
# INTEGRATING SUSTAINABLE DEVELOPMENT IDEAS INTO CHEMISTRY EDUCATION THROUGH A REAL-LIFE DECISION-MAKING MECHANISM

**Akbarova Saidakhon Rustamovna**
Chemistry Methodologist Republican Education Center, Tashkent, Uzbekistan

## ABSTRACT

This article addresses the problem of integrating sustainable development ideas into chemistry education through a mechanism that supports students' real-life decision-making. Chemistry curricula increasingly reference sustainability and the United Nations Sustainable Development Goals (SDGs), yet students often struggle to connect green-chemistry principles to concrete, everyday decisions, and classroom approaches rarely provide an explicit procedure for weighing competing sustainability-related criteria. Drawing on a multi-criteria optimization model of decision-making, context-led approaches to chemistry teaching, argumentation-based justification of scientific claims, and recent green-chemistry decision-making tools linked to the SDGs, this article develops and substantiates a four-stage mechanism — context selection, criteria identification and weighting, generation and rating of chemistry-based alternatives, and weighted decision with scientific justification. For each stage, the article proposes concrete instructional tools and illustrates their application through a worked example comparing packaging materials for a school cafeteria. The article is conceptual and methodological in nature: it proposes and theoretically justifies an instructional mechanism rather than reporting the results of an empirical trial. The article concludes with practical recommendations for chemistry teachers and outlines the design of an empirical study that would be needed to verify the mechanism's effectiveness in practice.

**KEYWORDS:** Sustainable development, green chemistry, decision-making, multi-criteria optimization, context-based chemistry education, Sustainable Development Goals, argumentation.

## INTRODUCTION

Chemistry education has increasingly been called upon to prepare students not only to understand chemical concepts but to apply them in making informed, real-life decisions about sustainability. Contemporary curricula reference green-chemistry principles and the United Nations Sustainable Development Goals (SDGs) with growing frequency, reflecting a broader recognition that chemistry graduates and citizens alike must be able to weigh the environmental, economic, and social dimensions of chemical choices [1]. At the same time, decision-making itself is a general cognitive skill that has received comparatively little explicit attention in school science, despite being central to how people resolve everyday problems that involve trade-offs among competing, often conflicting objectives [2].

A persistent difficulty is that abstract chemical concepts, taught in isolation from authentic contexts, often fail to connect to students' everyday experience, so that many students do not see why sustainability-related chemistry content is relevant to decisions they might actually face [3]. Context-led approaches to chemistry teaching address this gap by using real-world situations — rather than decontextualized concepts — as the starting point for instruction, on the premise that students value a setting more, and engage with it more meaningfully, when it arises from their own lives or from social and industrial issues of contemporary importance [3]. However, providing an engaging sustainability context is not, by itself, sufficient to develop students' capacity to make a reasoned decision. Research on decision-making skills indicates that even when learners are taught a formal procedure for weighing multiple criteria, they frequently make characteristic errors: some ignore the relative importance of different criteria and treat them as equally weighted; others focus exclusively on a single, usually the most salient, criterion while ignoring the rest; and some select an option that fails to meet a critical threshold on one criterion altogether, without recognizing that this should eliminate it from consideration [2]. These difficulties suggest that sustainability-related decision-making in chemistry should be taught through an explicit, structured procedure rather than left to develop implicitly through exposure to green-chemistry content alone.

Recent developments in chemistry education have begun to supply the tools needed for such a procedure. Comparative decision-making approaches that integrate green-chemistry metrics with life-cycle assessment and systems thinking have been introduced to help students compare the sustainability of alternative chemical processes using industry-relevant, quantifiable criteria linked explicitly to the SDGs [4]. Separately, research on argumentation shows that structured, scaffolded argument construction — grounded in a formal pattern of claim, data, and justification — can improve students' ability to use scientific evidence to support conclusions, a competency directly relevant to justifying a sustainability-related decision once it has been made [5]. The purpose of this article is to integrate these strands — context-led teaching, structured multi-criteria decision-making, and evidence-based argumentation — into a coherent four-stage mechanism for developing chemistry students' capacity to make real-life decisions grounded in sustainable-development thinking, and to outline the design of an empirical study that would be needed to verify its effectiveness in practice.

## Materials and Methods

This article adopts a conceptual and design-based approach: the four-stage mechanism was developed through a synthesis of research on context-led chemistry teaching [3], multi-criteria optimization as a decision-making strategy [2], green-chemistry and life-cycle-assessment tools linked to the SDGs [1, 4], and structured argumentation for justifying scientific conclusions (Tsai, 2013). The mechanism is illustrated below through a worked instructional example rather than through the results of a controlled experiment, since a structured procedure grounded in the existing evidence base is itself a necessary contribution prior to large-scale empirical testing.

The proposed mechanism is structured around four stages, with an explicit provision for revisiting earlier stages as new contexts or information arise, as summarized in Figure 1.

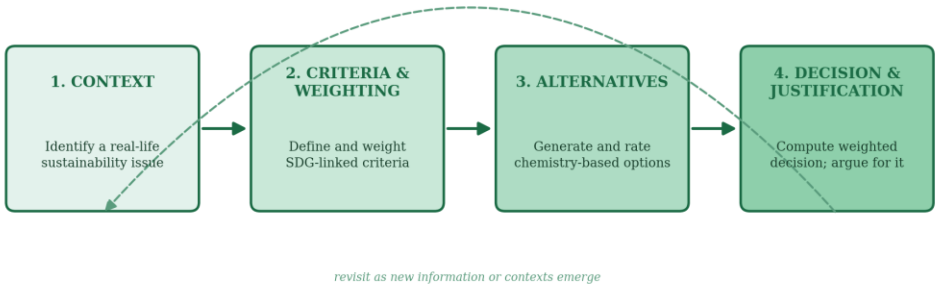


**Figure 1. The four-stage sustainability decision-making mechanism, shown as a narrowing decision funnel.**

Context stage. The teacher, or students themselves, identify a real-life sustainability issue with genuine chemical content — such as choosing among packaging materials, cleaning products, or energy sources — selected according to the criteria for a successful educational context: it must be a setting students value and recognize as falling within chemistry, it must exemplify important chemical concepts, and it must connect to students' existing background knowledge [3].

Criteria and weighting stage. Students identify the criteria relevant to the decision (e.g., environmental impact, cost, safety, biodegradability, functionality) and assign each a relative weight reflecting its importance, using a simple numerical scale; sustainability-specific criteria are explicitly linked to relevant SDGs and, where feasible, to simplified green-chemistry indicators such as those underlying industry tools like DOZN and life-cycle assessment [1, 4].

Alternatives stage. Students generate a small set of realistic chemistry-based alternatives and rate each one against every criterion using a consistent scale, producing a simple ratings table; any alternative that fails a critical threshold on a given criterion (e.g., a material identified as acutely hazardous) is flagged for potential elimination before further calculation, directly addressing a documented student difficulty [2].

Decision and justification stage. Students compute a weighted score for each alternative (multiplying each rating by its criterion weight and summing across criteria), identify the option with the highest weighted score, and then construct a structured written or spoken justification of the decision using a claim–data–warrant argument pattern, explicitly connecting the numerical outcome to the underlying chemistry [2, 5].

| Stage | Primary skill focus | Instructional tools | Theoretical basis |
|---|---|---|---|
| **Context** | Selecting an authentic, chemically relevant sustainability issue | Context-selection checklist based on Gilbert's criteria | Wilson et al., 2015 |
| **Criteria & Weighting** | Identifying and weighting SDG-linked decision criteria | Criterion-weighting worksheet; simplified green-chemistry indicators | Reyes et al., 2023; Hoffman & Dicks, 2023 |

| | | | |
|---|---|---|---|
| **Alternatives** | Generating and rating realistic chemical alternatives | Ratings matrix; threshold-elimination checklist | Mettas, 2011 |
| **Decision & Justification** | Computing a weighted decision and arguing for it | Weighted-score calculation template; claim–data–warrant frame | Mettas, 2011; Tsai, 2013 |

**Table 1. Overview of the four-stage sustainability decision-making mechanism.**

To illustrate how this mechanism would be embedded into a regular chemistry lesson, consider a worked example built around a genuine school context: "Which packaging material should the school cafeteria use for takeaway meals?" In the context stage, the class recognizes this as a setting they value (it affects their own school), with clear chemical content (polymer structure, biodegradability, material properties). In the criteria and weighting stage, students identify criteria such as environmental impact/biodegradability, functionality (heat resistance, durability), cost, and production safety, and assign weights reflecting their relative importance (e.g., environmental impact and functionality weighted highest). In the alternatives stage, students rate three realistic alternatives — single-use plastic, paper-based packaging, and a compostable bioplastic — against each criterion. In the decision and justification stage, students calculate the weighted score for each alternative and construct a justification explaining, in chemical terms, why the option with the highest score represents the most sustainable available choice given the school's constraints. Table 2 summarizes this worked example stage by stage, and Table 3 presents an illustrative (hypothetical) ratings matrix of the kind students would construct themselves.

| Stage | Student activity in the worked example |
|---|---|
| **Context** | Recognize the school cafeteria's packaging choice as a real, chemically relevant decision affecting their own school. |
| **Criteria & Weighting** | Identify criteria (environmental impact, functionality, cost, safety) and assign each a weight (1–5) reflecting its importance. |
| **Alternatives** | Rate single-use plastic, paper packaging, and compostable bioplastic against each criterion (0–4 scale); flag any option failing a critical threshold. |
| **Decision & Justification** | Compute the weighted score for each option; justify the highest-scoring option using chemical reasoning about polymer structure and biodegradability. |

**Table 2. Illustrative application of the four stages to a school-packaging worked example.**

| Criterion (Weight) | Single-use plastic | Paper packaging | Compostable bioplastic | Weighted basis |
|---|---|---|---|---|
| **Environmental impact (5)** | 1 | 3 | 4 | rating × 5 |
| **Functionality (4)** | 4 | 2 | 3 | rating × 4 |
| **Cost (3)** | 4 | 3 | 2 | rating × 3 |
| **Production safety (3)** | 3 | 4 | 3 | rating × 3 |
| **Weighted total** | **42** | **44** | **47** | sum of products |

**Table 3. Illustrative (hypothetical) weighted-ratings matrix of the kind students would construct in the alternatives and decision stages.**

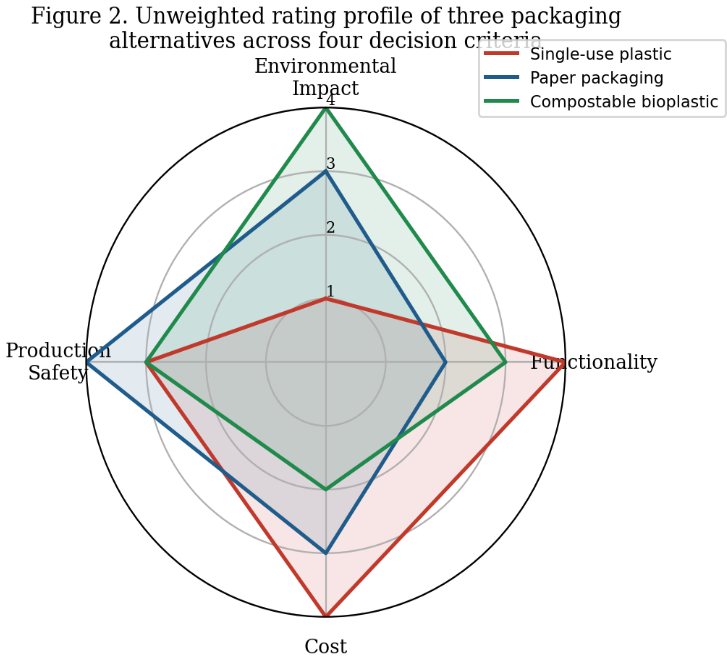


Figure 2 visualizes the unweighted ratings from Table 3 as a radar profile, allowing students to see at a glance which alternative performs strongly or weakly on each criterion before the weighting step is applied — a visualization step that can help students notice trade-offs (e.g., the plastic option's strength in functionality and cost against its weakness in environmental impact) prior to computing the final weighted decision.

To empirically test the effectiveness of this mechanism, a quasi-experimental design would be appropriate: a pre-, mid-, and post-intervention comparison, following the multi-phase design used in comparable decision-making research [2], between an experimental group of chemistry classes taught using the four-stage mechanism and a control group taught using conventional instruction on the same sustainability content. Suitable instruments would include a decision-making task scored using the same category scheme used in prior optimization-strategy research (i.e., whether students consider both ratings and weights, only ratings, only the single most important criterion, or ignore a disqualifying threshold; [2]), together with a rubric assessing the quality of students' written justifications along the lines of the claim–data–warrant structure [5]. Such a study, which the present article does not itself carry out, would allow the anticipated outcomes discussed below to be verified against measured classroom data.

## Results

As this article presents a theoretical-methodological proposal rather than the results of an empirical trial, this section does not report measured data. Instead, it sets out the outcomes that the proposed mechanism would be expected to produce at each of the four stages, based on the mechanisms identified in the cited research literature, together with the specific indicators that a future empirical study should measure to confirm or disconfirm these expectations.

In the context stage, because recognizing a relevant, engaging setting is a comparatively accessible entry point once a suitable context has been selected using established criteria, a modest, readily achievable gain would be expected; a future study should measure this as students' self-reported relevance ratings for the chosen context, alongside teacher-rated fidelity to the context-selection criteria [3].

In the criteria and weighting stage, a moderate gain would be expected, since identifying relevant criteria is a more demanding task than recognizing a context, but is supported by the explicit link to SDG categories and green-chemistry indicators; this should be measured as the number and appropriateness of criteria identified, and the extent to which weights assigned by students reflect a defensible ordering of importance [1, 4].

In the alternatives stage, moderate-to-large gains would be expected specifically in students' avoidance of the documented error of failing to eliminate an option that does not meet a critical threshold on one criterion, since this is a concrete, checklist-supported behavior; this should be measured using the same category scheme applied in prior optimization-strategy research, tracking the proportion of students who correctly disqualify a non-viable alternative [2].

In the decision-and-justification stage, the mechanism is expected to produce the largest and most educationally significant gains, since this stage combines the two components identified in the literature as most difficult in isolation — correctly weighting multiple criteria in the numerical decision [2] and constructing an evidence-based scientific justification [5]; this should be measured through the proportion of students whose final decision reflects a full weighted-criteria calculation (rather than a single-criterion or unweighted judgment) and through rubric scoring of whether their justification explicitly connects the numerical outcome to the underlying chemical reasoning. Table 4 summarizes these anticipated outcomes alongside the corresponding measurement indicators.

| Stage | Expected relative gain | Proposed measurement indicator |
|---|---|---|
| **Context** | Modest | Student-reported relevance ratings; fidelity to context-selection criteria |

| | | |
|---|---|---|
| **Criteria & Weighting** | Moderate | Number/appropriateness of criteria; defensibility of assigned weights |
| **Alternatives** | Moderate-to-large | Proportion correctly disqualifying a non-viable alternative |
| **Decision & Justification** | Largest (expected) | Proportion using full weighted calculation; rubric score for chemistry-grounded justification |

**Table 4. Anticipated outcomes and proposed measurement indicators, by stage (to be verified empirically).**

## Discussion

The proposed mechanism rests on the premise that sustainability-related decision-making in chemistry is best developed as an explicit, structured procedure rather than as an incidental outcome of teaching green-chemistry content, directly responding to evidence that students, even after formal instruction in a decision-making strategy, characteristically default to simplified heuristics — attending to a single criterion, ignoring relative weights, or failing to eliminate disqualified options — unless these errors are explicitly targeted [2]. Embedding the mechanism within an authentic, student-valued context is expected to strengthen this effect, since context-led approaches have been associated with increased engagement and a clearer sense of the relevance of chemical concepts to students' own lives [3].

Of the four stages, the decision-and-justification stage is expected to be the most demanding, precisely because it requires students to integrate a numerical, multi-criteria calculation with a qualitative, evidence-based scientific argument. This integration mirrors the finding that argumentation instruction improves students' ability to use scientific evidence to support conclusions, but does not automatically improve their ability to explain the underlying phenomenon unless this is separately addressed [5]; the proposed mechanism attempts to bridge this gap by requiring the justification to explicitly connect the computed decision to chemical reasoning, rather than treating the numerical outcome as self-explanatory.

The explicit linkage of decision criteria to the SDGs and to simplified green-chemistry indicators is intended to address a documented disconnect between students' enthusiasm for sustainability and their sense of being unprepared to make green and sustainable decisions using industry-relevant tools [4]. By scaffolding this connection at the secondary level, rather than introducing it only in specialized higher-education contexts, the mechanism aims to extend the reach of frameworks such as those recently proposed for incorporating the SDGs into high-school chemistry curricula [1] into everyday classroom decision tasks rather than only curriculum-level design documents.

Certain limitations of the present proposal should be acknowledged. Because the mechanism has not yet been empirically tested, the anticipated outcomes described above remain hypotheses derived from related research rather than confirmed findings, and their actual magnitude — and the extent to which students transfer this decision-making procedure to sustainability contexts not explicitly taught — can only be established through the empirical study outlined in the Materials and Methods section, ideally conducted across multiple classes and sustainability contexts to support generalizability. A further consideration concerns the selection of contexts: as prior research on context-led courses cautions, not every context is equally suitable for every student population, and contexts that are too emotionally engaging or too remote from students' experience may distract from, rather than support, the underlying chemical and decision-making learning goals [3]; teachers should therefore select or adapt contexts using the criteria outlined in the context stage rather than assuming that any sustainability topic will function equally well.

## Conclusion

This article has proposed and theoretically substantiated a structured, four-stage mechanism — context selection, criteria identification and weighting, generation and rating of alternatives, and weighted decision with scientific justification — for integrating sustainable-development ideas into chemistry education through real-life decision-making. Grounded in research on context-led chemistry teaching, multi-criteria optimization strategies, green-chemistry decision-making tools linked to the SDGs, and structured scientific argumentation, the mechanism specifies concrete instructional tools for each stage and has been illustrated through a school-packaging worked example; on this basis, the decision-and-justification stage is expected to require the most sustained instructional attention, since it uniquely combines weighted quantitative reasoning with evidence-based chemical explanation.

These proposals have direct practical implications for chemistry teaching practice: rather than treating sustainability as a topic to be covered through content alone, chemistry teachers can embed explicit, structured decision-making tasks — using authentic contexts, weighted criteria linked to the SDGs, and requirements for chemistry-grounded justification — directly into standard lessons on materials, energy, and industrial processes. The immediate priority for future work is to conduct the quasi-experimental study outlined above, so that the anticipated benefits of the mechanism can be verified against measured classroom data; continued refinement, supported by research across multiple sustainability contexts and school settings, would then further strengthen its practical applicability within the national chemistry curriculum.

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