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THE EFFECT OF AI-SUPPORTED SOCIOSCIENTIFIC TEACHING ON UNIVERSITY STUDENTS' ATTITUDES AND ARGUMENTATION SKILLS

Hong-Cheng Liu

Abstract. *Socioscientific issues (SSI) require students to apply scientific knowledge while taking social and ethical dimensions into account. In this process, both attitudes toward SSI and argumentation skills are important. This study examined the effects of AI-supported SSI teaching on university students' attitudes toward SSI and their argumentation skills. Additionally, the relationships between these two variables were examined. A pre-post test quasi-experimental design was used in the study. The participants were 247 undergraduate students majoring in Public Administration at a university in southern Taiwan. The experimental group received AI-supported SSI teaching for 18 weeks, while the control group received teacher-led SSI teaching. Data were collected using the ATLSIS and the PASS. ANCOVA and correlation analysis were employed. The results showed that the experimental group scored significantly higher than the control group on all dimensions of attitudes toward SSI and on argumentation skills. The largest increase was determined in Connectedness to Scientific Endeavor dimension (in attitudes) and evaluating counterarguments (in argumentation skills). The results suggested a somewhat more focused pattern of correlation between attitudes toward SSI and argumentation skills following the intervention. The findings suggest that the AI-supported SSI teaching condition was associated with higher attitudes toward SSI and higher perceived argumentation skills.*

Keywords: *argumentation skills, artificial intelligence-supported teaching, attitudes toward socioscientific issues, higher education, quasi-experimental design, socioscientific issues*

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Introduction

Contemporary societies are confronted with complex issues, including climate change, genetic engineering, nuclear energy, and biotechnology. These issues are areas of debate where scientific knowledge intersects with social values, ethical norms, and policy decisions. Such issues are defined in the literature as socioscientific issues (SSIs) (Sadler, 2004; Zeidler & Nichols, 2009). SSI is distinguished from other scientific content in that it requires processing on two distinct cognitive planes simultaneously. The natural science dimension examines the causes and mechanisms of phenomena, while the social science dimension addresses their societal consequences, ethical implications, and individual attitudes. This dual structure corresponds to Aristotle's rhetorical framework of logos (logical reasoning), ethos (credibility), and pathos (emotional engagement) (Stucki & Sager, 2018). Scientific evidence, value judgments, and personal concern about the issue must all be considered together. Due to its multi-layered nature, SSI has no single correct solution. Rather, these topics constitute value-laden spaces of inquiry that encompass scientific, ethical, economic, and environmental dimensions (Zeidler & Nichols, 2009). Integrating SSI into science education is therefore critical for developing students' capacity to understand and address complex problems (Zeidler et al., 2005).

Theoretical Background

SSI in Science Education

According to the studies (Ban & Mahmud, 2023; Sadler & Zeidler, 2005; Smit et al., 2025), SSI contributes to science education by helping students develop scientific literacy through argumentation, reasoning, decision-making, critical thinking, and sustainability awareness in relation to real-world controversial issues. The 2025 PISA framework emphasizes the importance of students' awareness and concern regarding the interactions between science, technology, society, and the environment (OECD, 2023). This framework suggests that a scientifically and environmentally literate student should

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draw on interdisciplinary perspectives to identify risks related to challenges such as climate change, biodiversity loss, and global pandemics and make informed decisions. Students build scientific reasoning, evidence evaluation, and decision-making competencies through participation in SSI (Jimenez et al., 2024; Pezaro et al., 2014; Sadler & Donnelly, 2006). A recent systematic analysis of 46 studies concluded that SSI-based teaching helped students understand science better in the context of global problems such as climate change and renewable energy (Arifin et al., 2025). SSI also involves uncertainty and dilemmas; even where scientific consensus exists on issues such as climate change, differing views persist in the social and political dimensions (Sadler, 2011). Socioscientific reasoning involves recognizing the inherent complexity of SSI, examining topics from multiple perspectives, and exercising critical skepticism toward potentially biased information (Smit et al., 2025; Viehmann et al., 2024). Atabey and Topçu (2025) further emphasized that SSI-based teaching plays an important role in character and value development. A systematic review showed that the pedagogical implementations of SSI increased significantly during this period, becoming particularly widespread in STEM and STEAM courses (Viehmann et al., 2024).

According to Akilli and Genç (2017) and Herman et al. (2021), SSI teaching involves both cognitive and affective dimensions. Students' attitudes toward SSI may influence their participation in classroom discussions and their motivation to engage with socioscientific issues. In literature (such as Klaver & Walma van der Molen, 2021; Topcu, 2010), it is indicated that the attitudes towards SSI have four components: curiosity and enjoyment, perceived relevance and usefulness, self-efficacy, and connectedness to scientific endeavor. Connectedness to scientific endeavor is especially relevant because it reflects the extent to which students see science as meaningful in addressing social problems rather than as an abstract school subject (Mendoza-De Los Santos, 2023; Rudolph, 2020). This sense of connectedness may also support the development of socioscientific reasoning. However, the effects of SSI-based teaching on attitudes may vary depending on students' initial resources and backgrounds (Klaver et al., 2024).

Scientific Argumentation in Science Education

Scientific argumentation is widely recognized as an important component of science education because it helps students justify claims, evaluate evidence, and consider alternative explanations (Yaman & Hand, 2024). These skills constitute the fundamental instruments of critical thinking and are recognized as core goals of 21st-century education (Khishfe & Abd-El-Khalick, 2002; Rapanta et al., 2013). The most widely used framework for argument analysis in the literature is the Toulmin (2003) model. This model consists of six components: claim, data/grounds, warrant, backing, qualifier, rebuttal and functions as both an analytical and design tool for scientific argumentation (Dawson, 2024; Driver et al., 2000).

According to Evagorou et al. (2023), students find it easier to construct arguments when they have knowledge of the subject. SSI discussions provide a useful context for developing students' argumentation skills (Aziz & Johari, 2023; Smit et al., 2025). According to Aziz and Johari (2023), argumentation in socioscientific contexts had positive effects on students' reasoning quality. Türk and Çam (2025) stated that argumentation-based SSI teaching improved students' science literacy, attitudes, and SSI knowledge. Also, Dawson (2024) reported that teacher-supported SSI discussions significantly improved students' argument quality between pre-test and post-test measurements.

Interventions (Nugroho et al., 2025; Ping et al., 2020; Redhana et al., 2026) have been implemented at various levels of education to develop students' scientific reasoning skills. Research consistently showed that students encounter significant difficulties with advanced argumentation skills. According to Ucar-Longford et al. (2024), students often find it more difficult to generate counterarguments and rebuttals than to provide basic claims or evidence. Kuhn and Udell (2003) classified counterargument and rebuttal as advanced argumentation skills requiring the analysis of claims from multiple perspectives. Hsu et al. (2015) stated that students' scientific explanation skills were significantly higher when using a structured argumentation framework than when engaging in free discussion. Guilfoyle and Erduran (2021) further emphasized that producing quality arguments requires sustained guidance and long-term programs. Taken together, these studies suggest that developing advanced argumentation skills often requires sustained scaffolding. This highlights the need to examine how to effectively provide such support in SSI-based teaching.

AI in Science Education

AI technologies have become increasingly visible in educational settings. Since the release of ChatGPT in November 2022, use of generative AI tools has rapidly increased in higher education, sparking extensive debate in the field (Dai et al., 2026; McDonald et al., 2025; Moorhouse et al., 2023). AI is increasingly being discussed not

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only as a tool, but also as a potential collaborative partner in learning (Karampelas, 2025; Li et al., 2025; Yan, 2025). Recent studies increasingly frame AI as a collaborative partner in learning, although they differ in how this role is defined. According to Atchley et al. (2024), AI should be positioned as a collaborative learning partner in higher education. Yan (2025) conceptualizes human-AI collaborative learning across four levels: adaptive tool, proactive assistant, co-learner, and peer collaborator. Woo and Cho (2025) showed that students' perceptions of generative AI differed by learning orientation. Some approached it mainly as a cognitive tool for information retrieval, others as a partner in two-way metacognitive interaction, while some questioned the possibility of genuine reciprocity in human–AI communication.

In science learning, generative AI may support planning, content development, assessment, and feedback (Kunnath & Botes, 2025; Moundridou et al., 2024). Recent studies suggest that both teachers and students use AI for different purposes during the teaching-learning process. Teacher candidates' intention to use generative AI has been linked to AI literacy, attitudes toward AI, and perceived behavioral control (Ramnarain et al., 2025). Students have used AI to help with tasks such as identifying variables, planning procedures, analyzing results, and finding information (Min et al., 2025). AI has also been used to assess inquiry skills in SSI contexts (Zhang et al., 2025). However, its role in argumentation is still not well understood. Although some findings are encouraging, experimental evidence remains limited, especially in SSI-based teaching (Nugroho et al., 2025). Although these studies point to the educational potential of AI in science learning, more experimental research is needed to clarify how AI can support argumentation and learning processes in SSI-based teaching.

Research Problem

Previous research on SSI-based teaching has mainly focused on separate lines of inquiry. The effects of SSI-based teaching on attitudes and skills have been extensively studied (Arifin et al., 2025; Högström et al., 2025; Türk & Çam, 2025). Other intervention studies have focused on the development of argumentation skills (Muslim et al., 2024; Smit et al., 2025). At the same time, studies on the use of AI in higher education have grown rapidly (Dai et al., 2026; Li et al., 2025; McDonald et al., 2025). However, experimental studies that integrate all three areas remain notably scarce. No research has been identified in the literature that simultaneously examines the effects of AI-supported SSI teaching on both attitudes and argumentation skills. Furthermore, the pattern of association between these two variables may change during an intervention process. The pedagogical role of AI in SSI studies has also been insufficiently operationalized; specific functions such as knowledge support, argumentation scaffolding, and feedback loops have not been experimentally tested.

Research Aim and Research Questions

Based on the gap identified in the literature above, this study aimed to examine the effect of AI-supported SSI instruction on university students' attitudes toward SSI and their perceived argumentation skills. It also aimed to examine whether the pattern of association between these two variables differed before and after the intervention. In line with this purpose, the following research questions were formulated:

1. Is there a significant difference in the attitude sub-dimension scores toward SSI between the experimental group, which received AI-supported SSI teaching, and the control group, which received teacher-centered SSI teaching?
2. Is there a significant difference in the perceived argumentation skills subscale scores between the experimental group, which received AI-supported SSI teaching, and the control group, which received teacher-centered SSI teaching?
3. Does the pattern of association between students' attitudes and argumentation skills differ before and after the intervention?

Research Methodology

A pre-test post-test control group quasi-experimental design was employed in this study. Quasi-experimental designs are a preferred research approach in natural educational settings where participants are assigned based on existing classroom groups and random assignment is not feasible (Rogers & Revesz, 2019). In this study, groups were selected from pre-existing class sections formed by the university's registration system rather than by the researcher; random assignment was therefore not possible. Nevertheless, baseline equivalence between groups

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was statistically verified through pre-test data, confirming that no significant difference existed between the two groups at the outset. To control for potential confounding variables that could threaten internal validity, pre-test scores were included as covariates in the ANCOVA analyses. The experimental group received AI-supported SSI teaching for 18 weeks in the 2024-2025 academic year, while the control group received teacher-centered SSI teaching over the same period.

Participants

Since the study was conducted as part of a course, the 247 students enrolled in the course comprised the study sample. They were studying in the Public Administration Department at a state university in southern Taiwan. Because the students were divided into two sections in the university's registration system, the groups were randomly designated as the experimental and control groups. There was no individual random assignment of students to groups. There are 124 students enrolled in the experimental group and 123 students enrolled in the control group. The sample comprised 98 males (39.7%) and 149 females (60.3%). This gender imbalance is attributable to the naturally occurring composition of the existing class groups and should be considered a limitation when interpreting gender-related findings. The course was conducted for three hours per week over a total of 54 class hours. Inclusion criteria required a minimum attendance rate of 80% and completion of both pre-test and post-test measurements.

Data Collection Instruments

Two scales were used as measurement tools in the study. The first one is The Attitudes Towards Learning Socioscientific Issues Scale (ATLSIS). It was developed based on theoretical frameworks for attitude measurement in science education (Klaver & Walma van der Molen, 2021; Mendoza-De Los Santos, 2023; Topcu, 2010). The scale is a 30-item, 5-point Likert-type instrument comprising six dimensions: *curiosity and enjoyment*, *perceived relevance and usefulness*, *connectedness to scientific endeavor*, *self-efficacy in SSI*, *future engagement*, and *concern and responsibility*. Validity and reliability studies were conducted using data collected from 654 undergraduate students who were not included in the experimental study prior to the start of the experimental study. Exploratory factor analysis yielded a six-factor structure accounting for 57.85% of the total variance. Confirmatory factor analysis indicated acceptable model fit (CFI = .948, TLI = .942, SRMR = .042, RMSEA = .031). Cronbach's α values for the dimensions ranged from .863 to .875, and McDonald's ω values ranged from .750 to .801. Internal consistency coefficients obtained in the present study were consistent with these values.

The second one is the Perceived Argumentation Skills Scale. It is a 27-item, 5-point Likert-type instrument developed to measure individuals' perceptions of their own argumentation competencies. The scale comprises 6 dimensions: *constructing arguments*, *evaluating counterarguments*, *responding to counterarguments*, *using evidence*, *collaborative argumentation*, and *metacognitive awareness*. Validity studies were conducted using data obtained from 528 undergraduate students who were not included in the experimental study. In the exploratory factor analysis, factor loadings ranged from .637 to .806, and the six factor structure accounted for 55.9% of the total variance. Confirmatory factor analysis fit indices were within acceptable limits (CFI = .937, TLI = .929, SRMR = .046, RMSEA = .045). Cronbach's α values for the dimensions ranged from .809 to .866, and McDonald's ω values ranged from .794 to .842.

Both instruments were administered in a self-report format. As self-reported measures may differ from actual demonstrated performance, this limitation should be considered when interpreting the findings.

Procedure

Teaching conditions in this study were defined as two observable and replicable treatments: (1) AI-integrated SSI teaching (experimental group) and (2) teacher-centered SSI teaching (control group). To make the between-group differences explicit and to strengthen internal validity, the educational manipulation was operationalized through four classroom process indicators.

Sources of informational support: In the experimental group, students were guided to use AI during in-class inquiry to organize issue-relevant information and key points. In the control group, informational support relied primarily on teacher-led teaching, assigned readings, and students' own notetaking and synthesis.

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Argumentation scaffolds: In the experimental group, AI-generated prompts and structured prompts supported students' argumentation process at key stages. These stages included argument construction, evaluation of counterarguments, use of evidence, collaborative argumentation, and metacognitive awareness. In the control group, a comparable framework was provided through the teacher's modeling and verbal questioning, without AI involvement.

Feedback and revision mechanisms: The experimental group adopted an iterative cycle of immediate feedback, revision, and re-feedback to encourage multiple rounds of improvement. In the control group, feedback was delivered primarily through teacher commentary and peer review.

Visualization and synthesis of discussion: In the experimental group, AI was used to synthesize discussions into structured outputs (e.g., points of agreement, disagreements, and elements requiring verification) to support reflection and review. In the control group, this synthesis task was completed using the whiteboard, handouts, or written organization.

Teaching time, core SSI content, and required learning products were held constant across both groups. This operationalization concentrated the manipulation on whether AI functioned as a learning support tool within inquiry and argumentation processes.

Weekly Implementation Schedule

The 18-week intervention was organized into four phases: (a) orientation and pre-testing (Week 1); (b) SSI inquiry cycles (Weeks 2–15); (c) integration, revision, and post-testing (Weeks 16–17); and (d) course wrap-up and learning portfolio review (Week 18). Within Weeks 2–15, each SSI cycle consisted of three fixed steps.

(a) Guided introduction and scenario framing: defining the issue, mapping stakeholders, and articulating an initial position.

(b) Inquiry-based exploration: collecting and comparing evidence, developing claims, generating counterarguments, and revising positions.

(c) Reflection and educational wrap-up: reviewing evidence sufficiency, uncertainty, ethical trade-offs, and the conditions under which conclusions hold, and re-interpreting the reasoning.

In the experimental group, AI use was embedded at key points within these steps, including information organization, perspective expansion, argument-structure checks, and iterative revision. In the control group, the same tasks were completed through teacher-led teaching and peer discussion, ensuring a consistent basis for comparison.

Fidelity of Implementation

Weekly classroom observation records were kept throughout the entire study to monitor the correct implementation of the teaching process. In each record, it was recorded whether the three-phase teaching sequence of guided introduction, inquiry-based activities, and closing reflection was implemented as planned and whether AI-based tasks were introduced at the designated stages in the experimental group. The control group did not encounter AI-based tasks at any stage, which clearly separated the two groups during the intervention.

Data Analysis

Prior to statistical analysis, the normality assumption was examined for all data. Skewness and kurtosis coefficients were calculated for the scores obtained by students in both groups on all scale dimensions. Values within the ±1.5 range are regarded in the literature as evidence of normal distribution. The analyses revealed that skewness and kurtosis values for all subscales remained within this reference range in both the pre-test and post-test measurements, indicating that the normality assumption was met. Accordingly, parametric tests were employed for all inter-group comparisons.

The analytical strategy was structured in three stages. In the first stage, baseline equivalence between the experimental and control groups was examined using independent samples t-tests applied to pre-test scores. In the second stage, the effect of the intervention on attitudes and argumentation skills was analyzed using ANCOVA, with pre-test scores included as covariates to statistically control for initial group differences. Effect sizes were reported as η^2, with thresholds of small ($\eta^2 = .01$), medium ($\eta^2 = .06$), and large ($\eta^2 = .14$) used as reference values.

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In the third stage, Pearson correlation analyses were conducted to examine the pattern of association between students' attitudes and argumentation skills before and after the intervention. In addition, approximate Fisher's r-to-z comparisons were conducted to examine whether the differences between corresponding pre-test and post-test correlation coefficients were statistically significant. Because the pre-test correlation matrix was based on the overall sample, whereas the post-test matrix was based on the experimental group, the Fisher's r-to-z comparison should be regarded as approximate and interpreted cautiously. A significance level of .05 was adopted for all analyses.

Research Results

Pre-Treatment Equivalence of the Groups

Prior to the experimental intervention, the pre-test scores of the experimental and control groups on the Attitudes Towards SSI and Perceived Argumentation Skill scales were compared using independent samples t-tests to determine whether the groups were equivalent at baseline. As shown in Table 1, no statistically significant difference was found between the experimental and control groups on any of the attitude or argumentation skills subscales ($p > .05$ for all comparisons). The mean scores of both groups across all subscales were closely aligned. These findings confirm that the two groups were equivalent at the outset of the study, providing a sound basis for interpreting post-intervention differences as effects of the experimental treatment.

Table 71
Independent Samples t-Test Results for Pre-Test Scores of Experimental and Control Groups

Variables	Experimental (n=124)		Control (n=123)		*t (245)*	*p*
	M	*SD*	*M*	*SD*		
Curiosity and Enjoyment (CE)	2.92	0.70	2.91	0.81	0.174	.862
Perceived Relevance and Usefulness (PRU)	2.93	0.75	2.8	0.76	1.373	.171
Connectedness to Scientific Endeavor (CSE)	3.18	0.82	3.16	0.73	0.181	.856
Self-Efficacy in SSI (SE)	3.19	0.80	3.21	0.75	-0.148	.882
Future Engagement with SSI (FE)	2.77	0.76	2.81	0.78	-0.396	.692
Concern and Responsibility (CR)	3.03	0.67	2.94	0.66	1.078	.282
Constructing Arguments (CA)	3.23	0.77	3.18	0.79	0.437	.662
Evaluating Counterarguments (EC)	2.89	0.82	2.9	0.85	-0.053	.958
Responding to Counterarguments (RC)	3.05	0.76	3.19	0.76	-1.475	.142
Using Evidence (UE)	2.99	0.93	2.98	0.91	0.087	.930
Collaborative Argumentation (COA)	3.07	0.75	3.02	0.77	0.449	.654
Metacognitive Awareness (MA)	2.78	0.83	2.87	0.82	-0.814	.417

Effect of the Intervention on Attitudes Towards SSI

To examine the effect of the teaching method on students' attitudes towards SSI, a one-way Analysis of Covariance (ANCOVA) was conducted, with pre-test scores and gender included as covariates. Table 2 shows that statistically significant group differences were found across all six attitude subscales in favor of the experimental group ($p < .05$ for all comparisons). CSE, CE, and PRU yielded large effect sizes ($\eta^2 = .364$, .304, and .286, respectively), while CR ($\eta^2 = .029$), SE ($\eta^2 = .044$), and FE ($\eta^2 = .018$) reached statistical significance with smaller effect size. Gender emerged as a statistically significant covariate in the SE ($p = .009$) and FE ($p = .011$) dimensions, whereas its effect was non-significant in the remaining four subscales.

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Table 2
ANCOVA Results for Post-Test Scores of Attitudes Sub-dimensions

Dependent Variable	Source	*SS*	*df*	*MS*	*F*	*p*	η^2
Curiosity and Enjoyment (CE)	Group	8.98	1	8.98	105.91	<.001	.304
	Gender	0.02	1	0.02	0.29	.590	.001
Perceived Relevance and Usefulness (PRU)	Group	7.94	1	7.94	97.02	<.001	.286
	Gender	0.05	1	0.05	0.67	.415	.003
Connectedness to Scientific Endeavor (CSE)	Group	14.39	1	14.39	138.41	<.001	.364
	Gender	0.02	1	0.02	0.27	.598	.001
Self-Efficacy in SSI (SE)	Group	2.06	1	2.06	11.07	.001	.044
	Gender	1.29	1	1.29	6.93	.009	.028
Future Engagement with SSI (FE)	Group	0.42	1	0.42	4.37	.037	.018
	Gender	0.63	1	0.63	6.58	.011	.027
Concern and Responsibility (CR)	Group	0.64	1	0.64	7.25	.008	.029
	Gender	0.38	1	0.38	4.259	.040	.017

Effect of the Intervention on Argumentation Skills

As shown in Table 3, the experimental group scored significantly higher than the control group on all six argumentation skills subscales ($p < .001$ for all comparisons). EC and CA produced the highest η^2 values (.695 and .650), and RC and UE were close behind (.625 and .606). COA (.236) and MA (.232) also reached significance, though the gap between individual-level and social or metacognitive skills was notable. Gender was a significant covariate only in the EC dimension ($p = .018$) and was non-significant across the remaining subscales.

Table 3
ANCOVA Results for Post-Test Scores of Argumentation Skills

Dependent Variable	Source	*SS*	*df*	*MS*	*F*	*p*	η^2
Constructing Arguments (CA)	Group	46.30	1	46.30	448.80	<.001	.650
	Gender	0.0538	1	0.0538	0.52110	.471	.002
Evaluating Counterarguments (EC)	Group	57.34	1	57.34	550.22	<.001	.695
	Gender	0.593	1	0.593	5.69	.018	.023
Responding to Counterarguments (RC)	Group	27.30	1	27.30	403.99	<.001	.625
	Gender	0.00550	1	0.006	0.0813	.776	.000
Using Evidence (UE)	Group	28.28	1	28.28	372.62	<.001	.606
	Gender	0.00384	1	0.004	0.051	.822	.000
Collaborative Argumentation (COA)	Group	5.83	1	5.83	74.61	<.001	.236
	Gender	0.00351	1	0.004	0.0449	.832	.000
Metacognitive Awareness (MA)	Group	7.13	1	7.13	73.18	<.001	.232
	Gender	0.00296	1	0.003	0.030	.862	.000

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Change in the Association Structure Between Attitudes and Argumentation Skills

To examine how the experimental intervention changed the association between students' attitudes and argumentation skills, Pearson correlation analyses were conducted separately on pre-test and post-test data for the experimental group. Table 4 reveals that, prior to the intervention, the associations between attitude and argumentation skills subscales were largely weak or non-significant. The Constructing Arguments (CA) dimension showed significant positive correlations with all six attitude subscales ($r = .180$ to $.329$, $p < .05$ or $p < .01$). By contrast, the more advanced argumentation dimensions—Evaluating Counterarguments (EC), Responding to Counterarguments (RC), Using Evidence (UE), Collaborative Argumentation (COA), and Metacognitive Awareness (MA)—showed few or no significant correlations with attitude subscales. Notably, the CSE dimension was significantly associated only with EC ($r = .141$, $p < .05$), UE ($r = .170$, $p < .01$), and COA ($r = .174$, $p < .01$), but not with the remaining argumentation subscales.

Table 4
Pearson Correlation Coefficients Between Pre-Test Attitude and Argumentation Skills (Overall Sample)

Variables	CE	PRU	CSE	SE	FE	CR
Constructing Arguments (CA)	.180**	.299**	.259**	.329**	.191**	.226**
Evaluating Counterarguments (EC)	.034	.098	.141*	.135*	.080	.023
Responding to Counterarguments (RC)	-.023	.046	.064	.043	.041	.024
Using Evidence (UE)	.036	.047	.170**	.062	.038	-.059
Collaborative Argumentation (COA)	.113	-.020	.174**	.087	.064	.010
Metacognitive Awareness (MA)	.057	.005	.059	.127*	.092	-.044

*Note: * p < .05, ** p < .01*

As shown in Table 5, some descriptive differences were observed between the post-intervention and pre-intervention correlation patterns. The CSE dimension emerged as the most consistently associated attitude subscale, showing significant positive correlations with CA ($r = .371$, $p < .01$), EC ($r = .248$, $p < .01$), UE ($r = .216$, $p < .05$), and COA ($r = .299$, $p < .01$). The PRU dimension also demonstrated a stronger association with CA in the post-test ($r = .383$, $p < .01$) compared to the pre-test ($r = .299$, $p < .01$). In contrast, the CE, SE, FE, and CR dimensions showed fewer significant correlations with argumentation skills in the post-test than at baseline. RC and MA showed no significant correlations with any attitude subscale in the post-intervention measurement.

Table 5
Pearson Correlation Coefficients Between Post-Test Attitude and Argumentation Skills for Experimental Group

Variables	CE	PRU	CSE	SE	FE	CR
Constructing Arguments (CA)	.183*	.383**	.371**	.196*	.159	.069
Evaluating Counterarguments (EC)	.072	.103	.248**	.061	.206*	.075
Responding to Counterarguments (RC)	-.087	-.002	.039	.053	.074	-.026
Using Evidence (UE)	.011	.016	.216*	.028	.151	-.108
Collaborative Argumentation (COA)	-.019	-.079	.299**	.126	.052	.021
Metacognitive Awareness (MA)	-.050	-.008	.169	.075	.117	.067

*Note: * p < .05, ** p < .01*

An approximate Fisher's r-to-z comparison was conducted to examine whether the differences between the corresponding pre-test and post-test correlation coefficients were statistically significant. The results showed that none of these differences reached statistical significance (all p > .05). Therefore, although some descriptive

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changes were observed in the correlation pattern, the intervention could not be said to have produced statistically significant changes in the correlation coefficients.

Discussion

Effect of AI-Supported SSI Teaching on Attitudes

Students in the experimental group scored significantly higher than those in the control group across all attitude subscales. This finding is consistent with studies demonstrating the positive effect of SSI-based teaching on attitudes (Smit et al., 2025; Türk & Çam, 2025). The present study adds to this line of research by examining SSI teaching in an AI-supported context and by offering further insight into possible patterns of attitude change.

Among the attitude dimensions, CSE stood out with the highest η^2 value (.364). This finding is broadly consistent with the theoretical framework of the study. At its core, SSI requires students to consider scientific knowledge together with social values and personal perspectives. Throughout the 18-week inquiry process, students in the experimental group worked within an AI-supported learning setting in which AI was used to access information, but also to organize ideas, refine arguments, and receive feedback. This teaching experience may have contributed to students' viewing science as more closely connected to real social problems rather than as an abstract school subject (Mendoza-De Los Santos, 2023; Rudolph, 2020). In the control group, classroom learning relied mainly on teacher-led explanation and discussion.

PRU (η^2 = .286) and CE (η^2 = .304) also showed sizeable gains, suggesting that the AI-supported process may have made SSI content feel more concrete and accessible to students. The use of structured outputs and immediate feedback within the instructional process may have supported students' ability to relate course content to everyday life. This interpretation is supported by research showing that context-based science education enhances students' perceived relevance of science (Ban & Mahmud, 2023; Viehmann et al., 2024). Arifin et al. (2025) similarly suggested that the integration of digital technologies into SSI teaching may increase student engagement. Systematic reviews further suggest that generative AI tools may be associated with increased classroom motivation and participation (Dai et al., 2026; Woo & Cho, 2025).

By contrast, the effects for Self-Efficacy in SSI (SE; η^2 = .044) and Future Engagement (FE; η^2 = .018) were smaller. Self-efficacy may be less responsive to change over the time frame of a single intervention. According to Bandura's (1977) self-efficacy theory, perceived competence is shaped by direct personal experience and indirect social observation. An 18-week program may therefore be insufficient to produce substantial change in this dimension. Klaver et al. (2024) stated that the effect of SSI-based teaching on self-efficacy varies according to students' initial resource profiles. The limited effect on future engagement may suggest that gains observed during the intervention did not readily translate into future-oriented intentions. Strengthening this dimension may depend on factors beyond the scope of the present study.

Gender was a significant covariate only for SE (p = .009) and FE (p = .011). No significant gender effect was found in the other four subscales. This pattern may indicate that gender differences were less pronounced in curiosity, relevance, connectedness, and responsibility within the present intervention. At the same time, self-efficacy and future engagement may be shaped by factors not directly addressed in the present study. This pattern is in line with research suggesting that attitudes toward AI use in higher education may vary by gender (Bergdahl & Sjöberg, 2025).

Effect of AI-Supported SSI Teaching on Argumentation Skills

Compared with the control group, the experimental group showed significant advantages across all argumentation skill subscales. This pattern is consistent with earlier research (Aziz & Johari, 2023; Smit et al., 2025; Türk & Çam, 2025), suggesting that SSI-based teaching can support the development of argumentation skills. The present study further suggests that the AI-supported SSI condition was associated with higher scores in several higher-order argumentation dimensions.

EC (η^2 = .695) and CA (η^2 = .650) showed the most pronounced gains among the argumentation subscales. As Hsu et al. (2015) also noted in their studies, structured argumentation supports students' scientific explanation skills more effectively than free discussion. Similarly, in this study, AI-supported teaching may have functioned as a scaffold for argumentation by supporting students in organizing, reviewing, and revising their responses.

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RC ($\eta^2 = .625$) and UE ($\eta^2 = .606$) also showed substantial gains. These skills are often described in the literature as among the more challenging aspects of argumentation (Kuhn & Udell, 2003; Ucar-Longford et al., 2024). The feedback-rich and revision-oriented teaching process in the experimental condition may have provided students with more opportunities to practice these demanding processes. This interpretation is in line with recent research suggesting that AI-enhanced feedback systems can support academic performance (Kaliisa et al., 2026).

COA ($\eta^2 = .236$) and MA ($\eta^2 = .232$) yielded smaller, though still significant, gains. Collaborative argumentation depends strongly on group dynamics and social interaction. In the present study, support appeared to be stronger in individual-level dimensions than in dimensions more directly related to group negotiation and shared decision-making. The relatively modest effect on metacognitive awareness may be related to the longer-term and more deliberate reflective practice that this skill requires. Xu et al. (2025) reported that metacognitive support in AI environments can enhance self-regulated learning, particularly when explicit metacognitive guidance is included. In the present study, AI use was focused mainly on argumentation processes and did not include explicit structures for metacognitive reflection.

An important limitation must be acknowledged at this point. Both instruments were administered in self-report format. Individuals' perceptions of their own skills may diverge from actual performance. The observed effect sizes may therefore reflect changes in perceived competence rather than objective skill improvement. This possibility requires caution when interpreting the findings.

Changing Relationships between Attitudes and Argumentation Skills

Another finding of this study is that some descriptive differences were observed in the correlation pattern between attitudes and argumentation skills during the intervention process. Before the intervention, the only argumentation dimension that showed a significant relationship with attitude dimensions was Constructing Arguments (CA). On the other hand, the relationships between more advanced skills, such as using evidence, responding to counterarguments, and metacognitive awareness and attitude dimensions, remained quite limited. This view suggests that positive attitudes alone may not be sufficient to explain the development of more complex argumentation skills (Akilli & Genç, 2017; Long, 2016).

After the intervention, it was observed that the Connectedness to Scientific Endeavor (CSE) dimension showed the most remarkable and consistent relationships with argumentation skills. Significant relationships with CSE were found especially in the dimensions of argument construction, evaluating counterarguments, using evidence, and collaborative argumentation. This finding is generally consistent with the theoretical framework that emphasizes the importance of addressing cognitive and affective dimensions together in SSI-based instruction. Indeed, Zeidler and Nichols (2009) stated that SSI-based instruction can bring cognitive and affective dimensions closer together. Similarly, Sadler (2004) emphasized that socioscientific reasoning requires the evaluation of scientific knowledge and personal values together.

However, it was also examined whether the differences between the pre-test and post-test correlation coefficients were statistically significant. Fisher's r-to-z comparisons showed that the differences between the corresponding correlation coefficients did not reach a significant level. Therefore, it seems more appropriate to consider the observed changes in the correlation pattern as descriptive differences rather than a statistically confirmed transformation. In other words, it cannot be said that the intervention produced a statistically significant change in the correlation coefficients.

This result does not mean that the findings are completely insignificant. Rather, it shows that some relationship patterns became visible after the intervention, but these changes were not strongly supported at the statistical level. From this point of view, it would be more appropriate to say that AI-supported SSI instruction is associated with some limited and descriptive shifts in these relationships, rather than suggesting that it reconstructed the relationships between attitudes and argumentation skills definitively.

On the other hand, it can be said that the Responding to Counterarguments (RC) dimension exhibited a remarkable appearance. Although ANCOVA results indicated a strong intervention effect in this dimension ($\eta^2 = .625$), there was no significant relationship with the attitude dimensions in the posttest. This suggests that the development of some advanced argumentation skills may proceed relatively independent of changes in attitudes. Therefore, the relationship between skill development and attitudinal orientations may not have emerged at the same level in every dimension.

Overall, AI-supported SSI instruction seems to be associated with higher scores. However, there is no strong statistical evidence that the relationships between attitudes and argumentation skills transformed significantly

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over time. Therefore, the correlation differences observed after the intervention should be interpreted cautiously. Rather, the present findings suggest that there may be convergences between some dimensions at a descriptive level. In order to test this possibility more strongly, future studies that directly test correlation differences on the same sample and are supported by process data are needed.

Limitations

Several limitations should be considered when interpreting these findings. One limitation concerns the generalizability of the sample. The study was conducted with undergraduate students enrolled in the Public Administration department of a single university in southern Taiwan. This limits the extent to which the findings can be generalized to other disciplines, educational levels, or cultural contexts. Students in fields such as natural sciences, engineering, or the humanities may respond differently to AI-supported SSI teaching because these disciplines have different traditions and learning expectations. For this reason, further studies in different institutional and cultural settings are needed before broader conclusions are drawn.

A second limitation relates to the measurement of argumentation skills. Both instruments in this study were based on self-report. Participants' perceptions of their own argumentation skills may differ from their actual performance. The reported effect sizes therefore reflect gains in perceived skills and may not fully represent objective improvement in argumentation quality. The absence of performance-based measures, such as Toulmin-based argument analysis or rubric-scored written arguments, limits the strength of the evidence.

Another limitation concerns the research design. Because the study was conducted as a quasi-experiment with pre-existing class groups, random assignment of participants to conditions was not possible. Although the groups were statistically equivalent at pre-test and pre-test scores were included as covariates in the ANCOVA analyses, unmeasured variables may still have influenced the results. For example, prior AI experience, general academic motivation, and individual learning strategies were not controlled. For this reason, the causal claims that can be made from the findings remain limited.

A further limitation involves the gender composition of the sample. The sample included 149 female and 98 male students, resulting in an unequal gender distribution. Although gender was included as a covariate, this imbalance requires caution when interpreting gender-related findings. The results related to gender should therefore be regarded as exploratory rather than conclusive.

Another limitation is the absence of qualitative data on AI use. Although the teaching functions of AI were defined through four concrete indicators, no data were collected on how individual students actually interacted with AI during the intervention. As a result, it is unclear whether some students used AI only superficially, whether others became over-reliant on it, or how much AI engagement varied across participants. The absence of process-level data limits our understanding of how AI may have influenced learning outcomes.

A final limitation is the lack of long-term follow-up data. The study assessed outcomes only at the end of the 18-week intervention. It was therefore not possible to examine whether the observed gains in attitudes and argumentation skills were sustained over time. Without delayed post-test data, no firm conclusions can be drawn about the durability of the intervention's effects.

Conclusions and Implications

This study examined the effect of AI-supported SSI teaching on university students' attitudes toward SSI and their perceived argumentation skills. Students in the experimental group outperformed the control group across all subscales of both measures. Among attitudes, CSE ($\eta^2 = .364$) and PRU ($\eta^2 = .286$) showed the largest gains; among argumentation skills, EC ($\eta^2 = .695$) and CA ($\eta^2 = .650$) stood out. Beyond these variable-level changes, some descriptive differences were observed in the pattern of correlations between attitude and argumentation dimensions during the intervention. While there was only a weak relationship between these two domains before the intervention, relatively stronger relationships were observed after the intervention, especially around the dimension of connectedness to scientific endeavor. However, Fisher's r-z comparisons showed that these differences were not statistically significant.

These findings contribute to the literature. Although previous studies have examined the effects of SSI-based teaching on attitudes and argumentation skills separately, and the educational use of AI has been explored independently, few studies have brought these three areas together within a single quasi-experimental design. The present study contributes to this gap by showing that an AI-supported SSI teaching condition was associated with

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attitudinal outcomes and perceived argumentation outcomes. In addition, the study went beyond mean-score comparisons by examining descriptive differences in the pattern of associations between attitudes and argumentation skills over the course of the intervention. Although these differences were not statistically significant according to Fisher's r-to-z comparisons, they still provide a useful basis for future research. The operationalization of AI's pedagogical role through four classroom process indicators also offers a transparent framework that may be adapted in future studies and practice.

Implications for Practice

In practice, AI tools in SSI teaching should go beyond knowledge transfer and take on pedagogical functions such as structuring argumentation, creating feedback loops, and synthesizing discussions. The strong CSE effect suggests that positioning AI within a cyclical inquiry model can help students connect science with real-world problems; teaching designers should build on this potential. At the same time, the comparatively modest gains in collaborative argumentation and metacognitive awareness point to the need for explicit reflective structures and group-based activities in which AI is purposefully designed to support negotiation and self-monitoring. Finally, the small effects on self-efficacy and future engagement indicate that strengthening these constructs may require longer and more intensive interventions.

Implications for Research

These findings offer several suggestions for future research. This study involved undergraduate students from a single Public Administration department in southern Taiwan. To increase the generalizability of the results, future studies should include people from other academic disciplines, educational levels, and cultural contexts. Similar research could also be conducted with humanities, engineering, natural sciences, or pre-service teachers. These groups may respond differently to AI-supported SSI teaching. Examining these differences will help to identify the limits of the current findings.

Another issue concerns the use of self-report scales. The instruments used in this study have good psychometric properties. However, students' self-reported assessments of their argumentation skills may not accurately represent their actual performance. Consequently, future research could integrate perception-oriented measures with performance-oriented assessments using Toulmin-based argument analysis or written assignments assessed with rubrics. This would give us a better idea of how students' argumentation skills develop.

In this study, outcomes were measured at the end of the 18-week intervention. Therefore, it is not known whether the observed gains changed in the long term. Follow-up assessments after a few weeks or months would help to assess the persistence of the effects. In addition, the study did not collect qualitative or quantitative data on how individual students interacted with the AI during the teaching process. Process-level data such as interaction logs, think-aloud protocols, or student reflections could be collected. This could show whether students interacted with AI in meaningful ways or only used it superficially.

Finally, the relative lack of improvement in collaborative argumentation and metacognitive awareness suggests that these areas may need more targeted assistance. Future interventions could include explicit metacognitive suggestions and group-oriented AI exercises. This would assist researchers in exploring whether more focused scaffolding could improve these specific skills.

Ethics Approval

Ethics approval was obtained from the Ethics Committee of the Shih Hsin University, Taiwan R.O.C. (No. IRB-SH20240029). Authors confirm that all experiments were performed in accordance with relevant guidelines and regulations of Helsinki's declaration.

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Appendix

A - Perceived Argumentation Skill Scale

Dimension	Item No	Items
1. Constructing Arguments	1	I can clearly and precisely express my claim when stating an opinion
	2	I can provide appropriate evidence to support my claim
	3	I can explain how my evidence supports my claim
	4	I can organize my opinions in a logical sequence
	5	I can gather evidence from different sources and use it in my argument
2. Evaluating Counterarguments	6	I can identify the strengths and weaknesses in opposing arguments
	7	I can critically analyze others' opinions
	8	I can notice logical errors in an argument
	9	I can evaluate the reliability of presented evidence
	10	I can carefully listen to and understand counterarguments
3. Responding to Counterarguments	11	I can effectively respond to counterarguments
	12	I can refute criticisms directed at my own opinion
	13	I can respond without being defensive during discussions
	14	I can strengthen my argument by considering counterarguments
4. Using Evidence	15	I can select appropriate evidence to support my claim
	16	I can distinguish between reliable and unreliable sources
	17	I can use different types of evidence (statistics, expert opinion, examples, etc.)
	18	I can evaluate whether my evidence is sufficient
5. Collaborative Argumentation	19	I can clearly share my ideas in group discussions
	20	I can constructively critique others' ideas
	21	I can synthesize different views to reach a common conclusion
	22	I show respect for others' contributions during discussions
	23	I can contribute to building consensus within a group
6. Metacognitive Awareness	24	I am aware of the strengths and weaknesses of my argument
	25	I can monitor my own thinking process during discussions
	26	I know what I need to change to improve my argument
	27	I can evaluate my own performance after a discussion

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B - Attitudes towards Learning Socioscientific Issues Scale

Item No.	Dimension	Item Statement
1	Curiosity and Enjoyment	I enjoy learning about socioscientific issues such as climate change, genetic engineering, or renewable energy.
2		In my free time, I like watching documentaries or videos about socioscientific issues.
3		I often share interesting information about socioscientific issues with my friends or family.
4		I feel excited about participating in activities or clubs related to socioscientific issues.
5		When I come across unfamiliar terms related to socioscientific issues, I am eager to learn what they mean.
6	Perceived Relevance and Usefulness	Understanding socioscientific issues helps me make better decisions regarding my health and safety.
7		Learning about socioscientific issues helps me understand current global challenges such as climate change or pandemics.
8		Knowledge of socioscientific issues can enhance my future career prospects.
9		Understanding socioscientific issues helps me solve everyday problems.
10		Knowledge of socioscientific issues is highly useful for understanding the world around me.
11	Connectedness to Scientific Endeavor	I believe scientists around the world collaborate to address socioscientific issues.
12		I can see myself contributing to efforts that address socioscientific issues in the future.
13		Scientists and researchers share their findings to help solve societal challenges.
14		I believe that individuals from diverse backgrounds can equally contribute to addressing socioscientific issues.
15		When I hear about scientific advancements related to socioscientific issues, I feel connected to the broader scientific community.
16	Self-Efficacy in SSI	I feel confident in my ability to understand socioscientific issues.
17		I can evaluate different perspectives and arguments on socioscientific topics.
18		I am capable of making informed decisions about socioscientific issues.
19		I can explain socioscientific issues to others in a clear and understandable way.
20		I feel competent when discussing topics like climate change, biotechnology, or nuclear energy.
21	Future Engagement with SSI	I would like to pursue a career that involves addressing socioscientific issues.
22		I plan to stay informed about socioscientific issues throughout my life.
23		I intend to participate in discussions or activities related to socioscientific issues in the future.
24		I am interested in taking more courses or training related to socioscientific topics.
25		I see myself contributing to solutions for socioscientific problems in my community.
26	Concern and Responsibility	I feel a sense of responsibility to be informed about socioscientific issues.
27		I am concerned about the potential consequences of ignoring socioscientific issues.
28		I believe that citizens should actively engage with socioscientific issues.
29		I think it is important for everyone to understand the socioscientific challenges facing society.
30		I feel motivated to take action on socioscientific issues that affect my community and the world.

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