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Developing Moral Agency through Coupled Ethical-Epistemic Analysis in Undergraduate Research [Research Paper, Engineering Ethics]

Dr. Caitlin A Grady, The George Washington University

Caitlin A. Grady is an Associate Professor in the Department of Engineering Management and Systems Engineering at George Washington University. She earned her Ph.D. in Civil and Environmental Engineering and her M.S. in Agricultural and Biological Engineering from Purdue University. She earned her B.A. in Humanities, Science, and the Environment from Virginia Tech. Her research expertise lies in ethical-epistemic inquiry, coupled systems modeling, science-policy interface, and decision-making.

Sachi Nandurkar, The George Washington University

Sachi Nandurkar is a Senior Research Analyst in the Department of Engineering Management and Systems Engineering at The George Washington University. She earned her M.S. in Engineering Management from George Washington University and her B.Tech. in Electronics and Communication Engineering from the Indian Institute of Information Technology, Pune. Her research focuses on systems modeling and qualitative methods, with applications in sustainability, technology, and decision-making.

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Abstract

Engineering programs are increasingly expected to prepare graduates to act as moral agents when working on complex, uncertain, and socially consequential problems. This paper reports a proof-of-concept evaluation of an undergraduate research experience that integrates coupled ethical-epistemic analysis and reflexive principlism to support moral agency development in engineering-relevant research contexts. The REU sequence spanned two semesters: a trial semester (n = 5) used to pilot program activities and assessment procedures, followed by a first implementation semester (n = 5; n = 4 completers) that is the focus of this paper. During the implementation semester, students conducted qualitative thematic analyses across climate-related projects, including natural hazards research with AI, electricity and climate change decision-making, and food security and climate change. Moral agency was assessed using pre and post case study exercises scored with a reflexive principlism rubric that evaluated six dimensions of ethical reasoning: principle identification, dilemma specification, perspective-taking, coherence and justification, reflectivity, and ethical-epistemic reasoning.

Results are descriptive due to the small sample and indicate increases in total rubric scores for all four completers, with the largest gains occurring in the ethical-epistemic dimension. Post-program URSSA responses (n = 4) further suggest perceived gains in time management, interpreting research literature, and analyzing data patterns, alongside more modest gains in communication and documentation practices. These preliminary findings support the feasibility of embedding coupled ethical-epistemic analysis within undergraduate research and suggest that the framework may help students more explicitly connect ethical reasoning with uncertainty, evidence, and ways of knowing, motivating future work with larger cohorts and comparative designs.

This work contributes to ongoing efforts to define empirically grounded methods for integrating ethics into engineering education. By connecting epistemic and ethical reasoning within authentic research contexts, this study provides preliminary evidence that coupled ethical-epistemic analysis supports the cultivation of moral agency, a central objective in educating engineers equipped to confront complex socio-technical challenges. Next steps include expanding this assessment process to groups of REU students undertaking an international applied research experience in Sweden.

1. Introduction

The development of moral agency in undergraduate engineering education is meant to represent an evolution in the preparation of professional engineers, transitioning from a narrow focus on technical competency to a comprehensive model of professional responsibility. As the pace of scientific and technological change accelerates, the ethical implications of engineering decisions have become increasingly complex, necessitating a curriculum that equips students to handle dilemmas involving public safety, environmental sustainability, and social justice [1], [2]. The American Society for Engineering Education (ASEE) and the Accreditation Board for

Engineering and Technology (ABET) have explicitly identified the understanding of professional and ethical responsibility as a core competency for engineering graduates [2], [3]. Central to this educational shift is the concept of the engineer as a "moral agent". In this paper, moral agency refers to a developing the capacity to notice moral features of engineering situations, deliberate using moral reasons, choose and act with appropriate control, and be answerable for those choices within relevant communities [4], [5]. Research Experiences for Undergraduates (REUs) have played a role as pedagogical sites for this development, offering a situated learning environment where students engage with the ethical-epistemic dimensions of real-world research [4, 5].

At the same time, research suggests challenges remain regarding training engineering undergraduate students to develop moral agency. For example, scholars have found that some first-year engineering students exhibit lower moral disengagement scores compared to non-engineering students using the same instrument [6]. Longitudinal surveys have also suggested that engineering students are less interested in public welfare and the societal impacts of their work at the end of their undergraduate career compared to the beginning [7], [8]. Previous research has shown that many students fail to identify and contextualize real ethical challenges in engineering [3], [9], [10], [11]. To combat this challenge, several studies have investigated potential pedagogical improvements to enhance ethical reasoning and the development of moral agency [9], [12], [13], [14]. Despite this progress, overall dissatisfaction remains with regard to the status of ethics education for engineering students [11]. Empirical and conceptual scholarship has highlighted numerous individual challenges with pedagogical implementation such as instructor’s abilities, assessment methods, and classroom activities [11], [15].

One reason these challenges persist is that the path toward fostering moral agency is challenged by deeply ingrained cultural and institutional barriers within the engineering education system. Research consistently identifies a "culture of disengagement" that characterizes many programs, where the focus on rigorous technical problem-solving systematically marginalizes social and ethical considerations [6], [7], [16]. This phenomenon is driven by an ideological framework known as technical-social dualism, which treats the social dimensions of engineering as peripheral to the "real" technical work [7], [16]. Consistent with this, empirical studies demonstrate that engineering students' commitment to public welfare often declines over the course of their four-year education [7]. This decline is not necessarily due to an inherent lack of ethics in the student population but is rather a result of the cultural emphases of their programs [7]. As students progress through highly structured curricula, they are socialized into a professional identity that values value neutrality and technical efficiency above all else [6], [16]. This socialization creates a binary cultural frame where "real engineering" is synonymous with mathematical and physical modeling, while ethics is viewed as a "soft" or "non-technical" subject that does not belong in the engineering classroom [6], [16]. The institutional structure of engineering programs further reinforces this disengagement. Disciplinary elitism and the physical or curricular distance between engineering and the liberal arts often prevent students

from exploring the ethical dimensions of their content knowledge [16]. For example, when students work on technologies for military purposes, they often focus solely on immediate technical usability or improved efficiency, failing to acknowledge the broader social and ethical implications of their innovations [16].

Relatedly, another challenge in developing moral agency is the phenomenon of moral disengagement, a theoretical framework developed to explain how individuals can behave unethically without experiencing self-sanction [6], [17]. In the engineering context, students may utilize various mechanisms to disengage from their ethical principles. While first-year engineering students may initially exhibit lower levels of moral disengagement compared to non-engineering peers, their propensity to disengage often remains stable or increases as they adapt to professional norms [6]. A particularly concerning finding is the existence of "unreflective disengagement," where students fail to reflect on the moral dimensions of a situation because they deem non-technical factors to be outside the scope of the profession [6]. This is often tied to the "binary conceptualization" of engineering courses, where technical courses are prioritized over those discussing ethics or social responsibility [16].

To overcome these challenges, faculty and researchers have developed diverse pedagogical methods that leverage the unique environment of research experiences. Unlike traditional classroom settings, research experiences allow for a hands-on approach based on situated learning and apprenticeship theories, where students learn the tools and skills of their discipline through direct participation [18]. Within this broader effort, one pedagogical framework identified in the literature is the SIRA (Scaffolded, Interactive, and Reflective Analysis) framework which is designed to enhance the ethical reasoning of engineering students, by moving beyond simple case-based analysis by integrating a theory-based approach [19], [20]. Within the SIRA framework, scaffolding is implemented through structured assignments, clear directions on materials, and instructor feedback to ground students in the facts and sociotechnical context of an ethical dilemma [19]. Reflection is developed through writing activities that require formalized thinking and application of ethical principles, with the goal of strengthening higher-order ethical reasoning and increasing students' awareness of their own values and assumptions [19]. The reflectivity component of SIRA has been shown to be a strong predictor of positive change in a student's ethical reasoning scores [19]. Building on this, reflexive principlism teaches students to balance four key ethical principles, nonmaleficence, beneficence, justice, and autonomy. By progressing through stages that include establishing knowledge, perspective-taking, contrast analysis, inducing conflict, and meta-reflection, students learn to navigate the complexity of ethical behavior in real-world scenarios [19], [21], [22].

Previous research has suggested that coupled ethical-epistemic inquiry advances knowledge around climate change [23], [24], [25], public health [26], environmental science [27], and research ethics [28], but it has yet to be analyzed from a perspective of its influence on undergraduate student education. Coupled ethical-epistemic analysis, as envisioned by philosopher Tuana [29], [30], is a formal methodological approach for examining how ethical

questions, such as whose interests are prioritized or what harms are acceptable, are intertwined with epistemic questions, such as what counts as evidence, whose knowledge is trusted, and how uncertainty is handled. This approach is motivated by the assertion that difficult and wicked problems cannot be separated from the evidentiary resources, normative constructs, or human values used to respond to them. Furthermore, this pedagogy is predicated on moving beyond traditional ethics training which often adopts some form of procedural ethics, that which refers to bad behavior in research or the workplace, and incorporates extrinsic ethics and intrinsic ethical thought [29]. The use of this method can highlight that the research enterprise is not a value-neutral activity but a sociotechnical one where discovery carries the risk of unanticipated outcomes and ambiguous results [29], [30], [31], [32]. To understand how training focused on coupled ethical-epistemic analysis on topics of engineering relevance influences the development of moral agency, we tested the efficacy of coupled ethical-epistemic analysis in the context of an undergraduate REU.

As engineering increasingly engages international and socially complex problems, cultivating moral agency remains a core priority. This study integrates coupled ethical-epistemic analysis and reflexive practice into an undergraduate research experience and examines how this approach may shape students' ethical reasoning in the context of engineering decision-making. Accordingly, we ask: Does undergraduate research using coupled ethical-epistemic analysis influence the development of moral agency in undergraduate engineering students?

2. Methods

This paper reports results from the second semester of an REU sequence structured around coupled ethical-epistemic analysis. The first semester served as a trial phase with five undergraduate researchers and was used to pilot the overall structure and assessment approach while students conducted qualitative thematic analysis of climate adaptation plans for megacities. The second semester, also comprising five undergraduate researchers, is treated as the first implementation experiment and is the focus of the methods described below.

During the second semester, five undergraduate students were hired as research assistants and worked across three research projects. Each project was led by a graduate student (PhD or master's) who provided technical supervision and weekly mentoring. Students were assigned to projects based on background, prior experience, and interests. Two students were assigned to a project researching AI use in natural hazards research, two students were assigned to a project examining how balancing authorities use climate projections in electricity planning decision-making, and one student was assigned to a project examining local food systems. All students participated in shared training activities and research group meetings in addition to project-specific work. One undergraduate discontinued mid-semester due to time-management constraints; four students completed the full pre and post assessment set used for analysis. The students were expected to contribute 10 hours per week to the REU though specific hours logged

each week were permitted to flux depending on the individual's personal semester demands in courses and extracurricular activities.

Students met weekly with their assigned project leads to review progress, receive tasks, and plan next steps. In addition, the full research group met every two to three weeks for cross-project discussion and conference presentation practice. Project coordination, task assignment, and progress tracking were managed using Asana, with work organized at project and task levels and weekly deliverables tracked through assigned due dates and collaborators.

2.1 Training intervention

Training was structured around coupled ethical-epistemic analysis and reflective practice and was integrated throughout project work, training sessions, and evaluation activities. The intent was to embed ethical reasoning into how students approached uncertainty, evidence, stakeholder perspectives, and decision-making rather than treating ethics as a separate skill. The formalized training focused on ethics, reflective practice, and reflexive principles, with explicit connections to students' ongoing research work was delivered by the Laboratory PI.

There were also several trainings on REU related professional development skills taught by the Laboratory Manager. For example, training sessions included onboarding to Asana and strategies for managing multiple projects. Students also received training in AI prompt engineering and ethical and appropriate use of AI in research, including context-setting, iterative refinement, and lab-specific AI guidelines. Additional sessions addressed file and document management practices, including standardized file naming conventions, folder structures, version control practices, and protection of raw data to support collaboration and reproducibility. Students were trained in searching for, reading, and managing academic literature using platforms such as Google Scholar, Web of Science, and Scopus and were introduced to reference management practices using Zotero. A visualization-focused session trained students to use Lucidchart for flowcharts, process diagrams, and thematic representations of literature reviews and workflows.

2.2 Measures

To track ethical reasoning over the semester, students completed a pre and post case study assessment. The pre case study was administered at the start of the semester prior to delivery of the ethics-focused training. The pre case focused on the Jakarta subsidence and flooding crisis and provided background on drivers, governance arrangements, and proposed response options such as large-scale coastal defenses, managed retreat, and nature-based approaches. Students responded to six prompts designed to elicit ethical and reflective reasoning. The prompts required students to analyze how risks and benefits are distributed over time, map stakeholder interests and power dynamics, propose and defend a preferred course of action, identify key uncertainties and competing ways of knowing, outline how they would act under uncertainty, and reflect on how their own background and values shaped their analysis. At the end of the

semester, students completed a second case study using the same structure and rubric to assess change over time. The post case focused on deep-sea mining for critical minerals needed for the green energy transition and included background on mineral demand, relevant governance frameworks, the role of the International Seabed Authority, and associated political and environmental debates. Students were asked to adopt the perspective of members of the International Seabed Authority council and reason through decision-making under uncertainty using the same six prompts.

2.2.1 Reflexive principlism rubric

Case study responses were evaluated using a rubric developed to assess reflective principlism and coupled ethical-epistemic analysis. The rubric evaluates case-based learning across six categories: ethical principle identification, specification of the ethical dilemma, perspective-taking, coherence and justification, reflectivity, and coupled ethical-epistemic analysis. Each category is scored on a 0 to 3 scale, where higher scores indicate clearer ethical identification, stronger contextual specification, deeper perspective-taking, better-justified reasoning, stronger reflexivity, and more explicit coupled ethical-epistemic thinking. We use this rubric as a proxy measure for moral agency because it captures several observable components of moral agency in written reasoning, including recognizing ethical dimensions, considering stakeholder perspectives, justifying decisions, and reflecting on uncertainty and values. However, it is a limited stand-in because it assesses students' case-based written reasoning rather than their actual choices, actions, or accountability in real engineering practice. Grades were compiled in a tracking sheet to compare pre and post performance at both the total score level and the category level.

Table 1: Reflexive Principlism Rubric used to grade case studies

Score	0	1	2	3
Ethical Principle Identification	No evidence of identifying relevant ethical principles	Mentions an ethical issue but does not name or describe relevant principles	Identifies one or more relevant principles but incompletely or vaguely	Clearly identifies all relevant principles (e.g., autonomy, justice, beneficence, non-maleficence) with accurate understanding
Specification (Recognizing the Ethical Dilemma)	No attempt to apply principles to the case context	Mentions principles but does not tailor them to the case	Attempts to apply principles to the context but with gaps or generalities	Fully specifies each principle's meaning in the specific context of the case
Perspective-Taking (Assessing Stakeholder Viewpoints)	No evidence of considering multiple viewpoints	Acknowledges only one perspective without contrast	Considers at least two perspectives but without depth or balance	Thoughtfully considers multiple stakeholder perspectives, including conflicting interests and power dynamics
Coherence & Justification	Provides a conclusion without reasoning	Offers minimal reasoning with little connection to principles	Reasoning is mostly connected to principles but lacks depth or clarity	Provides clear, logical, and well-supported rationale that explicitly balances principles

Reflectivity	No reflection on decision-making process	Minimal acknowledgment of limitations or broader implications	Some reflection on process, limitations, or implications	Deep reflection on reasoning process, limitations, uncertainties, and broader ethical implications
Coupled Ethical-Epistemic Analysis	No recognition of knowledge-ethics connections	Mentions knowledge gaps but doesn't connect to ethical issues	Makes some connections between knowledge uncertainties and ethical concerns	Explicitly analyzes how epistemic issues (knowledge gaps, uncertainties, different ways of knowing) interact with and shape ethical considerations

2.2.2 Undergraduate Research Student Self-Assessment

At the end of the second semester, the four students who completed the case studies also completed a slightly modified Undergraduate Research Student Self-Assessment (URSSA) survey [33] online. URSSA captures self-reported learning and experience during undergraduate research and includes sections on gains in thinking and working like a scientist, personal gains related to research, gains in skills, engagement and identity in research, and the mentoring and research environment [33]. The modifications we made to this survey included removing questions that were not relevant such as questions relating to increasing knowledge of bench laboratory techniques given none of our three research projects included bench laboratory work. We retained 39 total questions from the URSSA survey and did not modify the phrasing of those retained questions. Program activities were also assessed, including items aligned with structured activities such as training in library and database search methods and ethics seminars.

2.2.3 Data processing and analysis

Rubric-based case study scores were summarized at the category level and as a total score. Change over the semester was evaluated by comparing pre and post scores within student and by examining total change normalized by the maximum possible rubric score. URSSA responses were summarized by section. Likert-style responses were converted to a 0 to 4 numeric scale within each section and summarized using mean scores across respondents.

3. Results

Four students completed the second-semester REU and both the pre and post case study assessments. All four students identified as female. The cohort included one sophomore (Student 4), two juniors (Students 1 and 3), and one senior (Student 2). Participants represented four majors: political science (Student 1), mechanical engineering (Student 2), environmental studies (Student 3), and computer science engineering (Student 4). Because the institute has a small engineering program, the applicant pool did not yield an exclusively engineering-major cohort; the final group included two engineering majors, an environmental studies major with strong overlap with environmental engineering, and a political science major with a sustainability

minor, reflecting a National Science Foundation interdisciplinary approach to climate and environment research.

3.1 Changes in rubric scores from pre to post

Because this implementation included only four completers, we report results descriptively and are not intended to imply statistical significance. We found that the pre assessment total scores were in the mid-teens (approximately 13.6 to 14.6 out of 18), which corresponded to "Good" performance for all four students (Figure 1). Following the semester, our results show that post assessment totals increased to approximately 17.4 to 17.8, with all four students classified as "Excellent" (Figure 1). All four students showed increases in total score. The size of improvement ranged from about +1.8 to +2.8 points, which corresponds to roughly 10% to 15% improvement by percentage. While each student improved overall, the size and distribution of gains differed across rubric categories. Unsurprisingly, across the cohort, the largest and most consistent gains occurred in the ethical-epistemic category. Ethical-epistemic scores increased by roughly +0.9 to +1.4 points across students. In contrast, changes in perspective were smaller. One student showed no change in perspective, and the others increased by roughly +0.3 to +0.4 points. Other categories showed moderate gains overall, including specification, coherence, reflectivity, and principle, with most changes falling in the range of about +0.3 to +0.8 points depending on the student and category.

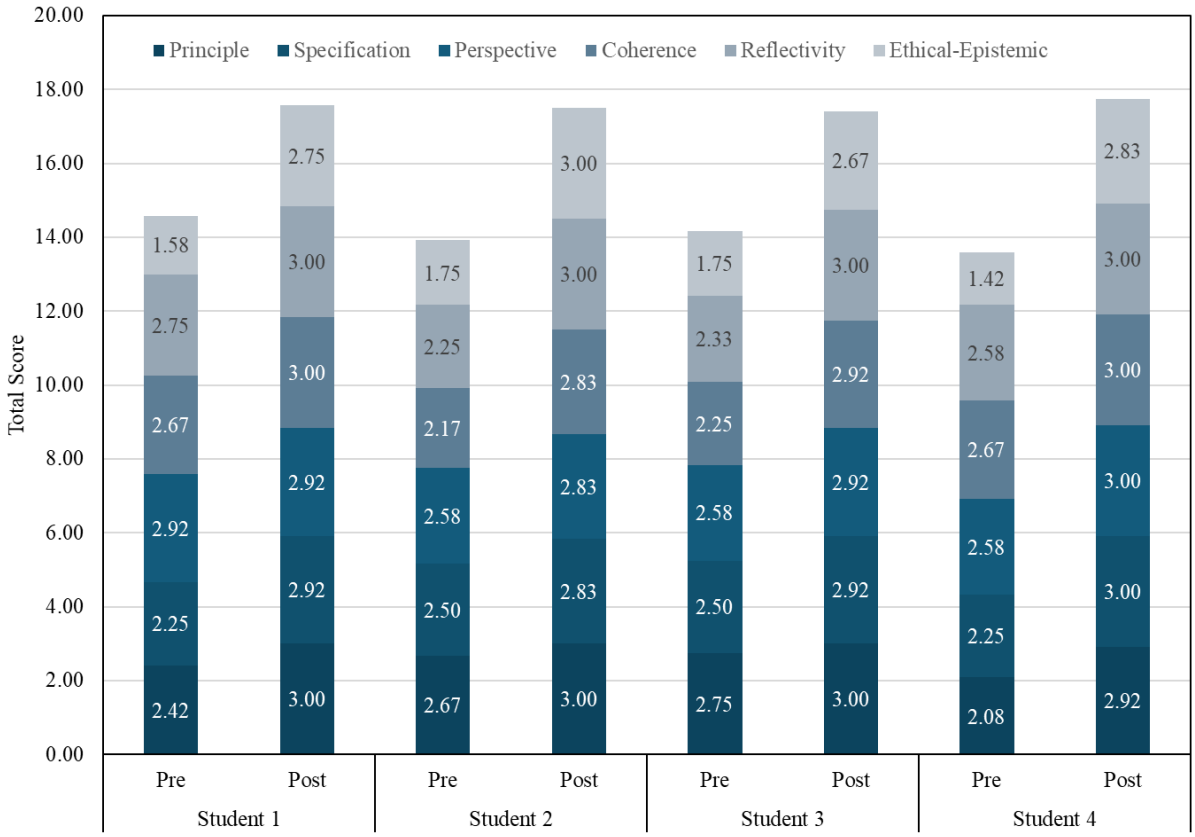

Figure 1: Case Study Rubric Scores for Four Students

Students' trajectories reflected different starting points and different areas of growth. Student 4 showed the largest overall increase (approximately +2.8 points) and improved across all rubric categories, including comparatively large gains in principle, specification, and ethical-epistemic reasoning. Student 1 showed the smallest overall increase (approximately +1.8 points), with most gains concentrated in specification and ethical-epistemic reasoning, and little change in perspective. Students 2 and 3 showed similar total increases (approximately +2.3 points each) but differed in how improvement was distributed across categories. Student 2's gains were most pronounced in ethical-epistemic reasoning and reflectivity, while Student 3 showed more evenly distributed gains across specification, coherence, reflectivity, and ethical-epistemic reasoning.

Overall, the pattern of change suggests that students entered the REU with relatively strong performance in perspective-taking and coherence compared to ethical-epistemic reasoning. By the end of the semester, students' scores approached the top of the rubric scale across most categories, particularly in reflectivity and coherence.

3.2 USSRA Scores

We summarize URSSA responses descriptively for the four students who completed the survey, and item-level differences should be interpreted cautiously given the small sample size. Among items with responses from all four students, the strongest reported gains were in managing time (average 4.0), analyzing data for patterns (average 3.8), understanding journal articles (average 3.8), and developing patience with the slow pace of research (average 3.8). Students also reported solid gains in conducting database or internet searches (average 3.5), understanding what everyday research work is like (average 3.5), and confidence in their ability to contribute to science (average 3.3), along with moderate gains in comfort working collaboratively (average 3.3), engaging in real-world research (average 3.3), and confidence in doing well in future science courses (average 3.0). The mentorship relationship was rated as a clear strength, with students reporting the highest possible rating for their working relationship with their research mentor (average 4.0).

At the same time, several items indicated areas for improvement, including keeping a detailed lab notebook (average 1.3), explaining their project to people outside their field (average 2.3), and formulating a research question that could be answered with data (average 2.0). Students also reported comparatively lower levels of working extra hours due to excitement about the research (average 2.3) and only moderate ratings for the amount of time spent doing meaningful research and the amount of time spent with their research mentor (both averages 2.8). Finally, students varied in how the experience shaped disciplinary commitment, with lower agreement that research confirmed their interest in their field of study (average 1.8) but higher agreement that research clarified which field of study they want to pursue (average 3.3). This pattern may reflect the cohort's varied disciplinary backgrounds, such that the REU did not

necessarily reinforce commitment to a current major but instead helped students clarify how their interests might align with a future field or pathway.

3.3 Discussion

These findings should be interpreted as a proof of concept for integrating coupled ethical-epistemic analysis into an undergraduate research setting and for using a case-based rubric as a feasible assessment mechanism within an REU context. The observed increases from pre to post are consistent with the intended direction of the intervention, particularly in the ethical-epistemic category, which aligns most directly with the program's emphasis on linking evidentiary uncertainty, ways of knowing, and normative decision-making. At the same time, the post scores were near the top of the scale for most students, which limits the ability to distinguish degrees of improvement at the high end and suggests potential ceiling effects in this small implementation.

Several limitations constrain interpretation. First, the sample size is small (four completers), which precludes statistical claims and limits generalizability. Second, participants were recruited into a climate and environment focused research program. Students who applied to and accepted a position in this REU may have been predisposed toward reflection on societal impacts and public welfare, which could elevate pre assessment scores and contribute to observed improvements independent of the intervention. Third, the assessment relied on written responses to case studies. Improvements may reflect increased familiarity with the response format, expectations, or the rubric-aligned prompts rather than a durable shift in moral agency.

Implementation factors also matter. Students received sustained mentoring and participated in structured research meetings and professional development activities across the semester. Growth in rubric scores may therefore reflect broader research socialization, increased confidence in writing, or greater comfort articulating decisions under uncertainty, rather than the specific influence of coupled ethical-epistemic framing. Finally, because the analysis emphasizes the second-semester implementation, results may also reflect refinements to program structure that improved consistency, clarity of expectations, or participant support relative to the trial semester.

Within these constraints, the results support continued development of coupled ethical-epistemic analysis as a pedagogical framework that can be implemented in undergraduate research. Future work should include larger cohorts and comparison conditions, such as students in research experiences without explicit coupled ethical-epistemic training or students completing alternative ethics instruction formats. Additional measures could help strengthen interpretation, including delayed post assessments to examine persistence, interviews to capture how students describe ethical responsibility in their research work, and artifact-based analysis of research products to identify how ethical reasoning is enacted during inquiry rather than only in case study responses.

In addition to the assessment-based outcomes reported for the implementation semester, the pilot semester produced several professional development outcomes that were meaningful for participants. Students in the pilot cohort contributed to conference-focused research products, including coauthoring a manuscript that is currently under review and presenting results at an academic conference. These outputs are consistent with the intent of REU programs to provide authentic research experiences that extend beyond skill acquisition to include participation in disciplinary communication practices, such as scholarly writing and dissemination. Although these outcomes were not evaluated as part of the moral agency measures in this study, they provide complementary evidence that the coupled ethical-epistemic research structure supported students' engagement with research processes and products in ways that are valued within academic and professional pathways.

4. Conclusions

This proof-of-concept study suggests that embedding coupled ethical-epistemic analysis and reflexive practice within an undergraduate research experience is a feasible approach for supporting ethical reasoning in engineering-relevant contexts. Across a small implementation cohort, students showed descriptive pre to post increases on a reflexive principlism rubric, with the most consistent gains in ethical-epistemic reasoning, and URSSA responses indicated perceived growth in several core research skills and mentoring experiences. At the same time, conclusions are constrained by the small sample size, the absence of a comparison condition, near-ceiling post scores, and the likelihood of selection effects associated with a climate-focused REU applicant pool. Future work should test this framework with larger and more diverse samples, include comparison groups, and examine persistence of learning through follow-up assessments. In addition to research settings, classroom-based implementations, such as integrating coupled ethical-epistemic analysis into design courses, lab courses, or first-year seminars, may offer scalable pathways to evaluate the framework's effectiveness and identify which instructional elements are most responsible for changes in students' ethical reasoning.

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