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Student Self-Reported Knowledge Gains from Reflection Implementation in Two Biological and Agricultural Engineering Courses

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Abstract

ABET 7 emphasizes the importance of developing engineering students' ability to acquire and apply knowledge through effective learning strategies. Reflection is one way to encourage students to evaluate their learning strategies, identify knowledge gaps, and plan ways to achieve their learning objectives. To reap the benefits of reflection, instruments are necessary to understand and monitor the impact of reflection implementation in courses. This study focused on the use of the Reflection Knowledge Gains Instrument (RKGI) to capture students' self-reported knowledge gains due to reflection. The RKGI was administered in multiple engineering undergraduate courses in which reflection was implemented over multiple semesters. Evidence of the validity of the RKGI was sought. The evidence of internal structure validity indicated acceptable fit of RKGI instrument while the internal consistency validity revealed a new four-factor model. Then two Biological and Agricultural Engineering courses use cases were developed using students' RKGI data and descriptive statistics. The use cases demonstrated differences in the impact each BAE course had on students' knowledge gains that were consistent with the reflection implementation in each course. Ultimately, this study revealed that the RKGI is a valuable tool that can provide insight concerning reflection instruction and implementation.

I. Introduction

Engineering's accreditation student outcome ABET 7 is concerned with students developing an ability to acquire and apply new knowledge as needed, using appropriate learning strategies [1]. Implied in this outcome is students' transition from a reliance on pedagogy to andragogy. The term pedagogy refers to a structured style and method of learning that relies heavily on instructors to help students meet learning objectives. Andragogy is adult learning, wherein students have greater control over their own learning with instructors only acting as facilitators [2]. Being self-directed about one's learning is a major component of andragogy [3]. Self-directed learning requires metacognitive skills, an ability to control one's learning. Such skills can be taught [4] and need to be developed throughout undergraduate studies, including in engineering, for successful academic experiences in college [5] and careers [6].

Reflection can encourage students to think critically about their own learning, behaviors, and experiences in ways that lead to personal growth (e.g., [7]), improved academic performance (e.g., [8]), and professional identity (e.g., [9], [10]). Reflection activities when implemented within a course possess the potential for students to improve their metacognitive skills [11] which underlie self-directed learning habits. Through reflection, students are better equipped to draw a connection and apply between what is taught in the classroom to real-world engineering practice. Students become better prepared to progress into upper-level courses and develop necessary lifelong skills for academic and professional careers [12].

While reflection has gained some traction in engineering [13], engineering instructors remain largely hesitant to bring reflection into their courses. One instructional struggle lies in determining whether a reflection activity has achieved its intended purpose. Assessing the impact of specific reflection activities can help educators and programs determine if reflection has effectively contributed to students learning as intended so that teaching approaches can be adjusted to better meet student needs and improve overall instructional quality. Instructors need tools that can help assess reflection activities implemented in their classroom.

This study was part of a larger research project to integrate reflection across two engineering programs. The purpose of this study was to (1) investigate a tool that instructors can use to assess the impact of integrating reflection into their courses and (2) demonstrate its use in two Biological and Agricultural Engineering courses. The intention is to provide validity evidence for the tool and determine whether it can capture differences in reflection implementation across courses. Such a tool could then be used by instructors and programs to improve reflection integration in classrooms and across the curriculum. The tool might also be considered for ABET 7 assessments.

II. Background

A. Self-Reflection

Assigning meaning to experiences is important in learning, and focusing on experiences is an intentional form of thinking [14]. Reflection is considered to be a key component in effectively enhancing one's ability to assign meaning to experiences and developing metacognitive ability more generally. Metacognition or "thinking about one's thinking" entails the interplay between one's metacognitive knowledge (i.e., of persons, tasks, and strategies) and their metacognitive regulation strategies (i.e., monitoring, evaluating, and planning) [15].

It has been asserted that when reflection is implemented regularly, over time, students should be able to improve their ability to assess their learning and their metacognitive skills in general (e.g., [5]). This assertion followed a study in which reflection activities were implemented weekly after clinical experiences during an eight-week nursing student internship. Students showed some evidence of higher-level thinking through their reflections (e.g., greater evaluation) as the short program progressed.

In engineering, reflection has been anchored by course learning activities such as homework (e.g., [16]) and exams (e.g., [17], [18]). Reflection has also been implemented in a variety of engineering courses [19]. Literature concerning the implementation of reflection have tended to emphasize the nature of the intervention and the impact of reflection on student performance metrics.

B. Reflection Knowledge Gains Instrument RKGI

The Reflection Knowledge Gains Instrument (RKGI) is a self-report tool that was developed to capture students' learning from reflection activities [20]. Initially, the instrument contained 72 items contributing to 16 factors and was piloted with 127 undergraduate engineering students all within their last year of university study. Exploratory factor analysis was completed to reduce the number of items to 16 and the number of factors to four contributing to: Engineering Self (professional identity as an engineer), Course Understanding (comprehension of course content), Areas for Growth (identification of ways to improve), and Social Impact (seeing how engineering is connected to the world). Validity evidence was gathered (see section III.E.1 for details). This instrument was used in the current study.

D. Research Questions

The research questions addressed in this study were:
- What is the validity evidence for the RKGI in the current setting?
- What are the knowledge gains perceived by students as a result of the reflection activities?
- Does the RKGI reveal differences in students' knowledge gains when reflection is implemented in different courses?

III. Methods

A. Setting and Participants

This study took place at Midwestern US research intensive (R1) university. The participants were undergraduate engineering students across all academic levels enrolled in various core engineering courses in two departments offered in Spring 2023 (5 courses), Fall 2023 (6 courses), and Spring 2024 (7 courses). These courses implemented reflection as part of a larger study on integration of reflection in the core curriculum. The total enrollment across all three semesters was 689 students. Of this enrollment, 541 students consented to participate in this study.

For the investigation into the validity evidence for the RKGI, 266 participants from Fall 2023 and Spring 2024 (Table 1) were considered (see Section D). While for the use cases, participants in two core biological and agricultural engineering courses (BAE Course 1 and BAE Course 2) typically taken in sequence, were considered (Table 1). BAE Course 1 was a 3-credit engineering course focused on using computer tools and basic statistics to solve discipline-related engineering problems. The course had an enrollment of seventy-four students (N=74), out of which forty-eight students consented to participate in this study. Forty-two students (n=42) remained in the study after data cleaning. While BAE Course 2, was a 3-credit engineering course focused on the properties of biological materials. This course had a lecture-laboratory format. The course had an enrollment of sixty-five students (N=65) and forty students consented to participate in this study. Thirty-three students (n = 33) were determined to be eligible for the study after data cleaning.

Table 1. Demographic information of participants retained in study

Demographics		RKGI Validity Study			RKGI Use Cases			
					BAE Course 1 (*n*=42)		BAE Course 2 (*n*=33)	
		Fall 2023 (*n*=158)	Spring 2024 (*n*=108)	Total Percent	No. Students	Percent	No. Students	Percent
Gender	Female	59	46	39	29	69	19	58
	Male	80	61	53	13	31	12	36
	Other[a]	19	1	8	---	---	2	6
Race	White	112	85	74	33	79	24	73
	Asian	5	9	5	5	12	---	---
	Hispanic or Latino	14	6	8	3	7	---	---
	Other[a]	27	8	13	4	2	9	27
First Gen.	Yes	20	19	15	9	21	6	18
	No	119	89	78	33	79	25	76
	Other[a]	19	---	7	---	---	2	6
Academic Level	First-year	10	20	11	31	74	---	---
	Soph.	53	9	23	5	12	26	79
	Junior	30	27	21	---	---	---	---
	Senior	37	45	31	---	---	---	---
	Fifth-year	5	7	4	---	---	---	---
	Other[a]	23	---	9	6	14	7	21

[a] Other includes a count of all participants from other demographic subgroups with counts <5

B. Reflection Implementation and RKGI Administration

Reflections followed particular course assignments, referred to as anchor assignments. These anchor assignments provided a learning experience on which students could reflect. The reflections became available immediately after the due date for the anchor assignment, following a consistent pattern of completion, similar to the one shown in Figure 1. Typically, students had two days to complete a reflection following the submission of the anchor assignment. The RKGI was assigned towards the end of the reflection series to assess whether the reflection intervention contributed to students' knowledge gains.

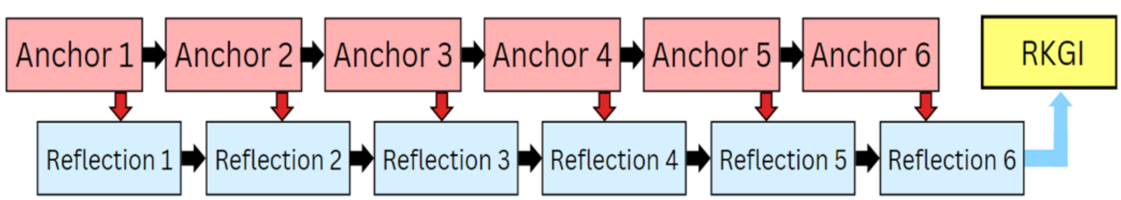

Figure 1: Typical Anchor - Reflection Sequence

The reflections entailed students' writing responses to four guiding prompts. The first prompt asked students to evaluate actions they took regarding a difficulty they wrote about in a previous reflection. The remaining three prompts asked, with respect to the anchor, to identify a difficulty they experienced, evaluate actions they took to resolve the difficulty, and plan further actions to improve their learning (Table 2). These prompts aligned to Zimmerman's self-regulation theory

[21], encouraging students to employ all three metacognitive regulation strategies (i.e., monitoring, evaluating, planning) in their reflections.

Table 2. Prompts for Reflection anchored to Laboratory Assignments

Metacognitive Regulation Strategy	Reflection Prompts
Evaluating	What have you done to address the difficulties you identified in the last reflection? Include a description of how your approaches were successful or unsuccessful.
Monitoring	What was one difficulty you are (or were) most concerned about? Be specific. Include a description of how you know (or knew) you are (or were) having this difficulty. *BAE Course 2 Only*: If you did not have any difficulty, what is something you learned from this assignment? Include a description of how you know you learned this.
Evaluating	How have you tried to overcome this difficulty? Include a description of how your approaches have been successful or unsuccessful and what you learned. *BAE Course 2 Only*: If you did not have a difficulty, what learning strategies did you employ while learning this? Include a description of how your approaches were successful or unsuccessful and what you learned.
Planning	What is your plan to further address this difficulty? Include an explanation of why you believe your plan will help. If you were successful in addressing this difficulty, discuss how you might use these approaches to address future difficulties.

BAE Course 1 was a first-year, second semester, required course. It was structured as a standard lecture classroom where students completed a variety of team projects. These team projects were designed for students to practice and incorporate defining a problem, collecting data, data analysis, and overall assessing the engineering design process. Reflection was anchored to one early assignment concerned with learning MATLAB basics. Project milestones served as another anchor for an additional four reflections. Reflection assignments constituted 2.2% of the course grade.

BAE Course 2 was a second-year, first semester, required course. Its eight laboratory assignments were designed to assist students in solidifying abstract ideas through concrete practice. Six laboratory assignments served as anchors for reflection. Mid-semester alternative Monitoring and Evaluating prompts (Table 2) were added to the reflection assignments because students indicated to the instructor that sometimes they did not have a difficulty to write about. Overall, reflection assignments constituted 10% of the course grade. Approximately 85% of the students enrolled in this course were enrolled in BAE Course 1 in the previous semester, making it suitable as the second use case in this study as it was assumed that students understanding of reflection would be greater, potentially enabling greater knowledge gains from reflection.

C. Data Collection with the RKGI

The Reflective Knowledge Gain Instrument (RKGI) was used in this study to capture learners' perceptions of knowledge gained through reflective activities. Table 3 lists its 16 items categorized in four different dimensions of a students' knowledge [20] The RKGI was assigned to students as part of a larger assignment towards the end of the semester, typically after the second to last or last reflection was completed. It was administered through Qualtrics. The administration of the RKGI was controlled in that participants were required to complete it within a specific open period, after which access was denied. However, participants had the flexibility to complete the instrument from any geographical location and at any time. While the RKGI was originally developed with a five-point Likert scale [20], in this study a 6-point Likert scale was used, with response options ranging from strongly disagree to strongly agree, with no neutral option. The even numbered scale forced an agree or disagree decision. In addition, two quality check items were added. For each of these items, students were instructed to check a specific Likert-scale response option.

Table 3. RKGI Items and Intended Factor Structure [20[

No.	RKGI Items	Factors
1	I was able to understand how I fit into the engineering community	Engineering Self
2	My interest in my major (or intended major) increased	
3	I was able to hone in on my interests for this course	
4	I thought about my path in my engineering career	
5	I thought about what I bring to engineering	
6	I better understood key concepts in this course	Course Understanding
7	I felt prepared to do well in this course	
8	I was able to refine my understanding of course concepts	
9	I made connections across course concepts	
10	I can now articulate main ideas of this course	
11	I understood more about my own weaknesses as a student	Areas for Growth
12	I was able to improve my work	
13	I gained insights about my study habits	
14	I thought about ethical concerns in engineering	Social Impact
15	I learned about the personal and emotional costs in engineering design	
16	I understood a different way of thinking about a problem	

D. Data Preparation

The data preparation process involved cleaning the RKGI dataset by removing redundant, incorrect, and unreliable entries. Two types of quality checks were conducted to ensure the integrity of the participants responses to the RKGI. In the first quality check, participants' responses to two quality assurance items included in the survey were examined for the correct response. If a participant did not provide the expected response i.e., if they provide an incorrect response to either one of these items - "*For quality assurance purposes, please select "Agree" for this statement*" and "*For quality assurance purposes, please select "Disagree" for this statement,*", the entire participant's responses was rendered unreliable as it suggested the participant was not reading the items carefully. The second quality check involved examining similar responses across all 16 RKGI item responses for each participant. Participants who provided the same response to 13 or more items (>80%) were identified and their data entries was excluded from data analysis as it was unlikely that knowledge gains across most of the items could be similar given the intent and implementation of the reflections.

In preparation for quantitative data analysis, students' RKGI responses were assigned a numeric value from 1 to 6. More specifically, the Likert-scale was translated so that strongly disagree was assigned 1 and was and strongly agree was assigned 6.

E. Data Analysis

1. Validity Evidence for the RKGI

In this section, the validity evidence of the RKGI is first briefly described before the use cases. Five sources of validity evidence were sought for the RKGI. The sources were internal structure, content, response process, relationship with other variables, and consequences [22], [23]. Below is a brief overview of the internal structure of the RKGI. Validity evidence for this instrument will be discussed in more detail in a separate paper.

Internal Structure. Internal structure validity describes the way in which the items on a survey are related to each other and how they align with the theoretical framework of the construct being measured [23]. Evidence of internal structure validity for the RKGI was demonstrated through statistical confirmatory factor analysis (CFA) and internal consistency reliability [22]. Computations were performed with R statistical tool.

Confirmatory Factor Analysis. CFA is a statistical technique used to test how well the measured variables (e.g., RKGI items) represent the latent variables constructs or factors they are proposed to measure [24]. The 16 items of the RKGI instrument were originally modelled as a composite of the four constructs [20] Engineering Self, Course Understanding, Areas for Growth, and Social Impact. The fitness of the RKGI data to the four-factor model was then examined to ascertain that it met these acceptable fit indices: comparative fit index (CFI) ≥ 0.90; Tucker–Lewis's index (TLI) ≥ 0.90; $\rho \leq 0.05$; standardized root-mean square residual (SRMR) ≤ 0.08; and root-mean-square error of approximation (RMSEA)- $0.05 \leq 0.1$ [25].

Internal Consistency Reliability. Internal consistency reliability assesses how consistent scores are across multiple administrations of a test [26]. Mejia and Turns [20] examined the internal consistency reliability for the RKGI by computing the Cronbach' alpha for each of the instrument's four dimensions. An alpha coefficient of ≥ 0.70 was considered an acceptable indication of the RKGI reliability. Their results showed the following alpha scores - Engineering Self (0.875), Course Understanding (0.829), Areas for Growth (0.716), and Social Impact (0.747).

In this study, two iterations of Cronbach's alpha computation were conducted using the RKGI data. The first iteration was based on the proposed four dimensions [20], while the second iteration was guided by new dimensions discovered through exploratory factor analysis (EFA). The EFA was performed to explore whether an alternative factor structure would better fit the data for this study. On both iterations, an alpha coefficient of ≥ 0.70 was also considered an acceptable reliability indication.

2. Use Cases Utilization of the RKGI

The new factor structure discovered from EFA was used for analysis of students' RKGI data in the use cases (BAE Course 1 and BAE Course 2). Data from these courses were analyzed using descriptive statistics in two ways. First, the frequency of students' responses to each RKGI item in BAE course 2 were represented graphically using stacked bar charts.

Second, a comparison of the BAE Course 1 and Course 2 data was then performed by examining the mean RKGI scores for both courses. The factor scores were computed by taking the average of students' responses to the items in each factor. Then a weighted mean and standard deviation was computed for each factor. A one sample, two-tailed t-test was conducted to determine if the mean factor score was significantly different from a neutral response score of 3.5. Cohen's *d* was computed to determine the effect size. An effect size of 0.2 was interpreted to be small, 0.5 moderate, and 0.8 large [27].

IV. Results & Discussion

A. Validity Evidence for the RKGI

1. Confirmatory Factor Analysis

The results of the first CFA computation (before EFA) indicated that all indices met the acceptable cut-off values: CFI = 0.94; TLI = 0.92; $\rho = 0$; SRMR = 0.05; and RMSEA = 0.08, providing sufficient evidence of internal structure validity. The second CFA iteration (after EFA) also lead to the same conclusion. These CFA results confirmed that the hypothesized four-factor model was a good fit for the data, suggesting that the constructs are well-defined and internally consistent.

2. Internal Consistency Reliability

The Cronbach alpha results for the first iteration (before EFA) revealed coefficient values that were above the 0.70 cut-off (Table 4). The EFA computation in this study resulted in an alternative factor structure similar to [20]. However, the categorization of the items onto the proposed factors differed. Three factors were labeled similarly to those in [20], while one factor was relabeled to reflect a shift from "social impact" [20] to "personal interest." Based on this updated factor structure, a second computation of Cronbach's alpha and CFA was performed with results also revealing alpha coefficients greater than the 0.70 cut-off (Table 4). This analysis indicated that the RKGI was consistently measuring the same underlying constructs and is reliable.

Table 4. RKGI Factor Structure with Cronbach Alpha values

First Iteration			**Second Iteration**		
Original Factor	**Items**	**Alpha**	**Alternative Factor**	**Items**	**Alpha**
Engineering Self	1-5	0.860	Engineering Self	1,4,5,14,15	0.860
Course Understanding	6-10	0.880	Course Understandings & Work	6-10, 12, 16	0.829
Areas for Growth	11-13	0.770	Areas for Growth	11,13	0.740
Social Impact	14-16	0.740	Personal Interest	2,3	0.710

B. Use Cases

1. BAE Course 2 in Detail

A detailed discussion of participants' RKGI responses in BAE Course 2 is provided in this section. Results are presented in the order in which students showed the greatest knowledge gains as a result of reflection in the course. Gains, or the lack thereof, are discussed for each factor with reference to the nature of the course and the implementation of reflection in the course.

Areas for Growth. Most students were able to recognize areas for personal growth as a result of reflection implementation in the course (Figure 2). They were able to understand more about their own weaknesses as an undergraduate student and they gained insights into their study habits (87%). Both BAE Course 1 and Course 2 were focused on problem solving and the reflection prompts directed students to unpack the difficulties they experienced with coursework by describing them and evaluating the actions they took to overcome them. As such, it is not unexpected that students would agree with the 'Areas for Growth' items.

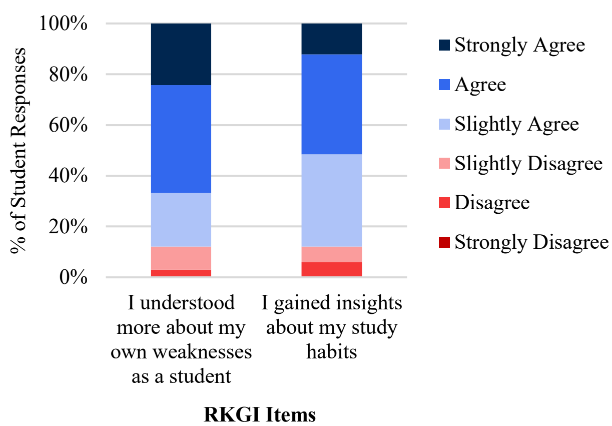

Figure 2. Students' agreement to RKGI Areas for Growth items

Course Understanding & Work. Overall, students expressed a high level of agreement (slightly to strongly) with the Course Understand & Work items (Figure 3). Meaning, students indicated that reflection enabled greater comprehension of or ability to think with or about the course content. In particular, students agreed to feeling prepared to do well in the course (90%), able to articulate the main ideas of the course (90%), and make connections across course concepts (87%). The positive response to these items may indicate there was a strong connection between the anchors, which were course content focused, and the reflections.

To a slightly lesser extent, students' agreed reflection led to thinking differently about a problem (75%). These results are mixed. While more students disagreed, more students also strongly agreed. For those that disagreed, the anchors (laboratory assignments), which required instructions to be closely followed, may have been perceived as providing less opportunities to think differently about how to perform biological property measurements. For those that strongly agreed, they may have been thinking about their experience with the course projects which asked students to develop measurement methods in the context of engineering design. These projects afforded opportunities to think differently about how to perform biological property measurements. While the projects were not intended to be the anchors for the reflections, these projects were going on in parallel with the laboratory assignments.

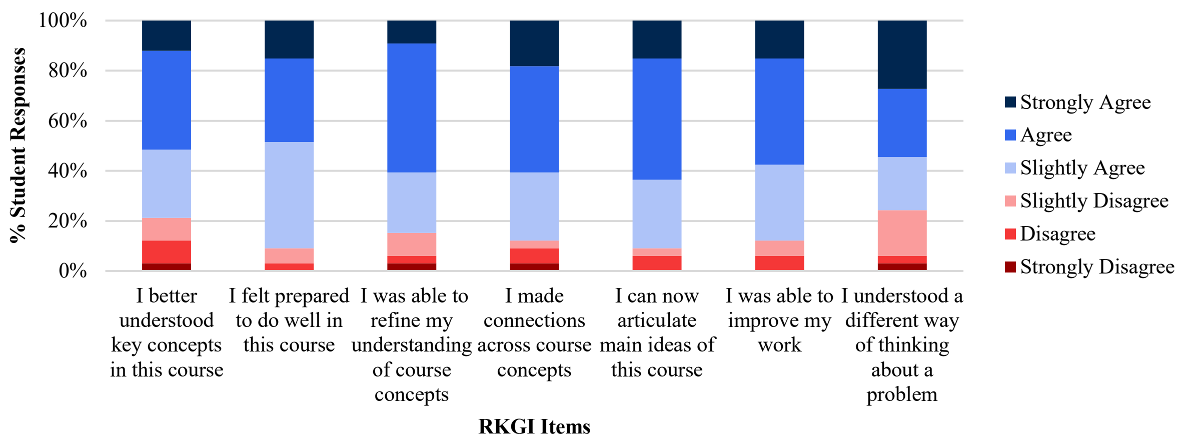

Figure 3. Students' agreement to RKGI Course Understanding & Work items

Engineering Self. Figure 4 shows students' responses to the five Engineering Self items. As a result of engaging in reflection, 60% of students slightly to strongly agreed to being able to see themselves as a member of the engineer community. Seventy-five percent were able to think about what they brought to engineering and their future career path within it. Students were also able to learn about personal and emotional costs in engineering design (70%). The laboratory assignments (and projects) were highly contextualized to BAE, likely providing insight into the work of someone with a BAE degree. Therefore, reflection may have afforded many individuals the opportunity to think about themselves in the greater BAE community and their career paths.

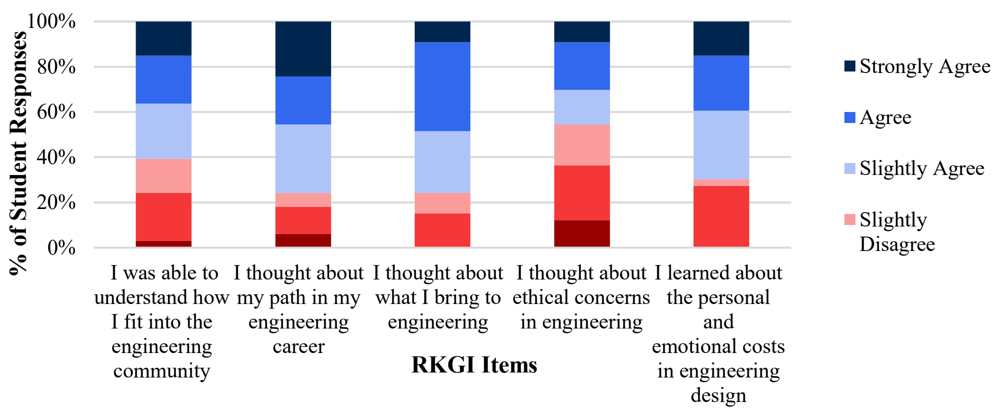

Figure 4. Students' agreement to RKGI Engineering Self items

The only items for this factor for which more than half of the students' disagreed was "I thought about ethical concerns in engineering." Students' responses to this item mirror the fact that engineering ethics was not an explicit topic in this laboratory course. Reflections were therefore not likely to draw out students thinking about ethical concerns.

Personal Interest. Among the RKGI dimensions, students slightly to strongly disagreed more with the Personal Interest items (Figure 4). Forty-five percent of students disagreed that reflection contributed to their interest in their major or honed their interest in the course. First, it should be noted that the reflections focused students' attention on difficulties with the anchoring lab assignments. The reflection prompts did not explicitly ask students to explore their interests in their major or the course. However, a deep response to the reflection prompts could have gotten some students there. In a parallel study of students' reflections, it was found that few students engaged deeply in reflection and seldomly in the more abstract aspects of reflection [28]. Their surface level engagement in reflection may have limited students use of reflection to be curious and make deep connections which might have promoted interest.

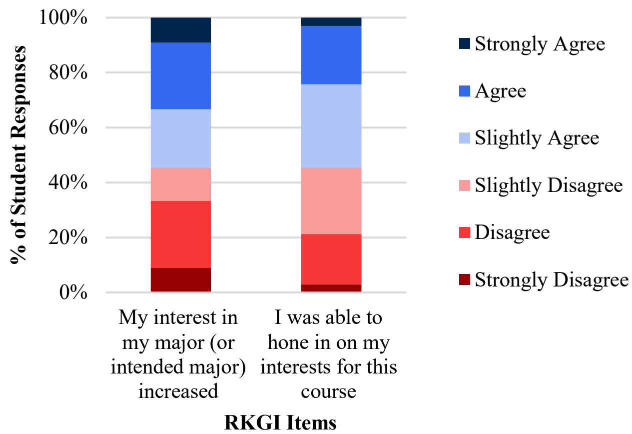

Figure 5. Students' agreement to RKGI Personal Interest items

2. Comparison of Use Cases

As was seen in Table 5 and highlighted in the previous section, in BAE Course 2, students' knowledge gains were most prominent for the factors Areas for Growth and Course Understanding & Work. Based on the *t*-test computation, there was a significant difference between the mean scores for these factors and a neutral response (mean= 3.50). For Areas for Growth, $t(32) = 7.28$, $p < 0.0001$, with the effect size ($d = 1.51$). For Course Understanding & Work, $t(32) = 6.17$, $p < 0.0001$, with effect size ($d = 1.06$). The high *t*-values and very low *p*-values ($p < 0.0001$) indicate that these differences are statistically significant. Additionally, the large effect sizes suggest that these differences are not only statistically significant but also practically meaningful. For the factors Engineering Self and Personal Interest, there was no significant difference between the mean scores for these factors and a neutral response.

Table 5. RKGI Mean Factor Scores and Standard Deviation

Course	No. Students	RKGI Factor *M*(*SD*)			
		Areas for Growth	Course Understanding & Work	Engineering Self	Personal Interest
BAE Course 1	42	4.07(1.06)[a]	3.66(0.92)	3.63(1.02)	3.24(1.04)
BAE Course 2	33	4.61(0.87)[a]	4.49(0.93)[b]	3.92(1.21)	3.56(1.21)

[a] *t*-test: $p < 0.0001$, [b] *t*-test: $p < 0.01$

The results for the BAE Course 1 are different. Although a similar interpretation as in BAE Course 2 can be made for the factor results, students' self-reported gains across all four dimensions were lower than the reported gains in BAE Course 2. The greatest gains were in the Areas for Growth category, reflecting the focus of the reflections on describing difficulties. Gains were less prominent for Course Understanding & Work and Engineering Self. Like in BAE Course 1, students' reported gains were the least for Personal Interest. Furthermore, only the Areas for Growth factor showed a significant difference between the mean score and a neutral response, with $t(41) = 3.48$, $p = 0.0012$. The effect size was moderate ($d = 0.54$).

Two factors that may contribute to the lower knowledge gains in BAE Course 1 compared to Course 2, familiarity with reflection and assessment of reflections. First, students in BAE Course 1 were unfamiliar with reflection, and their focus on learning the process of reflection may have overshadowed their ability to learn through it. The prior reflection experience from BAE Course 1 may have enabled students in the BAE Course 2 to better benefit from reflecting on their difficulties. Compared to BAE Course 1, students in BAE Course 2 generally demonstrated greater engagement with metacognitive regulation strategies—Monitoring, Evaluating, and Planning—by providing more detailed and richer reflections [28].

Second, the assessment of students' reflections was done by different people in the two courses. The BAE Course 1 instructor required support to incorporate reflection into the course for the first time. As such, the research team assisted by grading and providing feedback on students' reflections. This external involvement in assessment may have created a disconnect between the instructor and students regarding the implementation of reflection. Such disconnects often lead to student discontent with learning experiences that are perceived as being unusual [29]. In BAE Course 2, the instructor assessed students' reflections and discussed her observations in class, potentially enhancing the perceived value of reflection for students

V. Implications for ABET 7

The RKGI results suggest several important implications for integrating reflection to address ABET 7. These implications span student learning, reflection implementation in engineering classes, and reflection assessment.

The knowledge gains for Areas for Growth and Course Understanding & Work suggest that reflection helps students identify and articulate their challenges, which is critical for developing problem-solving and self-regulation skills. However, the more limited gains for Engineering Self and Personal Interest needs further consideration. There may be evidence in the results of this study that prior experience with reflection enhances students' ability to engage meaningfully with reflective practices to attain knowledge gains. As students' ability to reflect increases, and they start to engage in more abstract thinking about thinking, gains in Engineering Self and Personal Interest may increase. Alternatively, specific instruction or different reflection prompts may be necessary to encourage students to connect their reflections to broader learning outcomes and professional identity and interests. The lack of Personal Interests gains suggests an opportunity to design reflection activities that resonate more with students' individual motivations, potentially increasing relevance and engagement.

Reflection implementation and assessment can be enhanced for greater knowledge gains. First, the introduction of reflection in a course may require targeted support for instructors. Collaboration between instructors and those providing the support can ease this transition, but care should be taken to maintain strong instructor-student connections to foster engagement and valuing of reflection. Second, instructors can elevate the perceived value of reflection and deepen student engagement by discussing the benefits of reflection generally and in engineering specifically. Third, providing detailed feedback and aligning assessment criteria with learning objectives is crucial for maximizing the impact of reflection and supporting both metacognitive development and personal relevance.

Limitations

There are limitations to the generalizability of the results. This study was conducted in two specific engineering programs and two courses within one program. Also, the anchors for reflection were engineering science-oriented assignments. Reflection implementation in other engineering courses (e.g., technical writing, ethics) or using other anchors with a different emphasis (e.g., teaming) may yield different results. The reflection prompts also align to a particular self-regulation framework, drawing students' attention to difficulties in their learning. Reflection prompts with a different emphasis (e.g., on one's feelings or behaviors) might yield different results.

Conclusion

This study aimed to investigate undergraduate engineering students' self-reported knowledge gains through reflection and discussed steps to ascertain the internal structure validity of the Reflection Knowledge Gains Instrument (RKGI) which was used to capture students' these gains in two undergraduate engineering courses. The results were analyzed by categorizing responses under specific factors to illustrate the extent and nature of students' knowledge gains. This study also provided details about the implementation of reflection and how it aligned with its intended purpose of enhancing the student learning experience. The findings and insights presented in this paper are intended to support educators in engineering education by highlighting the benefits students derive from engaging in reflective practices. Moreover, this work contributes to the broader understanding of how reflection can be leveraged to promote lifelong learning skills as per ABET 7. Ultimately, the results underscore the importance of integrating reflection early and consistently across the curriculum, structured reflection activities, active instructor engagement, and effective assessment strategies in maximizing the educational value of reflection in engineering courses.

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References

[1] ABET. "Criteria for accrediting engineering programs, 2024-2025." Date Accessed. January 5, 2025. [Online]. Available: https://www.abet.org/accreditation/accreditation-criteria/accreditation-policy-and-procedure-manual-appm-2024-2025/

[2] M. S. Knowles, *The Modern Practice of Adult Education: Andragogy versus Pedagogy*, New York, NY, USA: Association Press, 1970.

[3] M. S. Knowles, E. Holton, and R. Swanson, *The adult learner: the definitive classic in adult education and human resource development*, *6*th ed., Burlington, MA, USA: Elsevier, 2005.

[4] B. J. Zimmerman, "Becoming a self-regulated learner: An overview," *Theor Prac*, vol. 41, no. 2, pp. 64-70, 2002, doi: 10.1207/s15430421tip4102_2.

[5] R. Kuiper, "Enhancing metacognition through the reflective use of self-regulated learning strategies," *J Cont Educ Nurs*, vol. 33, no. 2, pp. 78–87, Mar. 2002, doi: 10.3928/0022-0124-20020301-11.

[6] P. Faller, H. Lundgren, and V. Marsick, "Overview: Why and how does reflection matter in workplace learning?" *Adv Dev Hum Res*, vol. 22, no. 3, pp. 248–263, Jun. 2020, doi: 10.1177/1523422320927295.

[7] C. J. Travers, D. Morisano, and E. A. Locke, "Self-reflection, growth goals, and academic outcomes: A qualitative study," *Brit J Educ Psychol,* vol. 85, no. 2, pp. 224–241, Dec. 2014, doi: 10.1111/bjep.12059.

[8] M. D. N. Lew and H. G. Schmidt, "Self-reflection and academic performance: Is there a relationship?," *Adv Health Sci Educ*, vol. 16, no. 4, pp. 529–545, May 2011, doi: 10.1007/s10459-011-9298-z.

[9] U. Feldman, G. Ricco, and C. Wells, "Take this job and love it: Identity-conscious self-reflection as a tool to support individualized career exploration for graduating biomedical engineering students," in *ASEE Annu. Conf. & Expo.,* Oregon, OR, USA, June 23-26, 2024, doi: 10.18260/1-2--48052.

[10] N. W. Hamilton, "The foundational skill of reflection in the formation of a professional identity," *St. Mary's Univ Leg Mal & Eth*, vol. 12, no. 2, pp. 254-282, Jun. 2022, https://commons.stmarytx.edu/lmej/vol12/iss2/2

[11] D. Davis, M. Trevisan, P. Leiffer, J. McCormack, S. Beyerlein, M. J. Khan, and P. Brackin, "Reflection and metacognition in engineering practice," in *Using reflection and metacognition to improve student learning: Across the disciplines, across the academy*, N. Silver, M. Kaplan, D. LaVaque-Manty, and D. Meizlish, Eds., Taylor & Francis, 2013, doi: 10.4324/9781003448570.

[12] C. Magno, "The role of metacognitive skills in developing critical thinking," *Metacogn Learn*, vol. 5, no. 2, pp. 137–156, Mar. 2010, doi: 10.1007/s11409-010-9054-4.

[13] L. Sepp, M. Orand, M., J. Turns, L. Thomas, B. Sattler, and C Atman, "On an upward trend: Reflection in engineering," in *ASEE Annu. Conf. & Expo.,* Seattle, WA, USA, Jun. 2015, doi: 10.18260/p.24533.

[14] J. A. Turns, B. Sattler, K. Yasuhara, J. L. Borgford-Parnell, and C. J. Atman, "Integrating reflection into engineering education," in *ASEE Annu. Conf. & Expo.,* Indianapolis, IN, Jun. 2014, doi: 10.18260/1-2--20668.

[15] J. H. Flavell, “Metacognition and cognitive monitoring: A new area of cognitive-developmental inquiry,” *Am Psychol*, vol. 34, no. 10, pp. 906–911, 1979, doi: 10.1037/0003-066X.34.10.906.
[16] A. Singh and H. Diefes-Dux, “Pairing self-evaluation activities with self-reflection to engage students deeply in multiple metacognition strategies,” in *ASEE Annu. Conf. & Expo.,* Maryland, MD, USA, Jun. 2023, doi: 10.18260/1-2--43847.
[17] M. C. Lovett, “Make exams worth more than the grade: Using exam wrappers to promote metacognition,” in *Using Reflection and Metacognition to Improve Student Learning* Routledge, 2013, pp. 18-52.
[18] D. Benson, and H. Zhu, “Student reflection, self-assessment, and categorization of errors on exam questions as a tool to guide self-repair and profile student strengths and weaknesses in a course,” in *ASEE Annu. Conf. & Expo.,* Seattle, WA, USA, Jun. 2015, doi: 10.18260/p.24763.
[19] Consortium to Promote Reflection in Engineering Education [CPREE], 2014-2022, Date Accessed. January 5, 2025. [Online]. Available: http://cpree.uw.edu/
[20] K. Mejia and J. Turns, “Creating capacity to explore what students learn from reflection activities: Validating the knowledge-gain survey,” in *ASEE Annu. Conf. & Expo.,* Virtual Meeting, USA, July 26-29, 2021, doi: 10.18260/1-2--36872.
[21] B. J. Zimmerman, “Attaining self-regulation: A social cognitive perspective” in *Handbook of self-regulation*, M. Boekaerts, P. R. Pintrich, and M. Zeidner, Eds., Academic Press, 2000, pp. 13–39,. doi: 10.1016/B978-012109890-2/50031-7
[22] D. A. Cook and R. Hatala, “Validation of educational assessments: a primer for simulation and beyond,” *Adv Sim*, vol. 1, pp. 1-12, 2016, doi: 10.1186/s41077-016-0033-y
[23] J. W. Creswell and T. C. Guetterman. *Educational Research: Planning, Conducting, and Evaluating Quantitative and Qualitative Research*. 6th ed, Pearson, 2019.
[24] A. Field, J. Miles, and Z. Field, *Educational Measurement*, Sage Publishing. 2006. [Online]. Available: https://uk.sagepub.com/en-gb/eur/discovering-statistics-using-r/book236067
[25] L. T. Hu and P. M. Bentler, P. M. (1999). “Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives,” *Struct Equ Modeling*, vol. 6, no. 1, pp. 1-55, 1999.
[26] J. T. Steedle and R. J. Shavelson, “Coefficient alpha and the internal structure of tests,” in *Encyclopedia of Research Design*, Sage Publications, 2010, pp. 164-164.
[27] J. Cohen, *Statistical Power Analysis for the Behavioral Sciences*, Routledge, 1988.
[28] H. P. Schwab, H. A. Diefes-Dux, A. Singh, and E. B. Maluf, “Reflection for development of metacognitive strategies: A two-year implementation study,” in *ASEE Annu. Conf. & Expo.,* Montreal, CAN, Jun. 2025.
[29] E. Seymour, *Partners in Innovation: Teaching Assistants in College Science Courses*. Rowman & Littlefield, 2005.