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Integrating case study teaching and the four component model: Cultivating ethical decision in genetics education

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Abstract

Emerging genetic technologies present complex socio-ethical dilemmas, requiring biology students to develop ethical decision-making (EDM) skills. This study aimed to design and evaluate a learning intervention integrating case study teaching and the four component model of morality, while also identifying design principles relevant for EDM. The method of this study used educational design research across three phases: preliminary analysis, intervention development, and evaluation. A total of 101 undergraduate biology students and 22 genetics instructors and practitioners participated, with ethical approval obtained from Universitas Negeri Malang. The field evaluation revealed significant improvements in EDM skills, with the largest effects on moral sensitivity (Cohen's d = 0.83), followed by judgment (d = 0.78), character (d = 0.77), and motivation (d = 0.64). These findings confirm the intervention's effectiveness and provide design principles to guide the development of similar ethical learning interventions in science education.

Keywords: case study teaching, educational design research, ethical decision-making, four component model of morality, genetics course

INTRODUCTION

In recent years, science educators have been seeking meaningful ways to engage students with the rapidly evolving social challenges arising from advances in genetic technologies, including genetic testing in humans and animals, genetically modified food production, and population genetic studies of human ancestry (Kara, 2025; Macalalag et al., 2024). While such developments have generated substantial benefits, these advances also bring ethical dilemmas related to privacy, equity, and social implications (Baram-Tsabari & Rozenblum, 2025). These value-laden issues highlight the need for students to develop ethical decision-making (EDM) skills that enable them to navigate the moral dimensions of contemporary scientific practices (Kara, 2025). However, recent studies indicate that students' knowledge and attitudes towards genetic technologies remain limited (Haberbosch et al., 2025; Liu, 2019). Moreover, current pedagogical approaches in genetics education have yet to provide adequate opportunities for ethical reflection (Maghfiroh et al., 2024).

For more than two decades, Sadler and Zeidler (2005) have emphasized the urgency of integrating genetics issues into genetics instruction. Since then, scholars have recommended engaging university students in genetics-related ethical dilemmas to apply their conceptual understanding while reflecting on their personal values (Aivelo & Uitto, 2019; Macalalag et al., 2024). Consistent with these perspectives, international policies such as the next generation science standards (NGSS Lead States, 2013) and national frameworks, including the Indonesian National Qualification Framework (2015), have highlighted the importance of developing EDM skills through genetics education grounded in ethical dilemmas. However, despite the emphasis on ethical dimensions in policy and literature, their implementation in higher education remains limited.

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Contribution to the literature

- This study contributes to the existing literature by introducing the integration of case study teaching (CST) and the four component model of morality (FCM) as a structured framework for EDM, an approach that has not previously been systematically explored in genetics education.
- The results of this study identified three core design principles that address gaps in the literature regarding the implementation of an integrated ethics model in science pedagogy, while providing empirical guidance for educators.
- The implementation of the CST-FCM intervention demonstrated enhancements in students' EDM skills, including moral sensitivity, ethical judgment, character, and motivation, while also broadening their awareness of socio-genetic issues and the social-environmental implications of scientific decisions.

Numerous empirical studies have identified approaches to support students' EDM skills (Aalberts et al., 2012; Wan, 2023), yet there remains no consensus on the most effective framework. One of the most influential models in the moral education literature is the FCM (Narvaez & Rest, 1995), which is considered comprehensive because it extends beyond moral reasoning to include affective and behavioral dimensions (Garcia et al., 2024; Thoma & Bebeau, 2013). Although the FCM has been applied across multiple disciplines, its use in genetics education has rarely been explored (Baram-Tsabari & Rozenblum, 2025). Most studies have focused on only one or two components of students' morality, such as moral sensitivity or ethical reasoning (Aalberts et al., 2012; Liu, 2019; Maghfiroh et al., 2025), and therefore no research has yet integrated all four FCM aspects into the design of genetics instruction in higher education. Hence, there is a need for pedagogical approaches that enable students to cultivate FCM through active engagement with real-world cases.

One promising pedagogical approach for fostering the development of students' ethical competence is CST (Wijnia et al., 2024). Through the analysis of authentic cases, this method encourages students to develop critical reasoning, apply knowledge in practical contexts, and deepen their conceptual understanding (Sartania et al., 2022; Thistlethwaite et al., 2012). Although the effectiveness of CST has been well established in health-related disciplines (Sartania et al., 2022), its implementation within genetics education remains limited (Bonney, 2015). Furthermore, no study to date has explicitly combined CST with FCM to foster students' ethical competence.

To address this gap, the present study employed an educational design research (EDR) approach involving iterative cycles of analysis, design, implementation, and evaluation in authentic contexts (Nieveen & Folmer, 2013; Plomp, 2013). This approach has demonstrated effectiveness across STEM education (Kopcha et al., 2017), including in socio-scientific issue learning (Dayan & Tsybulsky, 2024) and biology instructional design (Van der Leij et al., 2024). Given these characteristics, EDR is considered suitable for designing and refining genetics interventions that integrate the CST and FCM.

Accordingly, this study aimed to develop and evaluate an instructional design that integrates CST and the FCM to support university students' EDM skills in genetics courses. Through the EDR approach, this study sought to produce a practical intervention model for science educators and to generate theoretical design principles that contribute to the literature on ethics education in higher science education.

METHODOLOGY

Research Design

This study used an EDR approach to design and evaluate a genetics intervention aimed at supporting students' EDM skills. The EDR process was iterative and collaborative, consisting of three phases:

(1) preliminary research to identify design needs,

(2) development and micro-level evaluation of prototype interventions, and

(3) field evaluation to examine the effectiveness of the final design (Nieveen & Folmer, 2013; Plomp, 2013).

Throughout all stages, the research team maintained active collaboration with lecturers and genetics experts to ensure contextual relevance, pedagogical feasibility, and theoretical robustness.

Participants and Sampling

This study involved genetics lecturers as teaching practitioners, genetics experts as disciplinary specialists, and undergraduate biology students in Indonesia. Prior to data collection, ethical approval was obtained from Universitas Negeri Malang, and all participants provided informed consent. In phase 1 (preliminary research), genetics lecturers from Education Institute for Educational Personnel were invited via email. Of the 25 invited lecturers, 18 agreed to share their genetics course learning plans (GCLP). Then, participants for the semi-structured interviews were selected based on two additional criteria: at least five years of genetics teaching experience and active involvement in curriculum development. The final sample included six experts: three in genetics who contributed disciplinary

Table 1. Demographic characteristics of expert interviews

Code	Area of expertise	Teaching experience	Academic degree
G1	Genetics	> 20 years	Doctorate
G2	Genetics	> 20 years	Doctorate
G3	Genetics	> 5 years	Master's
E1	Genetics education	> 20 years	Doctorate
E2	Genetics education	> 5 years	Master's
E3	Genetics education	> 5 years	Master's

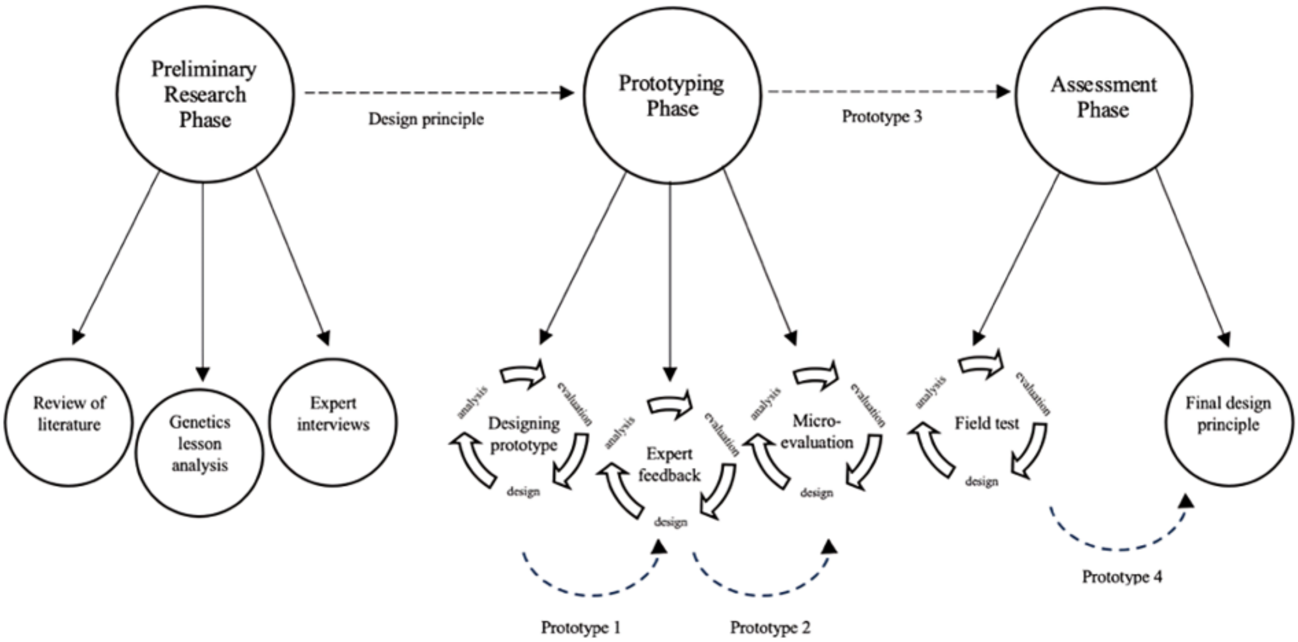

Figure 1. Main and micro stages of the intervention design (Source: Authors' own elaboration)

perspectives, and three in genetics education who provided pedagogical and curricular insights (see **Table 1**).

In phase 2 (prototyping), five genetics lecturers, three with master's and two with doctoral degrees, reviewed the initial prototype. Three universities in Malang, Indonesia, were purposively selected for the micro and field evaluations. The micro evaluation was conducted at two universities with 33 biology students who had completed a genetics course and agreed to provide feedback: 13 from the first university (4 males, 9 females) and 20 from the second (8 males, 12 females). This phase prioritized the depth of feedback rather than the breadth of representation (Nieveen & Folmer, 2013; Plomp, 2013). Each participant was assigned an anonymous code indicating their role (S = student, L = lecturer), institution (1 or 2), and quotation number (e.g., S1-03).

In phase 3 (evaluation), the field evaluation was conducted at a third university with a larger student cohort to assess the effectiveness of the intervention in an authentic context. Participants included 68 biology students enrolled in a genetics course who had attended at least 80% of the sessions: 36 students in class A (4 males, 32 females) and 32 in class B (8 males, 24 females). This number was considered sufficient to capture contextual variation and ensure ecological validity (Nieveen & Folmer, 2013; Plomp, 2013). An anonymous coding system was applied using a similar format, adapted to the class context (e.g., SA-05).

Research Procedures

This EDR was conducted over two years and consisted of three main phases (see **Figure 1**). Phase 1 (preliminary research) focused on identifying design needs through a literature review, analysis of GCLP, and semi-structured interviews with genetics experts to formulate initial design requirements and principles. Phase 2 (prototyping) involved the design and refinement of the learning prototype. The first prototype was reviewed by expert lecturers, and their feedback was used to develop the second prototype, which was then pilot-tested over two class sessions using perception questionnaires and written reflections. These sessions were implemented in collaboration with the genetics lecturer, and insights from the evaluation informing the refinement of the third prototype. Phase 3 (evaluation) examined the effectiveness of the intervention and produced the final design principles. The third prototype was implemented over eleven sessions covering six genetics-ethics issues, including pre- and post-tests. Similar to the previous phase, these sessions were implemented in collaboration with the genetics lecturer, with feedback from lecturers and students informing the refinement of the fourth prototype.

Research Instruments

This study used both quantitative and qualitative instruments that were adapted to each phase of development and evaluation. In phase 1 (preliminary research), the GCLP was evaluated in terms of two aspects, consisting of learning activities and learning resources. Learning activities were categorized as basic cognitive, higher-order cognitive (Anderson & Krathwohl, 2001), and ethics-oriented (Narvaez & Rest, 1995; Rest et al., 1999), whereas learning resources were assessed based on their recency and publication year. Additionally, semi-structured interviews with genetics experts (30-45 minutes) were conducted to explore students' needs for support in EDM and relevant pedagogical strategies.

Phase 2 (prototyping) involved the validation of the CST and FCM prototypes by genetics lecturers, focusing on three aspects: content relevance, pedagogical effectiveness, and language clarity (Nieveen & Folmer, 2013; Plomp, 2013). The micro evaluation employed a student perception questionnaire based on four dimensions: instructional usability, case analysis clarity, ethical relevance (Nieveen & Folmer, 2013; Plomp, 2013), and collaborative engagement (Suwono et al., 2023). The questionnaire consisted of 20 items rated on a five-point Likert scale. Qualitative data were collected through students' written reflections and lecturers' observations during implementation.

Phase 3 (evaluation) assessed students' EDM skills using 24 open-ended, scenario-based questions that encompassed four dimensions of morality (Narvaez & Rest, 1995; Rest et al., 1999). The instrument demonstrated acceptable validity ($r = 0.47$-0.66) and reliability (Cronbach's $\alpha = 0.85$). Student responses were evaluated using a four-point rubric developed based on the FCM framework and the criteria of the Association of American Colleges and Universities (2009) and were reviewed by expert lecturers to ensure content validity. Additional qualitative data were obtained from students' written reflections and classroom observation notes during the implementation.

Data Analysis

Data were analyzed both quantitatively and qualitatively according to the characteristics of each EDR phase. In phase 1 (preliminary research), the learning activities and learning resources in the GCLP were examined using content analysis (Bengtsson, 2016). All activities were identified, coded, verified, and categorized based on cognitive type. The results are presented as frequencies and percentages, showing high inter-coder reliability (Cohen's kappa = .83). The analysis of learning resources was descriptive, grouping references according to their year of publication. Interview data were subsequently analyzed using the same content analysis procedure. Relevant segments were coded, merged into categories, and synthesized into key themes. Inter-coder reliability was high (Cohen's kappa = .88), and any interpretive discrepancies were resolved through discussion.

In phase 2 (prototyping), feedback from validators was analyzed using deductive thematic grouping (Braun & Clarke, 2006). Trustworthiness was ensured through inter-validator triangulation and prototype revisions informed by the consistency of feedback. Quantitative data from the micro-evaluation were analyzed descriptively (mean [M], standard deviation [SD], and minimum-maximum scores), whereas qualitative data from student reflections and lecturer observations were examined through content analysis guided by four perceptual dimensions.

In phase 3 (evaluation), a repeated-measures ANOVA was conducted to examine the effects of time, skill dimensions, and their interaction, followed by paired t-tests for each dimension. Prior to analysis, the assumption of data normality was verified. Qualitative data were analyzed using content analysis focusing on the EDM skills.

RESULTS

Phase 1. Preliminary Research

Literature review

The literature review identified pedagogical approaches relevant to fostering EDM in genetics education. Recent studies have explored how morality can be conceptualized and developed in the science classroom through engagement with genetics-issues (Aivelo & Uitto, 2019; Lymbouridou, 2025), and how it can be cultivated through group discussions on genetics-related case studies (Bonney, 2015; Jeong et al., 2025) and supported through opportunities for personal value reflection (Lymbouridou, 2025).

Building on these insights, this study adopted a CST framework characterized by three key characteristics:

(1) integrating learning materials with real-life contexts, enabling students to connect genetic concepts with their ethical implications,

(2) developing EDM skills through the analysis of consequences arising from alternative decisions, and

(3) facilitating collaborative discussions to broaden perspectives and promote mutual respect (Sartania et al., 2022; Thistlethwaite et al., 2012).

Table 2. Categories of learning activities in genetics lesson plans (n = 18)

Category of activity	Lesson plans	
	n	%
Basic cognitive activities		
Lecture	11	61
Reading	9	50
Summarizing	7	39
Total	27	52
Higher-order cognitive activities		
Group discussion	14	78
Question generation	6	33
Brainstorming	3	17
Total	23	44
Ethics-oriented activities		
Case study	1	6
EDM	1	6
Total	2	4

To strengthen the moral dimension of this framework, the FCM was integrated through five components:

(1) moral sensitivity, fostering empathy and perspective-taking to understand diverse ethical viewpoints,

(2) moral reasoning, evaluating the advantages and disadvantages of alternative decisions,

(3) moral deliberation, guiding students to make choices aligned with their values,

(4) moral action, ensuring consistent application of ethical decisions while reinforcing value-based commitment, and

(5) moral reflection, cultivating moral responsibility through the evaluation and implementation of ethical decisions (Narvaez & Rest, 1995; Rest et al., 1999).

Finally, the integration of CST and FCM aimed to develop a genetics learning approach that promotes argumentative reasoning while reinforcing students' ethical values and sense of responsibility.

Genetics course learning plan

The GCLPs were analyzed to obtain a contextual understanding of how learning activities and resources supported the development of students' EDM. Of the 25 lecturers invited, 18 (response rate = 72%) provided their GCLPs, representing 18 universities across five major Indonesian islands: Java (9 universities, 50%), Sumatra (3 universities, 16.7%), and Kalimantan, Sulawesi, and Nusa Tenggara, each with 2 universities (11.1%). Results from the analysis identified 52 learning activities, grouped into three categories (see **Table 2**). Basic cognitive activities predominated (52%), followed by higher-order cognitive (44%) and ethics-oriented (4%) activities. The limited inclusion of ethics-related tasks indicates that moral considerations remain peripheral in GCLP.

Table 3. Distribution of learning resources by year of publication (n = 18)

Publication year range	Number of lesson plans	
	n	%
1980-1990	10	56
1991-2000	14	78
2001-2010	15	83
2011-2020	9	50

Note. Number of lesson plans shows how many lesson plans included at least one source in the specified publication range

Analysis of the 18 GCLPs revealed limited variation and currency of learning resources (see **Table 3**). Most textbooks had been published over a decade earlier, predominantly between 1991 and 2010 (78-83%), while only half of the references dated from after 2011. This pattern indicates reliance on outdated literature, leading to static content that does not adequately reflect recent advances in genetics.

Expert interviews

Expert interviews were conducted to identify students' support needs in EDM and to explore experts' views on essential pedagogical characteristics, with content analysis revealing three themes (see **Table 4**).

Theme 1. Integration of genetics and socio-ethical issues: The experts emphasized the importance of a comprehensive understanding of core genetics concepts as a foundation for critically evaluating social and ethical issues. They highlighted the need to connect instruction with real-world contexts, such as genetic diseases, pandemics, GMO, and the implications of genetic engineering. As one expert explained, "Without linking genetics learning to real problems, students perceive genetics as merely theoretical. Promoting genetics issues such as the GMO controversy is essential to raise their ethical awareness" (E1).

Theme 2. Pedagogical characteristics: Most experts spoke extensively about how effective genetics learning should be designed through pedagogical strategies that foster ethical reasoning, including case studies, collaborative discussions, the development of ethical reasoning skills, and the educator's role. They described that case studies were effective in linking theory with real-world contexts. As one expert described, "I think real genetics cases can provoke students to understand the application of genetics and practice decision-making in dilemmatic situations" (G1). Then, collaborative discussion was regarded as a method for critical thinking that broadens perspectives. As another expert explained, "In my view, exchanging viewpoints can broaden students' perspectives on ethical issues" (E3).

Table 4. Themes, categories, and codes derived from interviews

Themes	Categories	Codes
Integration of genetics and socio-ethical issues	Essential genetics concepts	DNA and inheritance (E3) Gene-environment interaction (G2, E3) Applied genetics knowledge in daily life (G2) Genetics–technology interconnection (G3)
	Awareness of societal and ethical issues in genetics	Genetic disease awareness (G3) Pandemics as genetics learning context (E2) Public concerns about GMOs (E1) Genetic technology dilemmas (G3) Impact of genetic engineering (E1, G2)
Pedagogical characteristics	Case study	Real-world case (G1) Ethical case analysis (E1)
	Collaborative discussion	Peer collaboration (E1) Facilitated reasoning (E3) Consensus dialogue (G2, E3)
	Ethical reasoning development	Integrative scientific-ethical thinking (E1, G2) Value-based justification (G2) Ethical reflection (E3)
	Role of educators	Role model (E2) Case facilitator (G1, E2) Evaluator of reasoning (E2, E3)
Resources	Instructional materials	Ethical decision module (G1, E1) Problem-solving scaffold (E1)
	Learning references	Textbooks as foundation (G1, G3) Up-to-date research articles (E2, G3)

Note. Reported codes denote transcribed data labels & the codes in parentheses indicate participant identifiers (e.g., G1 = genetics expert 1 & E2 = genetics education expert 2).

Furthermore, developing ethical reasoning was seen as essential for integrating scientific knowledge with moral values in constructing value-based justifications. As one expert shared, “In my opinion, students need to learn to connect scientific understanding with ethical considerations so that their justifications align with societal values” (G2). Finally, the educator’s role was considered crucial as a role model. As one expert reflected, “Educators should have ethical behavior while facilitating discussions and assessing students’ reasoning” (E2).

Theme 3. Resources: Most experts further stated that the availability of learning resources was essential to support students’ EDM. They highlighted an ethical decision module to guide students in linking genetics concepts with ethical dilemmas, using visual representations such as matrices or flowcharts. As one expert explained, “Students need a module that guides EDM, supported by visual representations such as matrices or flowcharts to clarify the reasoning process” (E1). Furthermore, textbooks were emphasized as providing a conceptual foundation, while current research articles were considered necessary to ensure learning remains aligned with recent developments. As another expert noted, “Textbooks provide the conceptual foundation, but students also need access to up-to-date articles on genetics and ethics to keep learning relevant” (G3).

Reflection on Preliminary Research Phase

Overall, the literature review, learning plan analysis, and expert interviews revealed that learning activities predominantly focused on cognitive aspects, with fewer activities targeting the development of reasoning and EDM skills in relation to contemporary issues. This limitation was further highlighted in expert interviews, which identified the need for an intervention that systematically integrates genetic issues, case studies, and ethical dimensions. These insights informed the formulation of initial design principles for an intervention framework aimed at supporting the development of students’ EDM skills. The design principles were elaborated further in the subsequent development phase.

Phase 2. Prototype Development

Intervention characteristics

Reflections from the preliminary research phase highlighted the need for an intervention that addresses not only what is taught but also how the content is delivered and how students are guided to reason critically when facing genetic ethical dilemmas. Based on these findings, the module prototype was designed around three key pedagogical principles:

1. **Integration of socio-ethical issues into genetics content:** The first principle was implemented by

Table 5. Summary of expert evaluations and implemented module design revisions

Validation aspect	Expert feedback and suggestions	Implemented revisions
Content	(+) Content aligned with learning objectives and current genetics-ethics issues. (–) Some issues overlapped.	Similar issues were merged, reducing nine topics to six key issues.
Pedagogy	(+) Learning activities structured sequentially with scaffolding. (–) The learning matrix remains complex.	The matrix was simplified for clarity.
Language & clarity	(+) Language appropriate for the undergraduate student level. (–) Diagrams lack sufficient annotations.	Diagrams were annotated.

Note. (+) represents strengths identified while (–) represents aspects that required revision provided by the validators

integrating socio-ethical issues into genetics content, linking core genetics concepts to contexts such as health, food security, and environmental sustainability. This integration positioned students within real-world dilemmas, fostering broader perspectives and enhancing critical conceptual understanding.

2. **CST:** The second principle was implemented through the use of CST as a pedagogical strategy to guide students in analyzing complex cases. CST implementation comprised five stages:
   (1) framing, identifying causal relationships to establish an analytical framework,
   (2) labeling, defining genetics terminology to facilitate discussion,
   (3) summarizing, selecting key facts to serve as the basis for argumentation,
   (4) synthesizing, formulating key questions, integrating information, and establishing decision criteria, and
   (5) concluding, determining decisions and formulating evidence-based recommendations (Puri, 2022).
3. **Development of ethical reasoning:** The third principle integrated the FCM as a framework to develop students' ethical reasoning through four subprocesses:
   (1) moral recognition, identifying ethical issues within genetics cases,
   (2) moral judgment, analyzing alternative decisions by considering their advantages and disadvantages,
   (3) moral motivation, selecting decisions aligned with personal values, and
   (4) moral character, cultivating responsibility through reflection and the formulation of strategies for implementing decisions (Narvaez & Rest, 1995; Rest et al., 1999).

Expert feedback

Experts indicated that the CST-FCM prototype contributed positively to students' EDM skills, with content, pedagogy, and language considered appropriate, though refinements to activity structure and diagram annotations were recommended (see **Table 5**).

Based on expert feedback, overlapping socio-ethical issues in genetics were consolidated to maintain conceptual coherence, reducing nine topics to six key issues (see **Table 6**).

Table 6. Comparison of socio-ethical issues in genetics before and after revision

No	Before revision	After revision
1	Prokaryotic gene expression: Should prokaryotic gene expression continue in antibiotic production despite the risk of resistance?	Prokaryotic gene expression & bacterial genetics: Should antibiotic development through bacterial gene expression continue to address medical needs despite the risk of accelerating global resistance?
2	Eukaryotic gene expression: Should mRNA-based vaccines be mandated despite long-term concerns?	Eukaryotic gene expression & immune system: Should COVID-19 vaccines that induce viral protein production be prioritized, even though immune responses vary and long-term effects remain uncertain?
3	Gene interactions: To what extent is gene therapy justifiable: Solely for disease treatment, or also for human enhancement?	Gene interactions: To what extent is gene therapy justifiable: solely for disease treatment, or also for human enhancement?
4	Immune system: Should antibody certification be required for travel, even though immune responses vary?	Merged with topic 2
5	Cell division: Should cancer gene therapy be prioritized, even if costly and accessible to few?	Cell division: Should cancer gene therapy be prioritized, even if costly and accessible to few?
6	Recombination: Should genetically engineered crops be used for food security despite safety concerns?	Recombination & genetic engineering: Should genetic engineering in plants and animals be pursued to improve quality of life despite ethical concerns?

Table 6 (Continued). Comparison of socio-ethical issues in genetics before and after revision

No	Before revision	After revision
7	Bacterial genetics: Should the use of antibiotics be restricted to prevent bacterial resistance?	Merged with topic 1
8	Population genetics: Should population genetics research continue for scientific advancement, even if it risks reinforcing discrimination?	Population genetics: Should population genetics research continue for scientific advancement, even if it risks reinforcing discrimination?
9	Genetic engineering: Should animal embryo genetic engineering be pursued to prevent genetic diseases?	Merged with topic 6

Table 7. Students' perceptions of CST–FCM instructional module (N = 33)

Item statement	M	SD	Min-max
Factor 1. Instructional usability			
1. I am able to follow the instructions of each stage without difficulty.	3.76	1.09	2-5
2. I can complete the activities in a logical and manageable sequence.	3.94	0.90	2-5
3. I find the time allocation for each activity appropriate.	4.09	0.80	3-5
4. I feel confident to complete each task as instructed.	4.55	0.67	3-5
5. The materials and resources provided are sufficient to support my learning.	4.06	1.27	2-5
Factor 2. Case analysis clarity			
6. I am able to recognize the context of the ethical dilemma.	4.15	0.76	3-5
7. I can identify key terms and ethical concepts in the case.	3.82	1.07	2-5
8. I am able to distinguish essential facts from less relevant information.	4.21	0.89	2-5
9. I can apply ethical principles to consider alternative decisions.	4.15	0.80	3-5
10. I feel motivated to make decisions consistent with ethical values.	3.94	1.14	2-5
Factor 3. Ethical relevance			
11. I am able to recognize ethical dilemmas that are relevant to the practice of genetics.	4.09	0.98	2-5
12. I can evaluate and compare possible decisions based on ethical principles.	4.15	0.62	3-5
13. This learning experience strengthens my motivation to act in line with ethical values.	3.88	0.99	2-5
14. I feel more prepared to act consistently with my ethical decisions even in challenging situations.	4.45	0.51	4-5
15. The ethical issues in the case reflect realistic challenges in genetics contexts.	4.09	0.88	3-5
Factor 4. Collaborative engagement			
16. I actively participate in group discussions.	4.24	0.83	3-5
17. I appreciate the different perspectives shared by my peers.	3.91	0.88	3-5
18. I engage in deeper thinking through interaction with my group.	4.45	0.51	4-5
19. I contribute my own ideas during the learning activities.	4.15	0.87	3-5
20. I enjoy collaborating with my peers during the case study.	4.39	0.66	3-5

This consolidation considered similarities in biological concepts and ethical contexts. For instance, antibiotic production (topic 1) was merged with usage limitations (topic 7) to link molecular mechanisms with bacterial populations. COVID-19 topics (topic 2 and topic 4) were merged because eukaryotic gene expression via mRNA translation produces antigens that trigger immune responses. Likewise, plant (topic 6) and animal (topic 9) genetic engineering were merged, as both involve the same DNA recombination principles.

Micro evaluation

Students' perceptions of the CST-FCM instructional module ranged from agree to strongly agree, with M scores of 3.76 (SD = 1.09) to 4.55 (SD = 0.67) (see **Table 7**). These results indicate that the module is suitable for implementation and practically applicable.

Students' perceptions of the instructional usability dimension indicated that the module's instructions were clear and logically structured, although some concerns were raised regarding the division of tasks (M = 3.76-4.55). As one student reflected, "The learning process was easy to follow, and discussions became more focused, though some task instructions were unclear" (S2-17). This perspective was consistent with a lecturer's note: "The instructions were clear, yet the distinction between individual and group tasks needs to be clarified to ensure a more balanced learning responsibility" (L2-05).

Regarding the case analysis clarity dimension, students perceived the genetics cases in the module as relevant and helpful in understanding complex concepts (M = 3.82-4.21). As one student stated, "The cases in the module helped me to understand difficult genetics concepts while learning how to analyze issues" (S1-05). Similarly, a lecturer commented, "The genetics-ethics cases stimulated students' curiosity, and the guiding questions in the module helped them reflect on ethical decision-making" (L1-12).

In the ethical relevance dimension, students demonstrated an increased awareness of ethical implications within the context of genetics (M = 3.88-

Table 8. Result of paired t-test on EDM skills

Dimensions	Pre-test		Post-test		p	Cohen's d
	M	SD	M	SD		
Moral sensitivity	2.39	0.38	2.86	0.40	< .001	0.83
Moral judgment	2.20	0.58	2.68	0.22	< .001	0.78
Moral motivation	2.29	0.54	2.66	0.23	< .001	0.64
Moral character	1.79	0.57	2.27	0.31	< .001	0.77
Total	2.17	0.30	2.62	0.17	< .001	1.32

4.45). As one student affirmed, "I became more aware that decisions in genetics have ethical consequences for myself and other fields" (S2-15). This aligns with a lecturer's observation: "Students practiced considering the consequences of each solution and relating them to their personal values" (L2-09).

Finally, the collaborative engagement dimension received high scores (M = 3.9-4.45), suggesting that the CST-FCM learning design effectively fostered active and cooperative discussions. Students felt motivated to participate and to appreciate differing viewpoints. As one student expressed, "Group discussions made me more confident to share my opinions and to respect different perspectives" (S1-09). Likewise, a lecturer observed, "Group discussions were lively, with certain 'playmaker' roles emerging to maintain the dynamics within heterogeneous groups" (L1-16).

Phase 3. Evaluation

Field evaluation

The field evaluation was conducted to assess the effectiveness of the instructional design in an authentic university context involving two classes. A repeated-measures ANOVA revealed a significant effect of time, $F(1, 67) = 72.80$, $p < .001$, partial $\eta^2 = .521$, indicating that post-test scores were overall higher than pre-test scores with a large effect size. In addition, a significant effect of dimension was found, $F(3, 65) = 75.60$, $p < .001$, partial $\eta^2 = .530$, suggesting that the four EDM skill dimensions differed significantly in their M scores, also with a large effect size. Then, there was an interaction between time and dimension, although with a small effect size, $F(3, 65) = 4.77$, $p = .003$, partial $\eta^2 = .067$. These findings revealed that the intervention had a significantly different impact on enhancing EDM skills, although the interaction effect was relatively limited. In addition, paired-sample t-tests showed significant increases across all EDM dimensions after the intervention ($p < .001$), with varying effect sizes (see **Table 8**).

The moral sensitivity dimension showed a large effect on students' ability to recognize ethical issues (d = 0.83). As one student affirmed, "The learning helped us identify genetic issues in everyday life, making genetics feel more relevant and engaging" (SA-05), which aligns with the lecturer's note that "Students became more aware of real-life issues and linked them to genetic content" (LA-04).

Moving to the moral judgment dimension, the results indicated a moderate-to-large effect on students' ability to evaluate alternative decisions (d = 0.78). As one student reflected, "The case discussions helped us understand complex genetic concepts and consider options more logically" (SB-11). Likewise, the lecturer observed that "The discussions prompted more structured reasoning" (LB-07).

Consistent with the improvement in analytical ability, the moral character dimension also showed a moderate-to-large effect on students' consistency in ethical attitudes (d = 0.77). As one student reflected, "I learned to resolve cases in a more structured and reflective way" (SB-20), which aligns with the lecturer's note that "Students became more consistent in completing the ethical decision-making matrix" (LB-16).

Meanwhile, the moral motivation dimension demonstrated a moderate effect on students' moral commitment (d = 0.64). As one student wrote, "I became aware that ethical choices are closely connected to personal and environmental values" (SA-17). Similarly, the lecturer observed that "Students' reflection on personal values became more evident, although it still requires more time for deeper engagement" (LA-13).

DISCUSSION

This study is the first to design and evaluate a genetics learning intervention that integrates CST with the FCM to enhance students' EDM skills. Unlike conventional genetics instruction (Johnston, 2023), this intervention explicitly connects ethical issues in genetics with authentic, real-world cases. The findings contribute to the literature by identifying key design principles that support EDM development and introducing a new framework that integrates CST and FCM for case-based science learning.

Design Principle 1. Integrating Socio-Ethical Issues into Genetics

The findings indicate that integrating socio-ethical issues into genetics instruction enhances conceptual understanding while improving students' engagement and EDM skills. This aligns with STEM ethics literature emphasizing the value of linking ethical dilemmas to science learning to support students' moral development (Park & Cho, 2022). As noted by Jeong et al. (2025) and Alexander et al. (2024), case-based discussions of ethical issues in genetics stimulate curiosity, deepen moral understanding, and promote active class participation. However, the effectiveness of EDM development also depends on educators' competence in facilitating ethical issues. In line with Aivelo and Uitto (2019), science teachers often face challenges in addressing controversial topics in the classroom. Therefore, curriculum support and targeted professional development are essential to ensure the sustainable integration of ethical issues in genetics teaching.

Design Principle 2. Case Studies as a Learning Strategy

This study highlights the critical role of case studies in fostering interactive and meaningful learning. As a learning approach rooted in Vygotsky's social constructivist framework, case studies enhance students' conceptual understanding and reasoning skills (Bonney, 2015; Puig et al., 2017; Puri, 2022). In line with Goudsouzian and Lo (2023), who reported increased student understanding and interest in the subject matter. Similarly, Alexander et al. (2024) documented that ethical discussions in metagenomics research modules strengthened students' academic engagement.

This study highlights a distinctive feature of case study implementation: the use of terminology-labelling strategies in genetics to support students' understanding of complex concepts. McEwen et al. (2025) similarly observed that educators struggle to integrate emerging topics such as epigenetics into curricula still dominated by Mendelian approaches, partly due to the complexity of the terminology involved. This aligns with Haskel-Ittah and Yarden (2021) argument that terminology complexity remains a major barrier in modern genetics education. Accordingly, incorporating terminology-labelling strategies into case discussions may promote deeper internalization and application of genetic concepts.

Design Principle 3. The FCM as a Framework for Ethical Reasoning

The findings revealed a consistent moral profile across participants, in which moral sensitivity demonstrated the strongest effect, moral judgment and moral character showed moderate-to-large effects, and moral motivation exhibited the weakest, moderate effect. Although no control group was included, this pattern suggests changes in students' moral development over time relevant to ethical genetics education. These findings align with FCM literature, which emphasizes that moral motivation is the most difficult component to enhance through ethics education interventions (Narvaez & Rest, 1995; Rest et al., 1999). In line with STEM literature, while students may demonstrate adequate moral sensitivity and judgement, motivation to act often remains low (Bayanova et al., 2023). Furthermore, this study highlights that integrating FCM components into instruction supports students in reflecting on personal values and making more considered ethical decisions. This is in line with Aalberts et al. (2012) and Lymbouridou (2025), who emphasize the importance of value reflection in science education for cultivating ethical and responsible academic citizens. Accordingly, the CST-FCM integration was found to strengthen students' ethical reasoning and awareness when addressing scientific moral issues.

The researchers acknowledge several limitations in this study. First, based on data from three universities in a single city, the findings may have limited generalizability to other universities in Indonesia or internationally. Second, although the intervention improved EDM skills, the interaction between time and dimensions showed only a small effect, likely due to the relatively short intervention period and its exclusive focus on biology. Future studies should consider extending the intervention duration and applying it to other disciplines, such as chemistry and physics. Finally, to strengthen the validity of the findings, it is recommended to include a control group, conduct randomized trials, or perform cross-cultural validations.

CONCLUSION

This study developed and implemented a CST-FCM genetics learning intervention to support students' EDM skills. Initial needs analysis revealed limited opportunities for ethical reasoning in genetics instruction, informing the design of an intervention incorporating contemporary genetics issues, case studies, and ethical dimensions. Micro-level evaluation confirmed its feasibility, relevance, and students' positive perceptions of case clarity, instructional usability, and ethical significance. Field evaluation demonstrated improvements in EDM skills, with moral sensitivity most prominent, followed by moral judgement, moral character, and moral motivation. Qualitative findings reinforced these results: students reported that the intervention helped them recognize real ethical issues, understand complex concepts, weigh logical options, and apply personal value reflection, while instructors observed enhanced ethical awareness, decision consistency, and the quality of students' argumentation.

Implications for Practice

The CST-FCM-based intervention is feasible and enhances students' engagement, understanding, and critical reflection. Educators can adapt the intervention to teach genetics ethics effectively, while curricula may incorporate ethical dilemmas to further strengthen EDM.

Implications for Research

Future studies should employ quasi-experimental designs or control groups to strengthen causal claims. The intervention could also be tested in other science disciplines or educational levels, while exploring how students' moral profiles, characterized by high moral sensitivity and low moral motivation, are influenced by culture, curriculum, and teaching methods within each FCM component.

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AI statement: The authors stated that no generative AI or AI-based tools were used in any part of the study, including data analysis, writing, or editing.

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