Creating Capacity to Explore what Students Learn from Reflection Activities: Validating the Knowledge-gain Survey

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Abstract

This paper reports on the methodological process of validating a survey instrument to measure student learning from reflection activities. Reflection is thought to be a helpful teaching and learning tool. In engineering education, reflection is gaining traction as a tool to help students think about their study habits, exam performance, command of the course content, and team interactions. Yet few validated instruments exist to systematically document what students are learning from reflection experiences. The purpose of this research project is to provide preliminary evidence of validation for an instrument to capture the knowledge gains of students from doing reflection activities in a course context. Having a validated survey will allow researchers and educators to compare knowledge gains across activities, between classes, and even across institutions. In order to create the instrument, the research team followed the survey validation process. The 72 items, or questions for the survey, were developed using various learning models, such as Bloom's Taxonomy cognitive and affect domain, and Dee Fink's Taxonomy of Creating Significant Learning Experiences, to ensure we captured multiple learning opportunities. Students give answers by choosing their level of agreement on a likert scale for each of the items. Our items ask about expected learning outcomes such as "I better understood what had been confusing about a topic" and "I understood how the topics in this course can be applied to the real world," which relate to course content knowledge and knowledge relevant to their careers. Additionally, our items ask about novel potential learning outcomes such as "I realized the skills I gained [in this context] will help me in my career" and "my confidence as a student increased," to help students connect their learning in the classroom to the real world and make their own progress in learning more visible. Pilot tests were conducted for comprehensibility and the data collection process is in progress. Exploratory factor analysis will be used to group and reduce the 72 current items. In the exploratory factor analysis, we will focus on undergraduate engineering students who have completed a reflection activity in the past academic school year. We are using a stratified random sampling approach to ensure we document student learning from a diversity of reflection activities. Here, we report the results of an exploratory factor analysis, highlighting the reduced number of questions contributing to the validated survey. We have reduced the number of questions from 72 to 16, as described by four factors: Engineering Self, Course Understandings, Areas for Growth, and Social Impact. We report data on inter-item reliability and concurrent validity. The contribution of this work is evidence of preliminary validation for a survey that will allow the engineering community to learn more about what students learn from doing reflection activities and what settings or types of activities lead to specific characteristics of learning.

Introduction

Reflection activities, or activities that invite students to pause, step "out," and create knowledge, as a teaching and learning tool in engineering education has continued to gain traction, given its potential to get students to think metacognitively about their learning. In work related to reflection in engineering education, few have looked at creating validated surveys to evaluate the learning outcomes of doing reflection. Other work in engineering education related to reflection has explored reflection, facilitated through portfolio construction, as a way to help students grapple with engineer identity and “feel more like an engineer” without additional courses or experiences [1]. But there is a push for the engineering education community to be rigorous as we adopt the practice of creating validated instruments [2], [3].

Additionally, reflection is also relevant to educational issues such as diversity in engineering and bringing broader perspectives into engineering. For example, consider the issue of belongingness and its link to inclusion and retention in engineering [4]. Belonging is frequently described as a feeling that emerges (i.e., not the product of intentional meaning making). While such emergence may be inevitable, it perhaps can be disrupted with reflection. In the event a student does not feel that they belong, it is also possible that they might revisit the experiences that are associated with the sense of not belonging, unpack what creates the feeling, and perhaps reconsider. For instance, if a student feels they don’t belong because all of their ideas are “shot down” by peers, they might come to a different understanding by examining these past experiences and realizing that there might be many reasons why their ideas might be getting “shot down,” including reasons that would suggest a reason to belong to engineering (e.g., the ideas are particularly creative or interdisciplinary). Further, while we certainly would not want to rely on reflection to help students overcome too many of such issues, reflection can play an important role in supporting the emergence of a sense of belonging.

Building on this research team’s previous work with reflection, we address the following research gap—a gap in being able to characterize students’ knowledge gains resulting from reflection activities. Information on knowledge gains would be valuable for research comparing reflection activities, seeking to understand why a reflection activity is not working, and refining activities. Having survey instruments to capture such information could significantly accelerate research on reflection, as well as create more local and national conversations about the use of reflection to improve engineering education. Despite all the work that is available on reflection, few studies have looked at systematically documenting the type of knowledge that is gained from completing a reflection activity, in particular in an engineering context. By exploring the research question, “What are meaningful ways to characterize the knowledge gains that result from engaging in reflection activities?,” we have provided preliminary evidence of the validity for this instrument.

In this paper, we discuss the development of the Reflection Knowledge Gains Instrument (RKGI), a survey that gives researchers and educators insight into the multiple learning opportunities a specific reflection activity provides for students. We document the development of items for a survey validation process, including the initial list of items from previous work and the iterative process of expanding the list with both student and educator feedback. We also discuss different learning models used to create and expand on what learning can be produced through reflection. After collecting data from over 100 students, we detail the methods and process for conducting an Exploratory Factor Analysis to refine and provide evidence of preliminary validity for the instrument in its final form. As Douglas and Purzer [3] discuss, clearly defining the terms of validity is critical to instrument development. Here, the research team is providing preliminary evidence of validity for an instrument that measures students’ self-assessed knowledge gains from reflection activities in undergraduate engineering courses. In the discussion section, we present use case scenarios for both educators and researchers looking to use the RKGI to learn more about student knowledge gains in engineering courses.

Prior Work

In previous work in the Consortium for Promoting Reflection in Engineering Education (CPREE) [8], we articulated a three factor conceptual model to describe knowledge gains resulting from reflection activities. This three factor conceptual model provides a way to illustrate the range of knowledge gains that could result from a reflection activity. These three factors are used as a basis to ideate on different kinds of learning possible, but they are not the final factor structure we aimed to have for the instrument. Below, we explain each factor, situate the factor briefly in relevant literature, and provide examples of student utterances that might align with the factor.

Professional knowledge: Reflection activities clearly have the potential to help students advance their knowledge of the topics they are studying in order to become engineers. Our way of framing "professional knowledge" as a type of knowledge arising from engagement in reflection activities is in alignment with Stevens et al.'s [5] notion of accountable disciplinary knowledge. In other words, reflection activities can help students gain or advance their knowledge in relation to course learning objectives, knowledge and skills required for accreditation, etc. In talking with students to explore whether the reflection activity did result in professional knowledge, we might be interested in statements from students such as: "I learned something relevant to the course objectives," "I learned something relevant to my degree," and "I learned something related to getting a university degree."

Personal knowledge: Reflection activities have the potential to help students advance knowledge about themselves. This factor bears much in common with Stevens et al.'s [5] identification of identity as an important part of the trajectory of engineering education. Further, calling out this factor as separate from professional knowledge recognizes recent attention to identity in engineering education (i.e., a chapter on identity in the recent Handbook on Engineering Education, [6] and the role of reflection in supporting identity work [1]. In talking with students to explore whether the reflection activity did result in personal knowledge, we might be interested in statements from students such as: "I learned about myself as a result of doing this reflection activity," and "The reflection activity helped me see that I fit in."

Preparedness knowledge: Reflection activities have the potential to help students prepare themselves to engage in future learning and/or professional work. The naming of this category is inspired by work by Schwartz and Martin [7] on activities that function to prepare a learner for a future learning event. More broadly, this factor in our conceptual model offers an opportunity to recognize when reflection activities give students a chance to identify questions to be answered in the future, perceive their own preparedness for the future, and/or get excited about the future. In talking with students to explore whether the reflection activity did result in preparedness knowledge, we might be interested in statements from students such as: "I now know what I need to do next," and "I am very excited about the next step."

The work documented in this paper involved moving beyond this initial conceptualization.

Item Development and Piloting

In this section, we detail how we developed a list of 72 items related to knowledge gains from reflection activities. We had an initial list of items from a survey used by those in the Consortium for Promoting Reflection in Engineering Education (CPREE) [8]. This list The research from CPREE had resulted in unvalidated surveys with knowledge gains in the three categories mentioned in the previous section: Professional Knowledge, Personal Knowledge, and Preparedness knowledge. These three categories from CPREE informed the initial basis of the item development, but were not used to inform the factor structure. Instead, the research team explored various learning models in order to capture different types of learning that could be produced in a classroom setting beyond the three initial categories.

The research team used Bloom's Taxonomy's cognitive and affective domains [9] and Fink's Taxonomy of Creating Significant Learning Experiences [10]. From Fink's Taxonomy, we introduced learning as connected to relevance and interests, emphasizing Fink's main idea that in order for learning to occur "there has to be some kind of change in the learner. And significant learning requires that there be some kind of lasting change that is important in terms of the learner's life [10]." From Bloom's taxonomy, we used the commonly cited cognitive model related to comprehension, application, analysis, and synthesis. But in our effort to provide a diverse set of statements describing student learning, we also included terms from Bloom's affective domain model such as receiving, responding, and valuing [9], which also seemed to align with Fink's Taxonomy.

After brainstorming more items using the various taxonomies, we had about 100 items to pilot. We pilot tested this list with five students and three educators. With educators, we asked them to share a reflection activity they had done in a recent class they taught and what they anticipated the students would learn. We then asked educators to sort our list of items into three categories: 1) knowledge gains they thought their students got out of their activity, 2) knowledge gains they thought would be interesting for their students to learn, but didn't with this specific activity, and 3), what knowledge gains they thought would not be relevant to reflection in their classroom. With the students, we followed a similar procedure, asking them to share a reflection activity from a recent class they participated in and what they had learned from doing the reflection activity. When asking the students to sort the items, we asked to focus on what they had learned. From these pilot sessions, we added about 15 new items reflecting knowledge gains that were not represented in the current list.

Once we had a list of 115 items we thought covered multiple types of knowledge expressed to be relevant by educators and students, we piloted these for comprehensibility. Using think out-loud methods, we had 5 students complete the draft survey, again, using a reflection activity they had recently completed in an engineering course. Through this process, we eliminated 43 questions to get to 72. Questions were eliminated if they were consistently confusing to students completing the think out-loud process, or did not make sense to students. Some questions were modified to represent wording that was more consistent with student understanding of their learning.

In summary, we arrived at the final list of 72 items through brainstorming multiple types of knowledge gains from reflection activities and by piloting with students and educators to ensure we covered multiple types of knowledge gains and comprehensibility of the items themselves. The pilot testing with educators and students ensured face validity of the items. In the next section, we present the results from deploying the survey to a broad range of students in order to collect data for our Exploratory Factor Analysis.

Table 1. Demographics of the 127 respondents.

Demographic	Number	Percentage (%)
Gender Identity		
Female	59	46.5
Male	51	40.2
Cisgender	5	3.9
Nonbinary, Trans, or Questioning	3	2.4
Did not answer	9	7.1
Class Standing		
2nd year	43	34.1
3rd year	39	31.0
1st year	28	22.2
4th year	13	10.3
5th year and beyond	3	2.4
Race or Ethnicity		
White	48	37.8
Asian	42	33.1
More than one	19	15.0
Hispanic/Latinx	7	5.5
Black	2	1.6
Pacific Islander	2	1.6
Prefer not to answer	7	5.5

Results

In order to continue refining and validating the items, we deployed the survey to 127 college level engineering students. With this data, we conducted an exploratory factor analysis to reduce the number of items on the survey. In the following section, we describe the survey deployment and exploratory factor analysis.

Instrument Methods

We recruited engineering undergraduate students from colleges and universities in the Pacific Northwest and from schools who had previously participated in the CPREE study. After consenting to participate, participants filled out basic demographic information about themselves and their school setting. As compensation, participants were entered in a drawing for a gift card. Of the 127 respondents, 59 identified as female, 51 as male, 5 as cisgender, 1 as nonbinary, 1 as transgender and 1 as questioning. Additionally, 42 identified as Asian, 2 as Black/African, 48 as Caucasian, 7 as Hispanic/Latinx, 2 as Pacific Islander, 19 as more than one race or ethnicity and 7 preferred not to answer. Additional data and percentages are reported in Table 1. The survey then asked participants to describe a reflection activity they had been asked to complete by their instructor in an engineering course in the last year. Keeping this activity in mind, students were then asked to answer questions on a five-point likert scale from highly disagree to highly agree, on their knowledge gains from the reflection activity.

Exploratory Factor Analysis

In order to identify the factors within our set of 72 questions, we conducted an exploratory factors analysis of the 127 responses using. Factor analysis traditionally requires a large sample size. In cases when the data has high communalities above 0.6 and well determined factors, as is the case with our data, a sample size below 100 is acceptable [11]. Prior to performing factor analysis, the suitability of data for factor analysis was assessed. The purpose of running this statistical computation was to psychometrically identify the optimal set of questions and scales to include in the instrument both to reduce the number of items and refine a set of factors. The varimax (orthogonal) rotation resulted in 16 factors having eigenvalues above one. Varimax rotation assumes the factors are uncorrelated, therefore future work involves exploring a more conservation analysis approach that considers the factors being correlated. We used this data to inform our survey refinement process. As a first step, we eliminated potential scales that had consistently low loadings across the items, below .4 using the threshold suggested by Stevens [12]. We then ran multiple iterations, removing any item that had strong loadings on multiple items. Through this process, we eliminated half these questions, leaving seven scales. At this point, we eliminated items, with low factor loading, keeping the highest loading five items for two of the scales. The two other scales only had three items per factor. The last three factors did not have high enough inter-item reliability to keep. This process decreased the number of questions from 72 to 16 and from 16 factors to four. The team chose to keep between three to five questions to have enough variety in the wording while maintaining strong inter-item reliability. We present the final set of questions, scales, and factor loadings in Table 2.

Final Factors

From the final set of factors from the exploratory factor analysis, we gave each factor a name. All of the items within a single factor measure one construct. The final set of four factors are Engineering Self, Course Understandings, Areas for Growth, and Social Impact. Again, we list the scales and associated items in Table 1. We give expanded definitions for each factor in the following section.

Knowledge Gain Factor Definitions

Here, we define each construct based on the items that contribute to each factor. In providing definitions, we connect how each of these factors reveal different aspects of learning possible in doing reflection activities in engineering courses. In general, Knowledge Gains represent the type of learning a reflection activity can contribute to, beyond the learning the student has done from the activity they are reflecting on.

Table 2. Final List of Questions for the Knowledge Gain Instrument and the corresponding factor loading and Cronbach's alpha.

	Factors and Item	Factor Scoring
Engineering Self, α = 0.875		
1	In doing this reflection activity, I was able to understand how I fit into the engineering community.	0.756
2	In doing this reflection activity, my interest in my major (or intended major) increased.	0.734
3	In doing this reflection activity, I was able to hone in on my interests for this course	0.67
4	In doing this reflection activity, I thought about my path in my engineering career	0.78
5	In doing this reflection activity, I thought about what I bring to engineering	0.706
Course Understandings, α = 0.829		
6	In doing this reflection activity, I better understood key concepts in this course.	0.622
7	In doing this reflection activity, I felt prepared to do well in this course.	0.672
8	In doing this reflection activity, I was able to refine my understanding of course concepts	0.681
9	In doing this reflection activity, I made connections across course concepts	0.671
10	In doing this reflection activity, I can now articulate main ideas of this course	0.761
Areas for Growth, α = 0.716		
11	In doing this reflection activity, I understood more about my own weaknesses as a student.	0.825
12	In doing this reflection activity, I was able to improve my work	0.644
13	In doing this reflection activity, I gained insights about my study habits	0.697
Social Impact, α = 0.747		
14	In doing this reflection activity, I thought about ethical concerns in engineering.	0.708
15	In doing this reflection activity, I learned about the personal and emotional costs in engineering design	0.71
16	In doing this reflection activity, I understood a different way of thinking about a problem	0.562

- *Engineering Self*: This construct emcompasses a student's ability to see themselves as engineers, whether it is in their majors or future careers.
- *Course Understandings*: This construct represents the most common way of evaluating student learning, related to measuring how well the students perceive they comprehend the material related to the course, including understanding aspects that are still unclear.
- *Areas for Growth*: This construct captures the fact that reflection activity can help students identify ways in which to improve either the way they are approaching the learning of the material, or understanding of specific aspects of the course.
- *Social Impact*: This construct reflects the extent to which the reflection activity has helped the student see how their learning in engineering is connected to aspects that influence the social component of the world, whether it be personal impact or on a broader societal level.

Validation Process

In order to provide support of validity and reliability of the instrument, we calculated the inter-item reliability. Additionally, we see preliminary evidence of concurrent validity as represented by data from four different reflection activities.

Inter-item Reliability

Inter-item reliability measures the consistency of results across items, or questions, within an instrument [13]. This measure is used to show how consistent the answers are for each question for the same factor. Using the 127 responses to the deployment of the initial set of items, we calculated the inter-item reliability for each of the four factors and their related items. We were able to achieve Cronbach's alpha results in the acceptable range, above .7, but above 0.8 is preferred [14], specifically for new scale development [15]. Our two factors with 3 items have Cronbach's alpha values in the acceptable range but below 0.8 and this might be attributed to the smaller number of items as the value increases as the number of items increases [14]. The Cronbach's alpha for each factor is listed next to the factor name in Table 1. Based on these metrics, the RKGI meets the requirement of inter-item reliability for use.

Concurrent Validity

In order to run preliminary validation analysis on the RKGI, the research team analyzed data collected from survey data from exam wrappers or reflection activities intended to have students think about an exam they took. The preliminary data was collected from four different courses at four different institutions. The research team hypothesized that because of the nature of the reflection, students would see more knowledge gains on Course Understandings and Areas for Growth. This was true for data from all four courses. Data varied more for Engineering Self and Social Impact. More students learned about their Engineering Self than Social Impact from these exam wrappers. Instructors did not intend for these exam wrappers to have such knowledge gains but were pleasantly surprised to know that their students learned more from their exam wrappers than what was planned. These trends show that the RKGI strongly measures learning outcomes for intentionally designed factors, but also gives insights to other potential knowledge gains the instructor might be inadvertently including in their reflection activities.

Table 3. Sample student scores representing both high knowledge gains and low knowledge gains for different reflection activities.

	Factors and Item	Student 1	Student 2
Engineering Self			
1	In doing this reflection activity, I was able to understand how I fit into the engineering community	2	1
2	In doing this reflection activity, my interest in my major (or intended major) increased.	2	0
3	In doing this reflection activity, I was able to hone in on my interests for this course	2	2
4	In doing this reflection activity, I thought about my path in my engineering career	3	2
5	In doing this reflection activity, I thought about what I bring to engineering	3	3
	KG of Engineering Self Score (0-20)	**12**	**8**
Course Understandings			
6	In doing this reflection activity, I better understood key concepts in this course.	3	2
7	In doing this reflection activity, I felt prepared to do well in this course.	3	2
8	In doing this reflection activity, I was able to refine my understanding of course concepts	3	1
9	In doing this reflection activity, I made connections across course concepts	4	3
10	In doing this reflection activity, I can now articulate main ideas of this course	3	2
	KG of Course Understandings Score (0-20)	**16**	**10**
Areas for Growth			
11	In doing this reflection activity, I understood more about my own weaknesses as a student.	3	3
12	In doing this reflection activity, I was able to improve my work	2	1
13	In doing this reflection activity, I gained insights about my study habits	4	2
	KG in Areas for Growth Score (0-12)	**9**	**6**
Social Impact			
14	In doing this reflection activity, I thought about ethical concerns in engineering.	2	4
15	In doing this reflection activity, I learned about the personal and emotional costs in engineering design	3	3
16	In doing this reflection activity, I understood a different way of thinking about a problem	3	3
	KG in Social Impact Score (0-12)	**8**	**10**
	TOTAL KNOWLEDGE GAIN SCORE (0-64)	**45**	**34**

Discussion

In this section, we provide guidelines for using and scoring the Reflection Knowledge Gains Instrument. Because this instrument can be used by both researchers and educators, we have a section on overall scoring of the RKGI and a separate section for use cases specific to researchers and educators separately. We see researchers using this for large data collection studies and educators using it within their own classroom and teaching practice. We also discuss limitations of the survey and suggestions for use.

RKGI Scoring and Analysis and Guidelines for Use

The Reflection Knowledge Gains Instrument uses a five-point likert scale that ranges from strongly disagree to strongly agree. When scoring, strongly disagree should be scored as “0”, all the way to “4” for strongly agree. The possible Reflection Knowledge Gain Instrument score ranges from 0, meaning the reflection activity did not help the student gain any learning in the four factors, all the way to 64, meaning the student felt there was a high degree of learning in all of the factors. Because each scale has a strong inter-item reliability, one can choose to use any number of scales separately to measure learning in specific categories such as in “Engineering Self” or “Areas for Growth.” In Table 3, we include a sample response from two students to represent what the scoring process would look like on an individual student basis for both a student with high knowledge gain and a student with lower knowledge gain.

Student 1 is doing a reflection on a team activity in an introduction to engineering course. Student 2 is in a civil engineering course and is reflecting on implicit bias and stereotype threat. As expected, Student 2 has a lower knowledge gain score because the reflection activity was very topic specific, implicit bias and stereotype threat. But because the topic is related to social impact, student 2 does score higher than student 1 in that particular construct.

Use Case for Research

Having a validated instrument is particularly useful for doing more research on learning outcomes of reflection activities in engineering education. Researchers can compare the learning outcomes from different reflection activities to gain an understanding about the type of questions or even framing of questions that lead to specific learning outcomes. The comparison can be done between two different reflection activities or two different iterations of the same reflection activity. Researchers can also compare how student learning is different across different demographics. Although researchers should take caution when making generalizations to larger populations, this data can be supplemented by qualitative data to give researchers a better understanding of what might be causing the differences in situated contexts. Data for these comparisons can be within or between subjects, giving researchers even more insights to differences that might arise from the reflection activity itself or from students themselves. There are multiple factors that might be compared when looking at the learning outcomes of students. Differences might result from the content being reflected on (i.e exam, group activity, problem set, lecture, etc.), the type of course the reflection is taking place in (i.e. lab, technical, or design), and even in the learning preference of a student. This survey can be augmented by using multiple validated surveys to document different factors that might be contributing to student learning.

Use Case for the Classroom
Because each factor can be used individually, educators can choose to use the entire RKGI or specific factors. An educator may want to evaluate the learnings from a reflection activity they just created or they may want to track the learning from a specific reflection activity across the term. Additionally, if the reflection activity was intended to target a specific type of learning, the educator can just use those factors. For example, an instructor might want to know how much a reflection activity is helping students realize the course material is making sense. In this case, the instructor could solely use the Course Understandings factor. Similarly to using the instrument for research purposes, educators can use the instrument to compare learning outcomes between different reflection activities, different courses, different class sections, or even different students. The RKGI allows educators to systematically track the learning outcomes their reflection activities create for their students.

Because reflection is a metacognitive process, it is critical that the timing of the survey is documented. The amount of time between the reflection and the survey may influence the students' perceptions of their learning. Filling out the survey itself also functions as a reflection activity.

Limitations
The Reflection Knowledge Gains Instrument is in its early stages of the validation process. As the survey is used more, we acknowledge the survey might be refined even more. We expect to continue to learn about the RKGI as it is implemented on a larger scale. Additionally, we would like to emphasize that using qualitative data to triangulate the interpretation of the data would be the strongest method of data collection, in particular as students have different learning histories and preferences. Finally, as the reflection activity and the activity being reflected on tend to overlap in a students mind, qualitative data can also help disentangle a students positive or negative feelings towards the reflection activity or towards the learning activity being reflected on, such as an exam or problem set.

Conclusion
The Reflection Knowledge Gains Instruments provides a way for researchers and educators to measure perceived student learning from reflection activities. We have provided preliminary evidence of validity for a survey that measures student learning, or knowledge gains, across four constructs: Engineering Self, Course Understandings, Areas for Growth, and Social Impact. These four constructs all together have 16 questions. This instrument can help researchers understand more about what students learn from reflection activities, and on the practice side, can help individual educators evaluate their own reflection activities in the classroom. We are excited to add to the conversation by providing a systematic way of measuring different aspects of learning that a reflection activity can contribute to.

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