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A SUSTAINABILITY-ORIENTED MODEL FOR DEVELOPING STUDENTS' DECISION-MAKING IN CHEMISTRY EDUCATION

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Abstract

This study examines the effectiveness of a sustainability-oriented instructional model for developing students' evidence-based decision-making skills in chemistry education. Grounded in competency-based pedagogy and education for sustainable development, the model integrates inquiry-based learning, socio-scientific issues, and structured decision-making within real-life contexts. A quasi-experimental mixed-method design was conducted with 124 secondary school students divided into experimental and control groups. Quantitative data were collected through pre- and post-tests measuring scientific literacy and decision-making competence, while qualitative data included classroom observations, reflective journals, and interviews. Results showed statistically significant improvements in the experimental group in scientific reasoning, use of evidence, evaluation of alternatives, and justification of decisions ($p < 0.05$), along with increased engagement and sustainability awareness. The study proposes an integrated pedagogical model that connects chemistry learning with real-life decision-making and highlights implications for curriculum design, assessment reform, and competency-based science education.

Keywords: chemistry education, decision-making competence, sustainability education, scientific literacy, competency-based learning

Introduction

Modern societies face challenges such as climate change, environmental degradation, public health issues, and rapid technological development. Addressing these problems requires individuals who can critically analyze scientific information, evaluate alternatives, and make informed decisions. Therefore, education is increasingly shifting toward competency-based approaches focused on critical thinking, problem solving, and decision-making in real-life contexts (OECD, 2023).

Science education plays an important role in this process because many societal issues are scientific in nature. Chemistry is especially connected to everyday life through topics such as water purification, food safety, household chemicals, waste management, and sustainable consumption. Thus, chemistry education provides opportunities to connect scientific knowledge with authentic situations and develop evidence-based decision-making skills.

International frameworks such as PISA and UNESCO emphasize scientific literacy, critical thinking, systems thinking, and responsible action as key educational priorities (OECD, 2023; UNESCO, 2020). However, chemistry teaching in many secondary schools still relies on teacher-centered instruction and memorization, limiting students' ability to apply knowledge in practical contexts.

Although inquiry-based learning and socio-scientific issues (SSI) approaches have been shown to improve engagement and higher-order thinking, limited research has examined integrated pedagogical models that systematically develop students' real-life decision-making competence through chemistry education. To address this gap, the present study proposes a sustainability-oriented instructional model for chemistry education.The proposed instructional

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model is conceptualized as a three-stage process: (1) contextualization of chemistry content through sustainability-related real-life problems, (2) engagement in inquiry and evidence analysis, and (3) structured decision-making involving comparison of alternatives and justification of choices. This framework positions chemistry learning as a pathway for developing higher-order cognitive and practical competencies.

Figure 1 illustrates the proposed sustainability-oriented instructional model for developing students' decision-making competence in chemistry education.

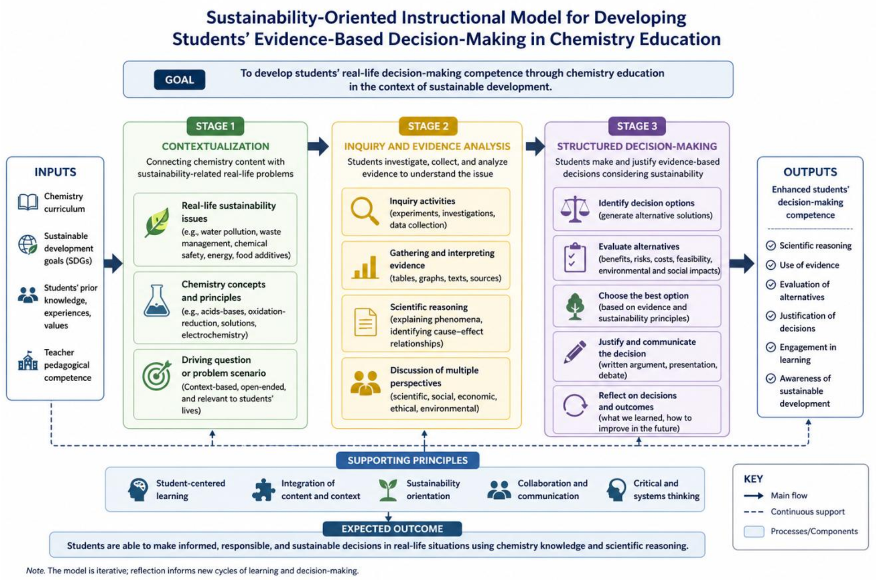

Figure 1. Sustainability-oriented instructional model developed in this study.

The instructional model proposed in this study integrates competency-based education, inquiry-based learning, socio-scientific issues (SSI) pedagogy, and education for sustainable development. Together, these approaches emphasize contextualized learning, evidence-based reasoning, and responsible decision-making in real-life contexts.

This study contributes to chemistry education in three ways. First, it proposes a sustainability-oriented instructional model combining inquiry-based learning, SSI, and structured decision-making processes. Second, it operationalizes decision-making competence through measurable components such as evidence use, evaluation of alternatives, and justification of decisions. Third, it provides empirical evidence that contextualized chemistry instruction can improve both scientific literacy and transferable life competencies.

The study addresses the following research questions:

Does sustainability-oriented chemistry instruction improve students' real-life decision-making skills?

Does the instructional model enhance students' scientific literacy and reasoning performance?

3. How do students perceive the relevance of chemistry to everyday life after the intervention?

2. Theoretical Framework and Literature Review

The proposed instructional model is based on complementary theoretical perspectives that support the development of students' evidence-based decision-making competence in chemistry education. These include competency-based education, inquiry-based learning, socio-scientific issues (SSI) pedagogy, and Education for Sustainable Development (ESD). Together, these approaches emphasize contextualized learning, evidence-based reasoning, and responsible decision-making in authentic real-life contexts.

Competency-based education serves as the main framework by emphasizing the effective application of knowledge in meaningful situations rather than simple memorization. In this study, decision-making competence includes identifying problems, analyzing evidence, comparing alternatives, and justifying decisions. Inquiry-based learning supports these processes through questioning, investigation, experimentation, and interpretation of scientific evidence, helping students develop analytical and reasoning skills. SSI pedagogy further strengthens the model by connecting chemistry learning with real-world scientific and social problems that require evaluation of alternatives and informed judgment. In addition, ESD promotes critical thinking, systems thinking, and responsible action through sustainability-related contexts.

Contemporary pedagogy increasingly evaluates learning not only through subject knowledge but also through transferable competencies that enable learners to function effectively in society. Decision-making is particularly important because it integrates cognitive, reflective, social, and ethical dimensions [1]. Research shows that students engaged in decision-oriented learning tasks demonstrate stronger critical thinking, independence, and metacognitive regulation [2]. Therefore, decision-making should be considered an intentional educational outcome supported through curriculum, instruction, and assessment practices.

Competency-based education has become a major direction of educational reform because it emphasizes learners' ability to apply knowledge in authentic situations rather than simply reproduce information [3]. This approach is especially relevant in secondary education, where students begin making increasingly independent choices related to health, technology, and environmental responsibility. Chemistry offers strong potential for competence development because many real-life decisions involve chemical knowledge, including issues related to nutrition, product safety, waste management, and water purification [4].

Education for Sustainable Development encourages learners to understand complex systems and make responsible choices for present and future generations. UNESCO highlights competencies such as systems thinking, critical reflection, collaboration, and responsible action [5]. Inquiry-based learning and SSI pedagogy are also widely recognized for improving reasoning, argumentation, and reflective judgment through engagement with complex scientific and social issues [6][7]. When combined, these approaches create powerful conditions for competence development because students must use evidence while considering multiple dimensions of real-world problems.

Despite growing support for competency-based learning, relatively few studies have proposed integrated pedagogical models specifically designed to develop real-life decision-making competence through chemistry education. Existing research often examines scientific literacy, inquiry learning, or sustainability separately rather than demonstrating how these elements can function together in classroom practice [8]. The present study addresses this gap by testing a structured model that integrates chemistry content, sustainability contexts, inquiry tasks, and evidence-based decision-making routines.

Methodology

This study employed a quasi-experimental mixed-method research design to examine the effectiveness of a pedagogical model aimed at developing students' real-life decision-making skills through chemistry education in the context of sustainable development [9]. The quantitative strand followed a pre-test/post-test non-equivalent control group design, while the qualitative strand included classroom observations, reflective journals, and semi-structured interviews.

The study was conducted during one academic semester in two urban secondary schools involving 124 students from Grades 9–10. Participants were divided into experimental (n=62) and control (n=62) groups. Preliminary analysis showed no statistically significant differences between groups before the intervention ($p > 0.05$).

Students in the experimental group participated in a 10-week intervention integrated into regular chemistry lessons. The instructional model combined:

- ✓ contextualization of chemistry content through sustainability-related real-life issues;
- ✓ inquiry-based learning and evidence analysis;
- ✓ structured decision-making activities;
- ✓ reflective dialogue and peer discussion.

Students applied chemistry concepts to authentic scenarios requiring interpretation of evidence, comparison of alternatives, and justification of decisions. The control group studied the same topics through conventional teacher-centered instruction.

Data collection included a researcher-developed Decision-Making Competence Test, a Scientific Literacy Test based on international frameworks such as PISA [10], classroom observations, reflective journals, and semi-structured interviews. Instruments were reviewed by experts and piloted prior to the main study. Reliability analysis showed acceptable internal consistency (Cronbachsα= 0.82 and 0.86) [12].

Quantitative data were analyzed using descriptive statistics, paired and independent sample t-tests, and effect size estimation. Qualitative data from interviews, journals, and observations were analyzed through thematic coding [13].

Participation in the study was voluntary, and informed consent was obtained from schools, parents, and students before data collection [14].

Results

Pre-test analysis showed no statistically significant differences between the experimental and control groups in scientific literacy or decision-making competence before the intervention ($p > 0.05$), indicating comparable baseline conditions [15].

Table 1. Pre-Test Comparison of Groups

Variable	**Control Group (n=62)**	**p-value**
Scientific Literacy	52.3	0.67
Decision-Making Competence	10.1	0.59

After the 10-week intervention, the experimental group achieved significantly higher scientific literacy scores ($M = 78.6$, $SD = 7.2$) than the control group ($M = 69.4$, $SD = 8.1$), $t(122) = 4.91$, $p < 0.001$, with a moderate-to-large effect size (Cohen's $d = 0.73$) [16].

Table 2. Post-Test Scientific Literacy Scores

Group	**Mean**	**SD**	**t-value**	**p-value**
Experimental	78.6	7.2	4.91	<0.001
Control	69.4	8.1		

Students in the experimental group also outperformed the control group in decision-making competence, achieving a mean score of 16.8/20 compared with 12.9/20 in the control group, $t(122) = 5.34$, $p < 0.001$.

Table 3. Decision-Making Competence Scores

Group	Mean Score (/20)	SD	p-value
Experimental	16.8	2.4	<0.001
Control	12.9	2.7	

Detailed rubric analysis revealed that the strongest gains in the experimental group occurred in the following dimensions:

- ✓ Use of scientific evidence (+28%)
- ✓ Comparison of alternatives (+31%)
- ✓ Risk-benefit evaluation (+26%)
- ✓ Justification of final decisions (+34%)

These gains suggest that repeated participation in authentic decision-making scenarios strengthened higher-order reasoning skills. Three dominant themes emerged from reflective journals, classroom observations, and interviews.

Qualitative data indicated increased perceived relevance of chemistry, stronger evidence-based thinking, and greater sustainability awareness among students. Many participants reported that chemistry became more meaningful when connected with real-life situations and environmental issues [17].

Observation data also showed higher classroom engagement in the experimental group, including greater participation in discussions, more frequent questioning, stronger collaboration, and more active use of evidence during debates.

Overall, the findings suggest that the proposed pedagogical model improved scientific literacy, decision-making competence, student engagement, and students' ability to apply chemistry knowledge in real-life contexts.

Conclusion and Pedagogical Implications

The findings of this study provide evidence that sustainability-oriented chemistry instruction can significantly improve students' scientific literacy, evidence-based reasoning, comparison of alternatives, and justification of decisions. Students in the experimental group demonstrated stronger decision-making competence than those receiving traditional instruction, indicating that such competencies can be intentionally developed through contextualized and inquiry-based chemistry learning [3].

The study also showed that connecting chemistry content with real-life contexts such as waste reduction, water quality, safer product use, and environmental responsibility increased student engagement and the perceived relevance of chemistry learning [4]. These findings support UNESCO's view that sustainability competencies should be integrated across subjects rather than taught separately [5]. Inquiry, dialogue, and evidence-based discussion also played an important role in strengthening students' reasoning and reflective thinking [18].

An important contribution of the study is the demonstrated compatibility between academic achievement and competency development. Students improved decision-making skills while simultaneously strengthening their understanding of chemistry concepts, supporting current international trends toward competency-based curriculum reform [1].

Teachers are encouraged to integrate contextual decision-making tasks requiring students to interpret evidence, compare alternatives, justify choices, predict consequences, and reflect on environmental and social impacts. Routine exercises should be balanced with inquiry-based activities, debates, and collaborative problem-solving tasks. Curriculum and assessment systems should also place greater emphasis on reasoning quality and applied judgment rather than factual recall alone, consistent with international assessment trends such as PISA [10].

Although the study was limited by sample size and intervention duration, the findings suggest that chemistry education, when guided by a sustainability-oriented and theoretically grounded pedagogical model, can effectively foster students' higher-order thinking and real-life decision-making competence.

Practical Recommendations for Implementation

Based on the findings of this study, several practical recommendations can support the implementation of decision-making-oriented chemistry pedagogy in secondary education. Chemistry instruction should incorporate real-life and sustainability-related contexts that encourage students to apply scientific knowledge in meaningful situations. Activities may include evaluating household chemicals, analyzing food labels, comparing water purification options, examining recycling systems, and assessing energy sources. Such context-based tasks enhance the relevance of chemistry learning and support the transfer of knowledge to everyday decision-making situations [4].

To develop decision-making competence systematically, teachers should guide students through structured stages such as identifying problems, evaluating scientific evidence, comparing alternatives, considering risks and benefits, and justifying final decisions. Regular engagement in these processes strengthens rational thinking and evidence-based reasoning skills.

An important component of this pedagogy is active student participation in dialogue, argumentation, and reflection. Peer discussions, debates, and collaborative problem-solving activities can strengthen critical thinking, reflective judgment, and the ability to justify conclusions using scientific evidence.

Assessment practices should extend beyond factual recall by incorporating performance-based approaches such as case-based tasks, open-ended questions, reflective journals, group presentations, and analytic rubrics. Such methods allow evaluation of both conceptual understanding and the ability to apply chemistry knowledge responsibly in real-life contexts.

Successful implementation also requires institutional and systemic support. School leaders should encourage collaboration, interdisciplinary projects, and access to context-based instructional materials, while education authorities should integrate decision-making competence into curriculum standards, assessment systems, and teacher professional development programs [19].

Future developments in chemistry education may involve digital tools, sustainability projects, and interdisciplinary integration to make learning more engaging and connected to real-life challenges. Overall, chemistry education, when supported by contextualized and student-centered pedagogical strategies, provides an effective platform for developing students' informed decision-making competence.

Limitations and Future Research

Although the study produced encouraging results, several limitations should be acknowledged. First, the research involved a moderate sample from only two secondary schools, limiting the generalizability of the findings. Future studies should include larger and more diverse samples from different regions, school types, and socio-economic contexts.

Second, the ten-week intervention allowed identification of short-term improvements but did not measure long-term retention of decision-making competence. Longitudinal research is needed to examine whether these competencies remain stable over time.

Third, the study focused specifically on chemistry education. Future research should investigate whether similar pedagogical approaches are effective in biology, physics, mathematics, and interdisciplinary STEM contexts. In addition, some qualitative findings relied on student reflections and interviews, which may involve self-report bias. Future studies could strengthen validity through classroom observations, video analysis, and performance-based data.

Teacher-related factors such as pedagogical expertise, facilitation skills, and enthusiasm may also have influenced the outcomes. Therefore, future research should examine teacher professional development models that support competency-based and decision-oriented instruction.

Future studies are recommended to:

a) investigate long-term retention of decision-making competence;

b) test the model in rural and urban schools;

c) compare digital, blended, and face-to-face implementations;

d) examine adaptation for different age groups;

e) explore relationships between decision-making competence and academic achievement;

f) analyze teacher readiness for competency-based pedagogy;

g) compare cross-national applications of the model.

Declarations

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Conflict of Interest

The author declares no conflict of interest.

Data Availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Ethical Approval

All procedures involving participants were conducted according to institutional ethical standards. Informed consent was obtained from participants, parents, and school administrations before data collection.

Author Contributions

The author solely contributed to the conceptualization, methodology, investigation, data analysis, writing, and final approval of the manuscript.

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