model where scientific thinking becomes a default cognitive state, enabling learners to critically evaluate evidence.

Beyond the classroom, science culture functions as a sociological bridge between scientific institutions and the public. Developing science culture at the secondary level ensures that the next generation possesses the epistemic vigilance necessary for active citizenship. In Indonesia, the push for science culture development is part of a larger national reform effort known as "Merdeka Belajar" (Freedom to Learn). For decades, Indonesian science education has been criticised for its over-reliance on teacher-centred instruction, resulting in historically low PISA scores. Fostering a culture of inquiry in the classroom means that students see science as a dynamic process for understanding the world rather than a set of static facts to be memorised for exams.

### ***Digital Pedagogy and Self-Regulated Learning (SRL) in Scientific Inquiry***

The "post-digital" era is characterised by the seamless integration of digital technologies into the fabric of everyday life. For the modern learner, technology is an environmental constant. However, having access to technology does not automatically equate to having the skills to use it for scientific inquiry. This mismatch is often referred to as the "digital native fallacy." While students may be highly proficient in social media navigation, they often lack the digital epistemic competence required to navigate complex scientific data.

To address this challenge, digital environments must be structured to actively foster Self-Regulated Learning (SRL) the proactive cognitive, metacognitive, and behavioural management of one's own learning goals (Zimmerman, 2002; Sinkkonen & Tapani, 2024). From a social-cognitive perspective, SRL operates as a three-phase cyclical process: forethought, performance, and self-reflection. When students explore complex ecological phenomena, they must negotiate a vast array of scientific data. A self-regulated learning framework enables them to plan their investigation, monitor their observations, and evaluate their findings, which in turn supports their basic psychological needs for autonomy and competence in active learning environments (Lamonedá Prieto et al., 2024).

Connectivism learning theory (Siemens, 2005) further emphasises that in the digital age, learning is the capacity to construct and navigate networks of information nodes. Fostering science culture requires digital structures that act as a "regulatory interface," managing students' cognitive load while supporting non-linear inquiry. These self-regulated and non-linear frameworks have been widely studied in active contexts such as physical education, where researchers have explored the integration of digital technology (Jastrow et al., 2022), the correlation between emotional self-regulation and peer dynamics (Capellán, 2025), autonomous learning portfolios (González-Valencia, 2025), and non-linear instructional scaffolding (Tri Kaloka, 2025). However, their integration to scaffold conceptual and procedural "science culture" in secondary natural sciences remains largely unexplored.



## ***Research Objectives and the Social Construction of Science Culture***

This study positions the science classroom as an arena of social practice where students construct science culture through collaborative activities, scientific writing, and digital publication. This approach integrates self-regulated learning and connectivism frameworks with a reading of science culture as a social practice of learning.

By pursuing these dual objectives, the research seeks to analyse the extent to which the integration of the 6SI model and hyper-content strengthens science culture through the enhancement of conceptual knowledge and scientific writing practices as forms of the social practice of learning. Specifically, the study is guided by the following two objectives:

- Quantitative Objective (Primary): To analyse the differences in the improvement of conceptual knowledge and scientific writing skills between the experimental group utilising the 6SI-hyper-content platform and the control group receiving conventional direct instruction.
- Interpretative Objective (Cultural Studies): To interpret how the specific task configurations of the 6SI model (collaborative inquiry, peer negotiation, and digital publication) represent active shifts and reconfigurations in the social practice of learning science in the classroom.

## ***Theoretical Framework***

### *Connectivism and Hyper-Content Architecture in Science Education*

Connectivism (Siemens, 2005) provides a networked perspective of learning that is highly relevant to contemporary education. In this paradigm, knowledge is distributed across networks of human and digital nodes, and learning is the ability to navigate, synthesise, and establish links between these nodes. Traditional educational resources present content in a rigid, linear fashion. In contrast, a hyper-content environment mirrors the non-linear complexity of natural networks. It provides "scaffolded non-linearity" where media, data, and conceptual tools are interlinked by query logic rather than sequential page numbers.

The architecture of hyper-content supports the development of science culture by requiring students to make navigational decisions. By allowing students to navigate between granular knowledge nodes, the platform provides opportunities for students to negotiate pathways of meaning-making, rather than following a passive, linear curriculum. In our implementation, these nodes included Media Nodes (video documentaries and interactive 3D models), Data Nodes (access to environmental datasets), Scaffolding Nodes (metacognitive prompts and help-seeking links), and Communication Nodes (shared workspaces). This is highly consistent with connectivism learning theory, where self-regulation plays a mediating role in fostering digital competence and networked engagement in technology-enhanced settings (Yang et al., 2025). Tri Kaloka (2025) suggests that non-linear pedagogical designs are highly effective for scaffolding contextual learning, as they encourage learners to construct their own meaning by establishing connections across diverse information blocks.

### *Zimmerman's Social-Cognitive SRL Cycle in Science Pedagogy*

The psychological framework underpinning the 6SI model is grounded in Zimmerman's (2000, 2002) social-cognitive model of SRL, which divides self-regulation into three recursive phases:

- Forethought Phase: Involves task analysis (goal setting, strategic planning) and self-motivation beliefs (self-efficacy, task value). In our integrated model, this phase is activated during the Orientation and Formulation stages of scientific inquiry.
- Performance Phase: Involves self-control (self-instruction, help-seeking, focus) and self-observation. In our model, this phase corresponds to the Collaboration and Revision stages, where students actively explore the hyper-content platform and refine their research notes.
- Self-Reflection Phase: Involves self-judgement (self-evaluation, causal attribution) and self-reaction (adaptive adjustments). This phase is operationalised in the Publication and Evaluation stages.



By embedding these regulatory phases directly into the six stages of the 6SI model, the instructional syntax acts as a cognitive guide. Students are trained to become active agents in their own learning, utilising scientific principles to regulate both their conceptual understanding and their practical communication. This aligns with González-Valencia (2025), who highlights that structured, portfolio-based reflection cycles are essential for fostering autonomous learning and helping students internalise self-regulatory strategies, as well as Bujosa-Quetglas et al. (2023) who demonstrate the effectiveness of structured self-regulated learning interventions. Furthermore, the surrounding learning environment and peer dynamics are central to shaping the perceived motivational climate, which has been shown to significantly influence students' self-concept and psychological well-being (Moreno-Rosa et al., 2026), as well as their self-regulated learning strategies (Bujosa-Quetglas et al., 2023).

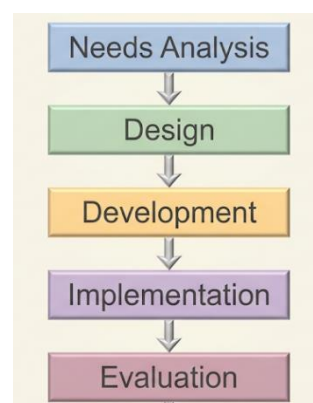
The philosophy of science culture represents a higher-order educational objective. Osborne (2014) argues that teaching science as a set of practices is essential for developing this culture. These practices include questioning, modelling, investigating, analysing, and communicating evidence. For a student to have a science culture, they must see these practices not as tasks assigned by a teacher, but as tools they own for understanding reality.

## Method

### Research Design

This study utilised a quasi-experimental, pretest–post-test non-equivalent control group design (N = 60) to evaluate the effectiveness of the 6SI-hypercontent model. This research design was chosen because it allows for a rigorous comparison between an experimental group and a matched control group in an authentic school setting where random assignment of individual students to classes is not feasible due to administrative and scheduling constraints. To evaluate the instructional model, the research followed a systematic five-phase Research and Development (R&D) cycle adapted from Borg and Gall (1983): (1) Needs Analysis and Information Collecting, (2) Instructional Planning and Platform Design, (3) Product Development and Expert Validation, (4) Field Testing and Implementation, and (5) Final Product Evaluation. This methodology allows for the systematic creation and validation of an instructional product (Gustiani, 2019). The Research and Development (R&D) process and implementation design are illustrated in Figure 1.

Figure 1. Research and development design adapted from Borg and Gall (1983).



The development process in this study followed a simplified R&D cycle in Figure 1, adapted to the research context, consisting of needs analysis, design, development, implementation, and evaluation. Such adaptation is common in educational research, where the full ten steps proposed by Borg and Gall are often streamlined to ensure feasibility without compromising methodological rigor (Borg & Gall, 1983).

### Participants and Selection Criteria



The participants were 60 secondary education students (Grade 8) from a public junior high school in Jakarta, Indonesia. The participants were drawn from two intact classes that were selected using purposive sampling based on the following selection criteria: (a) students were currently enrolled in the core science curriculum; (b) they possessed equivalent baseline academic performance; and (c) they had access to comparable digital devices in the school environment.

The two classes were assigned as follows:

- Experimental Group (n = 30): Comprised 14 male (47%) and 16 female (53%) students, aged 13 to 15 years (M = 13.8, SD = 0.6). This group received the interdisciplinary 6SI model integrated with the digital hyper-content platform.
- Control Group (n = 30): Comprised 15 male (50%) and 15 female (50%) students, aged 13 to 15 years (M = 13.9, SD = 0.5).

This group received conventional direct instruction covering identical environmental and biodiversity topics. Prior to the study, informed consent was obtained from all participants and their parents. The research protocol complied with the ethical guidelines of the Universitas Negeri Jakarta, ensuring participant anonymity and the right to withdraw at any stage of the intervention.

Operationalizing the 6SI-Hyper-Content vs. Conventional Instruction: A Study of Reconfigured Social Practices

The 4-week interventional period (focused on "Environmental Science and Biodiversity") was structured not merely as a comparison of pedagogical techniques, but as a systematic contrast between two distinct configurations of classroom social practices. Both groups met for two 90-minute sessions per week, totaling 8 sessions, covering identical curricular content under the same instructor.

Social Configurations and Learning Practices

1. Experimental Group (6SI + Hyper-Content): In this group, the learning environment was reconfigured as a collaborative, networked space. The social setting was defined by students working in fixed peer groups of three. These groups engaged in dialogic negotiations of environmental topics, collective field investigations, and peer-mediated editing. The structure of the 6SI model shifts the social practice of learning from passive consumption of content towards the collaborative production and negotiation of scientific meaning. Rather than consuming pre-packaged textbook answers individually, students navigated a non-linear digital hyper-content platform together. They were required to collaboratively formulate research problems (Week 1), explore and compile empirical data in shared digital spaces (Week 2), actively resolve conceptual discrepancies through peer discussions (Week 3), and publish their findings for public review on the school's digital portal (Week 4). Scientific writing skills are positioned as a social practice: students produce texts for a real audience through the school's digital portal.
2. Control Group (Conventional Instruction): In this group, the social configuration reinforced a traditional, individualized, and teacher-centric classroom culture. The social setting did not involve collaborative group work or digital peer-mediation. Instead, students worked individually, listening to teacher-delivered lectures (Week 1), participating in a highly structured, teacher-guided walk where they took individual notes (Week 2), completing standard textbook review exercises on paper (Week 3), and writing laboratory reports individually in class to be submitted solely to the teacher for evaluation (Week 4). Social interactions were strictly vertical (teacher-to-student), with no opportunities for peer review, public publication, or collective negotiation of meaning.

### ***Epistemic Reading of the Quantitative Data***

We explicitly position the pretest and post-test scores in conceptual knowledge and writing performance as empirical indicators of how these distinct classroom social configurations contribute to the formation of an active science culture. While these quantitative metrics are highly valuable for comparing performative gains, they are read here as external traces of the classroom's learning practices rather than the sole or absolute evidence of cultural transformation. The structural architecture and pedagogical flow of the 6SI contextual instructional model are detailed in Figure 2



Figure 2. Development Stages of the 6SI-Hyper-Content Model

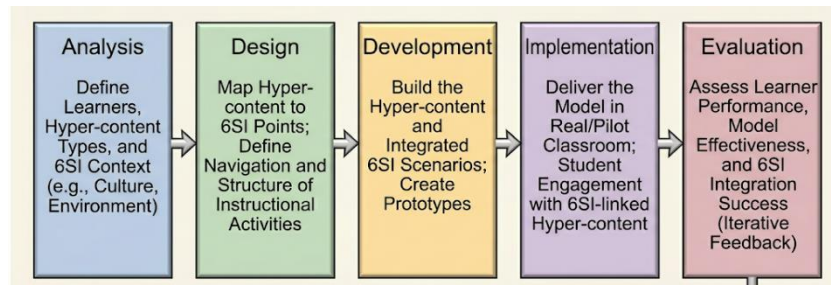


Figure 2 illustrates how each of the six instructional stages (Orientation, Formulation, Collaboration, Revision, Publication, Evaluation) corresponds to specific cognitive and self-regulatory scaffolding layers. Week 4 (Publication & Evaluation): Students synthesized their findings into digital scientific field journals and infographics. These were published on the school's Digital Science Portal (the Publication Node) for peer review. The intervention concluded with students submitting structured reflection journals in the Evaluation Node, evaluating their self-regulatory and collaborative strategies.

### ***Control Group Protocol (Conventional Instruction)***

The control group was taught by the same teacher using conventional direct-instruction methods. The class followed a teacher-centred, linear format:

- Week 1: The teacher delivered a structured lecture on urban biodiversity and ecosystem dynamics using slides and a standard textbook. Students completed individual worksheets.
- Week 2: Students participated in a standard, pre-planned teacher-guided school yard walk. The teacher pointed out ecological concepts, and students took notes in paper notebooks.
- Week 3: The teacher explained water pollution concepts in a classroom lecture. Students completed textbook review exercises.
- Week 4: Students wrote a standard laboratory report in class and submitted it individually on paper. The session concluded with a brief, teacher-led class summary of the unit.

### ***Instruments and Technical Specifications***

Data were gathered using two primary quantitative instruments, which were subjected to rigorous content validation and reliability checks, as detailed in Table 1:

Table 1. Instrument Specifications and Psychometric Properties

Instrument	Purpose	Form	Scale
Cognitive test	Measure conceptual understanding	Test	0-100
Practical test	Measure procedural performance	Performance test	0-100
Expert validation sheet	Assess content & design validity	Questionnaire	Likert

The content validity of both instruments was assessed by a panel of three senior university lecturers in educational technology and natural sciences. The resulting Content Validity Index (CVI) was 0.88 for the cognitive test and 0.91 for the practical test, indicating high content validity.

The instruments were validated by subject-matter and instructional design experts to ensure content validity and clarity. Pretests were administered before the instructional intervention, and posttests were administered after the implementation of the developed model.

### ***The Conceptual Knowledge Test measured students'***

understanding of biodiversity, ecological balance, urban pollution indices, and conservation strategies. The Practical Writing Test evaluated students' ability to synthesise scientific arguments in writing. Performance was assessed based on a 4-dimensional analytical rubric (Scientific Accuracy, Evidence Synthesis, Argumentative Structure, and Digital Media Layout), with each dimension scored from 1

(unacceptable) to 4 (excellent) by two independent senior science educators. The raw rubric scores were subsequently converted to a 0–100 scale. The inter-rater reliability of the writing assessment was calculated using Cohen's Kappa, yielding an index of kappa = 0.85, which represents high scoring agreement

### Data Analysis

Descriptive statistics (means and standard deviations) were calculated for both pretest and posttest scores. The Normalized Gain (N-Gain) score was computed for each student using Hake's (1998) formula:

$$g = \frac{(\text{posttest score} - \text{pretest score})}{(100 - \text{pretest score})}$$

Table 2. Data Analysis Techniques

Data Type	Analysis Technique	Output
Pretest–posttest scores	N-Gain	Effectiveness category
Pretest–posttest scores	Paired <i>t</i> -test	Significance
Validation data	Descriptive analysis	Feasibility level

Where values below 0.30 indicate low gain, values between 0.30 and 0.70 indicate medium gain, and values above 0.70 indicate high gain. Additionally, **paired sample *t*-tests** were conducted to examine statistically significant differences between pretest and post-test scores, with a significance level set at  $\alpha = 0.05$ .

To evaluate statistical significance:

- Paired-sample *t*-tests were conducted to evaluate the significance of pre-to-post improvements within each group.
- Independent-sample *t*-tests were performed on pretest scores to verify baseline equivalence between the groups, and on post-test and N-Gain scores to determine the comparative efficacy of the 6SI-hypercontent model.
- Cohen's *d* was calculated for independent comparisons to evaluate the magnitude of the effect size.

All statistical assumptions (normality via Shapiro-Wilk and homogeneity of variance via Levene's test) were verified, and analyses were executed using SPSS version 26.0 with the alpha level set at  $p < .05$ .

## Results

### Equivalence of Groups at Baseline

To ensure the validity of our quasi-experimental comparisons, independent-sample *t*-tests were conducted on the pretest scores of both groups. For the Conceptual Knowledge Test, the experimental group pretest means ( $M = 54.93$ ,  $SD = 15.02$ ) was highly comparable to the control group pretest mean ( $M = 55.10$ ,  $SD = 9.23$ ;  $t(58) = -0.05$ ,  $p = .959$ ). For the Practical Writing Test, the experimental group pretest means ( $M = 47.57$ ,  $SD = 14.59$ ) likewise showed no significant difference from the control group pretest mean ( $M = 47.00$ ,  $SD = 9.32$ ;  $t(58) = 0.18$ ,  $p = .858$ ). These results demonstrate that the experimental and control groups possessed equivalent baseline conceptual and practical competencies prior to the intervention.

### Enhancement of Conceptual Knowledge

Following the 4-week intervention, both groups showed statistically significant pre-to-post improvements in conceptual knowledge. However, the experimental group achieved a substantially higher gain. Table 2 presents the detailed descriptive and comparative statistics for conceptual knowledge.



Table 3. Descriptive Statistics, N-Gain, and t-tests for Conceptual Knowledge (N = 60)

Group	Pretest Mean (SD)	Post-test Mean (SD)	Paired t-test (df=29)	p-value	Mean N-Gain (SD)	Gain Category	Independent t-test (df=58)	Effect Size (Cohen's d)
Experimental (n=30)	54.93 (15.02)	84.50 (8.88)	t = 13.90	p < .001	0.68 (0.17)	Medium	t = 13.83 (N-Gain)	3.57 (N-Gain)
Control (n=30)	55.10 (9.23)	64.23 (8.00)	t = 13.45	p < .001	0.20 (0.07)	Low	t = 9.29 (post-test)	2.40 (Post-test)

As illustrated in Table 4, both groups achieved highly significant conceptual growth ( $p < .001$ ). Crucially, the experimental group achieved a mean post-test score of 84.50 (SD = 8.88) compared to the control group's post-test mean of 64.23 (SD = 8.00). The independent-sample t-test comparing the post-test scores revealed a highly significant difference in favour of the experimental group ( $t(58) = 9.29$ ,  $p < .001$ ), with an extremely large effect size (Cohen's  $d = 2.40$ ).

Furthermore, the experimental group achieved a medium-category mean normalised gain ( $g = 0.68$ , SD = 0.17), which was significantly higher than the low-category gain achieved by the control group ( $g = 0.20$ , SD = 0.07;  $t(58) = 13.83$ ,  $p < .001$ , Cohen's  $d = 3.57$ ). The reduction in standard deviation within the experimental group (from 15.02 to 8.88) indicates that the 6SI-hypercontent model acted as a strong scaffold, helping narrow the performance gap among students.

### ***Enhancement of Practical Scientific Writing Performance***

The practical writing test measured students' ability to synthesise their environmental field observations into structured digital journals and infographics. The results revealed a marked superiority in the experimental group's writing performance, as summarised in Table 5.

Table 4. Descriptive Statistics, N-Gain, and t-tests for Practical Writing Performance (N = 60).

Group	Pretest Mean (SD)	Post-test Mean (SD)	Paired t-test (df=29)	p-value	Mean N-Gain (SD)	Gain Category	Independent t-test (df=58)	Effect Size (Cohen's d)
Experimental (n=30)	47.57 (14.59)	81.23 (8.90)	t = 20.14	p < .001	0.65 (0.10)	Medium	t = 17.07 (N-Gain)	4.41 (N-Gain)
Control (n=30)	47.00 (9.32)	59.03 (8.80)	t = 11.40\$	p < .001	0.23 (0.09)	Low	t = 9.72 (post-test)	2.51 (Post-test)

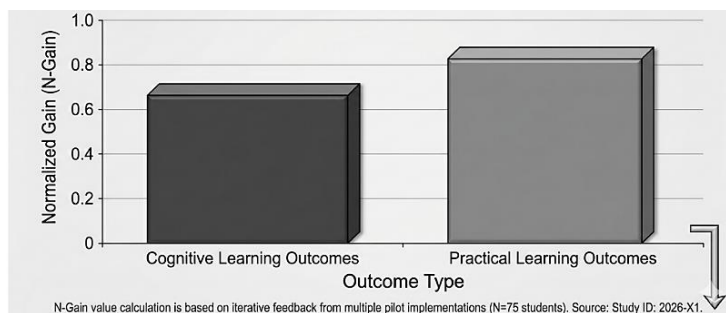
The statistical analysis in Table 5 shows that the experimental group's post-intervention writing mean rose to 81.23 (SD = 8.90) from a pretest mean of 47.57, whereas the control group's mean rose modestly to 59.03 (SD = 8.80) from 47.00. The post-test independent t-test demonstrated a highly significant difference between the groups ( $t(58) = 9.72$ ,  $p < .001$ , Cohen's  $d = 2.51$ ).

The comparison of normalised gains further confirmed this efficacy: the experimental group achieved a medium-category gain ( $g = 0.65$ , SD = 0.10), which was significantly higher than the low-category gain of the control group ( $g = 0.23$ , SD = 0.09;  $t(58) = 17.07$ ,  $p < .001$ ). The associated Cohen's  $d$  of 4.41 indicates an exceptionally large effect size. This demonstrates that the 6SI-hypercontent model was highly effective in scaffolding the practical, procedural writing skills essential for active communication within the classroom.

### ***Balanced Development of Science Culture Indicators***

To evaluate the consistency and balance of the learning gains, Figure 3 compares the mean normalised gain scores achieved by both the experimental and control groups.

Figure 3. Comparison of Mean Normalised Gain (N-Gain) Scores Between Groups



As visually depicted in Figure 3, the experimental group achieved nearly identical and balanced gains in both the conceptual ( $g = 0.68$ ) and practical ( $g = 0.65$ ) domains. From a quantitative perspective, occurs a significant increase in two key indicators understood as parts of science culture in the classroom, reflecting a coordinated and balanced growth across both conceptual and procedural dimensions. The findings demonstrate a significant increase in conceptual knowledge and scientific writing skills in the classroom that implemented collaborative learning practices based on the 6SI model. In terms of quantitative outcomes, this indicates that the configuration of learning social practices in the 6SI classroom is more productive in generating scientific performance compared to the conventional classroom.

## Discussion

### *Reconfiguration of Learning Social Practices in the Science Classroom*

The quantitative results of this study must be interpreted through a cultural lens that reads the science classroom as a space of dynamic social practices. To understand why the experimental group achieved superior outcomes, we must contrast the distinct social configurations of learning and classroom cultures generated in the experimental (6SI-hyper-content) and control (conventional direct instruction) groups:

- **Interaction Patterns:** In the conventional control classroom, social interaction was predominantly vertical, direct, and teacher centric. The teacher functioned as the primary authority node and transmitter of scientific concepts, while students occupied passive, isolated positions, digesting lectures and writing individual answers. Conversely, the 6SI classroom operated as a horizontal, peer-mediated social network. Students were organized into collaborative trials where they had to negotiate tasks, allocate responsibilities, and engage in peer-mediated discussions during field investigations. The teacher's role shifted from a lecturer to a culture-facilitating coach who guided, rather than dictated, the inquiry.
- **Task Profiles:** The control group completed traditional, highly structured tasks (e.g., answering textbook questions and completing worksheets individually). These tasks prioritised rote-memorisation and factual recall, reinforcing a classroom culture of science as a static, pre-packaged body of facts. In contrast, the 6SI experimental tasks required active conceptual negotiation, field-based data collection, and collaborative synthesis. The tasks were open-ended and non-linear, requiring students to collaboratively formulate research questions, reconcile conflicting field observations, and produce co-authored digital scientific journals.
- **Work Publication:** In the conventional group, writing was a private, transactional practice: students wrote reports on paper for an audience of one (the teacher) to receive a grade. In the 6SI classroom, writing was treated as a public, authentic social practice. Students synthesized their field observations into digital scientific journals and infographics to be published on the school's digital portal. This public exposure introduced real-world communicative stakes, converting the act of writing into an authentic negotiation of meaning aimed at a genuine audience.

In this study, the significant increases in conceptual knowledge and writing performance are understood as indicators that the reconfigured social practices in the 6SI classroom were highly productive in supporting a more active, collaborative science culture. However, we must explicitly state that the quantitative gains in scores represent external, performative indicators of this culture; other socio-emotional, behavioural, or deep psychological variables (such as shifts in student identity, intrinsic motivation, or individual self-efficacy) were not directly measured by our instruments. Therefore, the statistical improvements are interpreted as evidence that reconfiguring classroom social structures provides a far more fertile ground for active science culture than conventional structures.

### ***Cognitive and Pedagogical Analysis of the 6SI Instructional Syntax***

The significant performance improvements achieved by the experimental group can be explained by the specific cognitive and self-regulatory scaffolding provided at each stage of the 6SI instructional syntax:

- **Orientation (Metacognitive Priming):** Standard science courses often begin with abstract, textbook definitions, which can result in low task interest. In the 6SI model, the Orientation stage engages students' contextual and bodily senses in a localised environmental setting. This direct sensory experience activates Zimmerman's (2002) social-cognitive "Self-Motivation Beliefs." By establishing immediate relevance, it sustains students' interest through the more cognitively demanding subsequent stages.
- **Formulation (Strategic Planning):** Guided by digital templates, students defined specific scientific variables and formulated investigation plans. This stage scaffolds the "Forethought Phase" of SRL, helping prevent the chaotic, trial-and-error approach common in unstructured digital environments.

### ***Collaboration (Networked Connectivism***

- **Exploration):** Rather than working in isolation, students collaborated in groups of three, sharing observations through the platform's Collaboration Hub. This collaborative structure leverages connectivism learning principles (Siemens, 2005). Students learned to synthesize information from a variety of digital and human nodes, negotiating meaning and validating evidence collectively.
- **Revision (Collaborative Meaning Negotiation & Conceptual Refinement):** During this critical stage, students compared their field data with established environmental models and rules in the hyper-content platform. Encountering discrepancies triggered socio-cognitive conflict, requiring students to engage in collaborative negotiation and peer-mediated conceptual refinement. Rather than presenting this as a direct measurement of individual cognitive inhibitory control which was not measured in this study, we interpret this stage as a social practice where students collectively negotiated meaning and corrected scientific misconceptions through active dialogue. The platform's misconception alerts acted as a supportive peer node, prompting groups to revise incorrect initial assumptions in a collaborative manner.
- **Publication (Communal Synthesis):** By translating their field notes into co-authored digital field journals and infographics, students engaged in the "performance phase" of SRL. Preparing their writing for public school review motivated students to structure their arguments logically, summarize evidence accurately, and pay attention to media layout.
- **Evaluation (Closing the Metacognitive Loop):** The final stage required students to complete structured self-reflection journals. This reflection is the engine of Zimmerman's "Self-Reflection Phase." It helped students translate a single, localized inquiry project into generalized self-regulated habits of mind.
- **Comparative Analysis with Digital Interdisciplinary Interventions**

The learning gains observed in this study compare favourably with other recent digital interdisciplinary interventions in educational technology. Table 4 presents a comparative analysis of normalised gains across similar studies.



Table 6. Comparison of Normalised Gains with Related Educational Technology Literature

Study	Methodology	Target Curricular Domain	Sample Size (N)	Experimental N-Gain	Control N-Gain
This Study (2026)	6SI + Hyper-content Platform	Secondary Science Culture	60	0.68 (Cognitive) 0.65 (Practical)	0.20 (Cognitive) 0.23 (Practical)
Nurpratiwi et al. (2023)	Hyper-content E-materials	Pedagogical Concepts	45	0.58	No Control Group
Tanak (2018)	TPACK-based Science Course	Secondary Science Education	30	0.52	No Control Group
Tondeur et al. (2016)	Strategic Digital Integration	Teacher Training Pedagogy	688	0.49	0.38
Widodo et al. (2024)	Personalised E-module system	Physical Education Online	62	0.61	0.44

As summarised in Table 6, the 6SI-hypercontent model achieved higher normalised gains (0.65 - 0.68) than studies using digital hyper-content alone without a structured inquiry framework (e.g., Nurpratiwi et al., 2023), models using TPACK-integrated lessons in isolation (e.g., Tanak, 2018), or models relying on direct digital instruction (e.g., Tondeur et al., 2016). While Widodo et al. (2024) demonstrated strong gains (0.61) in digital physical education by personalising e-modules, our study indicates that combining a structured, contextual inquiry syntax (6SI) with non-linear hyper-content scaffolding leads to superior conceptual and practical growth. This comparative success highlights that the structured stages of the 6SI syntax serve as a critical differentiator, translating digital search into robust conceptual and practical learning.

### ***The Synergistic Loop of Inquiry and Self-Regulation***

At a theoretical level, the success of this model lies in the synergistic connection established between the stages of scientific inquiry and the phases of self-regulated learning. In many traditional digital systems, there is an educational gap between content delivery and cognitive regulation. Students are often expected to regulate their learning without any explicit tools to do so.

The integrated 6SI-hypercontent platform addresses this gap by embedding regulatory cues directly into the instructional syntax. The platform's stage-gated architecture manages students' cognitive load by providing resources dynamically as they become relevant. Rather than overwhelming students with extensive, unorganised information, the platform acts as a "navigational scaffold." This structured delivery allows students to focus their cognitive resources on active inquiry and synthesis.

### ***Limitations and Future Research Directions: A Cultural Studies Boundary***

While the quasi-experimental design revealed significant advantages for the 6SI-hypercontent model, several limitations and boundaries must be acknowledged:

- **Sample Size and Selection:** The study was conducted with a cohort of 60 students (\$n = 30\$ per group) selected via purposive sampling from a single urban school in Jakarta. While the groups were matched and equivalent at baseline, this sample size limits the direct generalisation of the findings to diverse rural or lower-resource school environments.
- **Intervention Duration:** The intervention was implemented over a 4-week period. Although this duration was sufficient to produce significant conceptual and practical gains, it did not allow for the evaluation of long-term retention.
- **Construct Measurement and Interpretative Boundaries:** The primary empirical data collected in this study were restricted to conceptual knowledge scores and rubric-assessed scientific writing performance.

Although frameworks of connectivism, self-regulated learning, and classroom culture were used to interpret the findings, specific individual psychological and cognitive constructs such as shifts in intrinsic motivation, adaptive expertise, executive functions, or cognitive inhibitory control were not directly measured using standardised psychological scales. Furthermore, from a Cultural Studies perspective, this research represents a 'light-level' or interpretive cultural reading rather than a pure qualitative Cultural Studies project. We did not collect micro-qualitative data on classroom discourse, individual student identities, or verbatim interactional transcripts. Although this study does not qualitatively analyse classroom discourse, the task structure of the 6SI model and the enhanced writing performance indicate a reconfiguration of learning social practices towards a more collective model of

knowledge production. Accordingly, science culture in this context is understood as a pattern of social practice articulated through how students work, write, and publish their findings.

- **Linguistic and Cultural Context:** The study was conducted in the Indonesian secondary education context under the "Merdeka Belajar" curriculum. Cultural differences in students' self-efficacy, digital access, and familiarity with collaborative inquiry may influence the model's implementation in other international contexts.

Future research should address these limitations by executing larger-scale, randomised controlled trials across diverse educational settings, including rural and under-resourced schools. Longitudinal designs incorporating delayed post-tests are needed to evaluate the long-term retention of science culture habits. Additionally, future studies should integrate multimodal learning analytics (de Mooij et al., 2025) and standard psychological scales to directly measure shifts in self-regulated learning, self-efficacy, and executive functions.

## Conclusions

This study demonstrates that the integration of the 6SI contextual instructional model and a digital hyper-content platform is highly effective in enhancing key indicators of science culture among secondary education students within a structured cross-curricular framework. The quasi-experimental evaluation revealed that the experimental group ( $n = 30$ ) achieved significantly greater conceptual knowledge gains ( $g = 0.68$ ,  $SD = 0.17$ ) and practical scientific writing gains ( $g = 0.65$ ,  $SD = 0.10$ ) compared to the matched control group ( $g = 0.20$  and  $g = 0.23$ , respectively;  $p < .001$ ), with exceptionally large effect sizes (Cohen's  $d = 3.57$  for knowledge,  $d = 4.41$  for writing).

This study demonstrates that when the social practices of science learning are reconfigured through the 6SI-hyper-content model, students not only experience improvements in conceptual knowledge and writing scores but also engage in scientific literacy practices that are more collaborative and publicly oriented. At a theoretical level, the efficacy of the 6SI model lies in its capacity to scaffold active learning dynamics. Rather than relying on traditional direct instruction, the six structured stages guide students through collaborative inquiry, digital negotiation, and shared publication.

However, claims regarding shifts in student identity, motivation, or executive functions remain speculative and must be tested in more in-depth Cultural Studies research employing qualitative data. Future investigations should build on this study by combining quantitative assessments with rigorous qualitative discourse analysis to fully capture the rich, interactive dimensions of science learning cultures.

## Policy and Practical Recommendations

At the policy and practical levels, these findings support several key recommendations for contemporary educational reform:

- **Cross-Curricular Curriculum Integration:** Educational ministries and school administrators should actively promote cross-curricular initiatives that link cognitive science culture with active environmental projects. Integrating environmental literacy projects into active spaces provides a rich, contextual environment for student engagement.
- **Instructional Design over Hardware:** Professional development programmes should move beyond basic digital literacy and hardware provision. Training should focus on equipping teachers with validated pedagogical frameworks like 6SI that can transform digital devices into structured learning environments.
- **Shift in the Educator's Role:** Implementing interdisciplinary, digitally scaffolded models require teachers to transition from traditional lectures to acting as facilitators of self-regulated learning. Educators should be trained to monitor student inquiry, provide targeted conceptual feedback during the Revision stage, and guide reflection during the Evaluation stage.
- **Balanced, Rubric-Based Assessment:** School assessment policies should move away from an exclusive reliance on high-stakes testing of factual recall. Evaluating student-created portfolios,



field journals, and infographics using clear analytical rubrics is essential to assess the practical and inquiry dimensions of science culture.

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## References

- Borg, W. R., & Gall, M. D. (1983). *Educational research: An introduction* (4th ed.). Longman.
- Bujosa-Quetglas, G., Estévez-González, A., Vidal-Conti, J., Cantalops-Ramón, M., & Ponseti-Verdaguer, F. (2023). Efectividad del aprendizaje autorregulado en intervenciones en Educación Física promotoras de actividad física: Revisión sistemática. *Retos*, 50, 487–499. <https://doi.org/10.47197/retos.v50.99702>
- Capellán, S. B. (2025). Correlation between social comparison and emotional self-regulation: A narrative study in a youth indoor football team. *Retos*, 67, 783–793. <https://doi.org/10.47197/retos.v67.110579>
- de Mooij, S., Lämsä, J., Lim, L., Azevedo, R., Bannert, M., Gašević, D., Järvelä, S., & Molenaar, I. (2025). A systematic review of self-regulated learning through integration of multimodal data and artificial intelligence. *Educational Psychology Review*, 37, Article 54. <https://doi.org/10.1007/s10648-025-10028-0>
- González-Valencia, C. (2025). Autonomous learning and portfolio: perceptions of Trainee Teachers in physical education pedagogy. *Retos*, 67, 406–415. <https://doi.org/10.47197/retos.v67.109693>
- Gustiani, S. (2019). Research and development (R&D) method as a research method in education and its procedure. *Sriwijaya University Learning and Education International Conference*, 2(1), 227–235.
- Hake, R. R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics*, 66(1), 64–74. <https://doi.org/10.1119/1.18809>
- Holbrook, J., & Rannikmäe, M. (2009). The meaning of scientific literacy. *International Journal of Environmental and Science Education*, 4(3), 275–288.



- Jastrow, F., Greve, S., Thumel, M., Diekhoff, H., & Süßenbach, J. (2022). Digital technology in physical education: A systematic review of research from 2009 to 2020. *German Journal of Exercise and Sport Research*, 52(4), 504–528. <https://doi.org/10.1007/s12662-022-00848-5>
- Kaloka, T. P., Nopembri, S., & Yudanto, Y. (2023). Nonlinear learning pedagogy: Does it have an impact on physical education in elementary schools? *Retos*, 48, 1078–1085. <https://doi.org/10.47197/retos.v48.99760>
- Lamonedá Prieto, J., Matos-Duarte, M., Smith Palacio, E., & Fraile, J. (2024). Impact of an intervention program based on self-determination theory on basic psychological needs, intention to be physically active and life satisfaction of high school students: A longitudinal study. *Retos*, 56, 228–237. <https://doi.org/10.47197/retos.v56.103825>
- Martín-Rodríguez, A., & Madrigal-Cerezo, R. (2025). Technology-enhanced pedagogy in physical education: Bridging engagement, learning, and lifelong activity. *Education Sciences*, 15(4), 409. <https://doi.org/10.3390/educsci15040409>
- Moreno-Rosa, G., Del Pino-Morales, C. A., López-Gutiérrez, C. J., & Castro-Sánchez, M. (2026). Clima motivacional en Educación Física y su efecto sobre el autoconcepto: análisis de correlación en educación primaria. *Retos*, 78, 478–491. <https://doi.org/10.47197/retos.v78.117155>
- Nurpratiwi, S., Amaliyah, A., & Hakam, A. (2023). Development of digital hypercontent teaching material to improve students' understanding of pedagogical concepts. In *Proceedings of the 4th International Conference on Law, Social Sciences, and Education, ICLSSE 2022, 28 October 2022, Singaraja, Bali, Indonesia. EAI*. <https://doi.org/10.4108/eai.28-10-2022.2326398>
- Osborne, J. (2014). Teaching scientific practices: Meeting the challenge of change. *Journal of Science Teacher Education*, 25(2), 177–196. <https://doi.org/10.1007/s10972-014-9384-1>
- Roberts, D. A. (2007). Scientific literacy/science literacy. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research on science education* (pp. 729–780). Lawrence Erlbaum Associates.
- Siemens, G. (2005). Connectivism: A learning theory for the digital age. *International Journal of Instructional Technology and Distance Learning*, 2(1), 3–10.
- Sinkkonen, M., & Tapani, A. (2024). Review of the concept "self-regulated learning": Defined and used in different educational contexts. *International Journal on Social and Education Sciences*, 6(1), 130–151. <https://doi.org/10.46328/ijonses.640>
- Sjöström, J., & Eilks, I. (2018). Reconsidering different visions of scientific literacy and science education based on the concept of Bildung. In *Cognition, Metacognition, and Culture in STEM Education* (pp. 65–88). Springer.
- Tanak, A. (2018). Designing TPACK-based course for preparing student teachers to teach science with technological pedagogical content knowledge. *Kasetsart Journal of Social Sciences*, 41(2), 430–437. <https://doi.org/10.1016/j.kjss.2018.07.012>
- Tondeur, J., van Braak, J., Siddiq, F., & Scherer, R. (2016). Time for a new approach to prepare future teachers for educational technology use: Its meaning and measurement. *Computers & Education*, 94, 134–150. <https://doi.org/10.1016/j.compedu.2015.11.003>
- Tri Kaloka, P. (2025). Integrating ecological dynamics in primary school physical education: a systematic review of nonlinear pedagogy. *Retos*, 67, 123–135. <https://doi.org/10.47197/retos.v67.112112>
- Widodo, A., Irianto, D. P., Graha, A. S., Yudanto, Y., Hardianto, D., Sutapa, P., Kauki, M. K., Syed Ali, S. K., Kristiyanto, A., & Pratama, K. W. (2024). The personalized system of E-modul instructions in Physical Education online learning. *Retos*, 56, 319–327. <https://doi.org/10.47197/retos.v56.103515>
- Yang, P., Liu, Y., & Li, Y. (2025). The mediating role of self-regulation in fostering digital competence in physical education teacher education students. *Scientific Reports*, 15, Article 34126. <https://doi.org/10.1038/s41598-025-21795-9>
- Zimmerman, B. J. (2000). Attaining self-regulation: A social cognitive perspective. In M. Boekaerts, P. R. Pintrich, & M. Zeidner (Eds.), *Handbook of self-regulation* (pp. 13–39). Academic Press.
- Zimmerman, B. J. (2002). Becoming a self-regulated learner: An overview. *Theory Into Practice*, 41(2), 64–70. [https://doi.org/10.1207/s15430421tip4102\\_2](https://doi.org/10.1207/s15430421tip4102_2)



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