Testing a Reflective Judgement Scale for Suitability with First-Year Student Reflective Responses

Ms. Natalie C.T. Van Tyne, Virginia Tech

Natalie Van Tyne is an Associate Professor of Practice at Virginia Polytechnic Institute and State University, where she teaches first year engineering design as a foundation courses for Virginia Tech's undergraduate engineering degree programs. She holds bachelors and masters degrees from Rutgers University, Lehigh University and Colorado School of Mines, and studies best practices in pedagogy, reflective learning and critical thinking as aids to enhanced student learning.

Dr. Lisa D. McNair, Virginia Tech

Lisa D. McNair is a Professor of Engineering Education at Virginia Tech, where she also serves as Director of the Center for Research in SEAD Education at the Institute for Creativity, Arts, and Technology (ICAT). Her research interests include interdisciplinary collaboration, design education, communication studies, identity theory and reflective practice. Projects supported by the National Science Foundation include exploring disciplines as cultures, liberatory maker spaces, and a RED grant to increase pathways in ECE for the professional formation of engineers.

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Abstract

This Complete Evidence-Based Practice paper describes the use of reflection in a first-year engineering design course. Reflection is an essential part of learning, but it is not widely used in engineering curricula. However, using reflective learning techniques in the classroom can help students develop critical thinking skills [1] [2], which are highly valued in the modern workplace [3]. Critical thinking consists of an objective analysis and reconstruction of available information, often from multiple sources, before deciding what to accept as valid. While we expect that the ability to think critically develops with practice and time, it would be useful to discern how well our students could learn to reflect and think critically during their first year of college, even with minimal guidance in reflection.

Two theoretical models are useful when evaluating student performance on reflective learning tasks. The Perry Model of intellectual development [4], as interpreted by Pavelich and Moore [5] suggests that students with extensive practice in open-ended problem solving involving reflection will be more successful than their peers. Similarly, the King and Kitchener Reflective Judgment Stages model [6] contains a scale which is useful for measuring increased complexity of reflective thinking over time, another indicator of future success. Both models emphasize that knowledge is largely contextual, meaning that it is sometimes true, and sometimes not true, depending on the applicable context. Thus, context is another important factor to consider when evaluating students' reflective learning performance or ability.

In the present study, we assess the extent to which students use reflective judgment when writing about their experiences in a semester long introductory design course. Based on our theoretical models, we hypothesized that students whose reflections acknowledge the role of context in learning will additionally show a higher intellectual level of thinking over the course of the semester, as well as earn a higher grade on successive assignments. Therefore, we wanted to determine whether students' ability to reflect on their experiences in the course improved over time.

Sixty-five first year engineering students completed a series of five graded short essays. Four essays incorporated reflection about a specific three-week period in the course, while the fifth essay prompted reflection about the entire course content. In each case, students answered three questions whereby they identified the most important item of knowledge that they learned, why it was important, and where else they could use this knowledge, outside of the course. Assignment prompts also stipulated that reflection should extend beyond the specific needs of the course.

We operationalized the ability to exercise reflective judgment by using the Perry Model and King and Kitchener's Reflective Judgment Stages in parallel with an internally-developed grading rubric. Rubric criteria included the extent of relevant detail in describing items of knowledge and their context, and the application of specific knowledge to aspects of lifelong learning. By comparing the grades for each assignment over time, in conjunction with corresponding Perry Model and King and Kitchener stages, we expect to find a mixture of continual, sporadic or lack of progress. These results will help further develop this course in the

future and can provide new insights as to how students view the importance of reflection for their learning.

Introduction

When you reflect on an experience, you re-visit it in your mind and may wonder why something happened, and what it means to you. How important is it to remember what you saw or heard? What does it remind you of? What else can you learn from it? Kember, McKay, Sinclair and Wong described reflection as a “re-examination and evaluation of experience, beliefs and knowledge” [1], stating that reflection was necessary to solve ill-structured problems, which is a key aspect of engineering practice [3]. Since our overall objective is to help first year students deal with the expanding and often conflicting information, assumptions and opinions which accompany ill-structured problems, our results will inform our practice by revealing additional opportunities to exercise reflection within the context of technical skill development and engineering design.

Reflection should be included as an essential part of learning in engineering curricula, given that engineering educators intend to prepare students for the workplace, where professionals practice reflection-in-action [7] . What makes reflection valuable to learning is that it can improve metacognitive skills, such as self-awareness and comparisons to prior knowledge, which leads to more effective and sustained learning for knowledge retention, which are the overall goals of higher education [8]. Knowledge retention is particularly valuable to engineering students because of demands to learn, remember and apply large amounts of technical information in order to succeed in their courses.

Using reflective learning techniques in the classroom also helps students deal with problems, often ill-structured, for which there is no “right” answer. An ill-structured problem often contains missing, incomplete, and/or conflicting information [6]. The ability to solve these seemingly intractable problems is highly valued in the modern workplace, where they abound [3]. Reliance on authority figures or published information is not always prudent, because solutions to these problems are based on judgments about available knowledge, i.e., the combination of information and experience, and the acceptance of an unpredicted outcome. Models for intellectual development, such as the Perry Model by Pavelich and Moore [5] and King and Kitchener’s Reflective Judgment Stages [6] are useful for describing the various ways in which knowledge is regarded and employed to solve problems.

Reflection can also serve as a facilitator for critical thinking, which is a common learning outcome in first-year engineering courses, in particular. Critical thinking consists of an objective analysis and reconstruction of available information, often from multiple sources, before deciding what to accept as valid [9]. Niewoehner’s model A model for the development of critical thinking skills [10], based on Paul and Elder’s Critical Thinking Model [11], includes clarity, relevance, significance and depth as attributes of critical thinking, which are necessary for any field of study.

While we expect that the ability to think critically develops with practice and time, it would be useful to discern how well our students could learn to use reflective judgment during their first year of college, and apply it to their habits for critical thinking and metacognition. This knowledge could inform our guided practice in reflection through essays and other prompts. Our first-year engineering design course at a research institution in the southeastern United States already includes practice in certain professional skills, such as ethics and integrity, teamwork and technical communication. It is evident that reflective judgment is another important professional skill that should be initiated early in the engineering curriculum, both for solving ill-structured problems and for retaining knowledge.

Our research question is as follows:

- How well do first year students develop higher level thinking skills through reflective judgment, given periodic guided practice in a first-year design course?

We would expect that many of our students would advance to a higher level of thinking with reflection over the course of the semester, although their progress may not be continuous. Others, who already reflect as a habit, may already exhibit a sustained higher level of thinking with reflection. A third possibility is that a high level of reflection may emerge occasionally in response to one reflective prompt, but this level may not be sustained over the course of the semester.

Theoretical frameworks and their models were selected from the Perry Model [4], as applied by Pavelich and Moore [5], and the work of King and Kitchener [6]. These models were correlated to the grading rubric applied to the short reflective essays written by the study population. The data were de-identified in accordance with Institutional Review Board policies.

Background and Theoretical Framework

The Perry Model of intellectual development [4], as applied by Pavelich and Moore [5], suggests that students with extensive practice in ill-structured, open-ended problem solving will be more successful than their peers. The Pavelich and Moore study involved college students who were briefly exposed to "experiential learning" or what is now part of "active learning", or even "entrepreneurial engineering", through the pursuit of open-ended design problems based on real world needs. Their results revealed that few senior level students had reached a stage that would be expected in the engineering workplace, even after practice with experiential learning, although some progress toward higher level thinking had been made [5].

Similarly, the King and Kitchener Reflective Judgment Stages model [6] contains a scale that is useful for measuring the increased complexity of reflective thinking over time, which these authors based on studies with college students involving the ability to deal with ill-structured problems containing uncertainty. Both models emphasize that knowledge is largely contextual, meaning that it is sometimes true, and sometimes not true, depending on the applicable context, and that it contains uncertainty. Thus, the recognition of context and uncertainty are important factors to consider when evaluating students' reflective learning performance or ability. In order to prompt our students to consider alternative contexts in which their knowledge might or might not be valid, we linked levels of specificity in our reflective assignment rubric to several Reflective Judgment and Intellectual Development stages, as described below.

The ability to think critically is widely recognized as valuable, but the ability to exercise reflective judgment does not necessarily share this reputation in the community of first-year engineering educators, from our observations. King and Kitchener distinguished between reflective judgment and critical thinking by offering a critique of the Cornell Critical Thinking Test and the Watson-Glaser Critical Thinking Appraisal, which are two standardized tests to measure critical thinking ability [6]. The authors asserted that critical thinking relies on logic and specific methods to analyze problems, and does not include the recognition of epistemic assumptions about the nature of knowledge, which is a part of the Reflective Judgment Stages model [6]. These assumptions include the acceptance of uncertainty and the willingness to make judgments in view of it. In addition, King and Kitchener's description of critical thinking was largely limited to solving well-structured problems, whereas the Reflective Judgment Model addresses ill-structured problems directly. Ill-structured problems are often characterized by incomplete and ambiguous information.

As indicated by Niewoehner's model, a critical thinker applies specific attributes to their analysis, namely clarity, relevance, significance and depth [10]. King and Kitchener indicated that reflective judgment goes beyond using critical thinking tools to analyze and solve problems. It employs epistemic assumptions, or the ways in which people regard knowledge. The King and Kitchener model embeds these assumptions into each of their seven stages, which range from absolute knowledge based only on personal experience to an acceptance that knowledge is inherently uncertain, and often incomplete [6]. The middle stages exhibit an emergence of the role of context and evidence in making judgments about the validity of available knowledge in exercising judgment.

Research Methods

This study took place within a one-semester introductory engineering design course, which includes technical skill development in graphics and computer programming in addition to a design project pursued by teams. Short-essay assignments were graded according to a rubric based on the extent to which reflection was employed to describe emerging knowledge and its relationship to prior knowledge, alternative contexts, and lifelong learning. Specific rubric criteria appear in Table 1 on the next page, aligned with our adaptation of the Perry Model into seven stages corresponding to the King and Kitchener model.

Based on our theoretical models and the grading rubric, we hypothesized that students whose responses clearly applied their knowledge to alternative contexts would not only show signs of reflective judgment leading to higher level thinking skills, but would also be able to use the tools of critical thinking to weigh evidence and form more flexible beliefs about the dynamic nature of knowledge. There is also a relationship between a student's willingness to present a position backed by a variety of evidence and the necessity to think more deeply in order to identify and articulate that evidence. This is why the rubric criteria prompt students to consider alternative contexts in which to use their knowledge, and to give specific examples. Moreover, deep thinking is another attribute of King and Kitchener's concept of reflective judgment and Perry's concept of intellectual development.

Table 1: Intellectual Development and Reflective Judgment Stages Compared to Our Reflective Learning Journal Rubric

Stage	*Perry Model of Intellectual Development Regarding Knowledge*	*King and Kitchener's Reflective Judgment Stages Regarding Knowledge*	*Rubric Criteria for "Importance of This Item of Knowledge"*	*Rubric Criteria for "Where Else Could You Use It?"*
1	Is right or wrong, a collection of facts obtained from authority	Is absolutely certain and concrete, based on observation		
2	Is generally right or wrong. Authority gives us the right answer or give us problems to solve in order to find it.	Is absolutely certain but not immediately available, based on either observation or authority figure		
3	Is right or wrong, but some of it may be unknown. Authority gives the answers or the means by which to find them.	Is absolutely certain (from authority figures) or temporarily uncertain (beliefs serve as substitute until absolute knowledge is available)	Identifies a non-specific benefit or consequence (e.g., " I can use this in my job as an engineer.")	Names a non-specific use (e.g., " I can use this in my job as an engineer.")
4	Some of it is right or wrong, but most of it is unknown. If authority does not know, then everyone can have their own opinion.	Is uncertain because knowing always involves some ambiguity; data are not always reliable and may be subject to error. Idiosyncratic beliefs may exist.		
5	Most of it is contextual and can be judged qualitatively or subjectively.	Is based on context, and is subjective because it depends on individual perception and criteria for judgment	Identifies a specific benefit gained or consequence avoided	Identifies a specific use outside of this course
6	Is not absolute. Student accepts responsibility for making judgments and commitments based on their values.	Is constructed as a series of individual conclusions about ill-structured problems; information comes from a variety of sources. Conclusions are based on evaluations of evidence across contexts and can be derived from the opinions of well reputed others.	Identifies a specific benefit gained or consequence avoided clearly and convincingly	Identifies a specific use outside of this course clearly and completely
7	Is relative. Judgments are made among alternative views, and doubt is recognized and accepted.	Is constructed as a series of individual conclusions about ill-structured problems; is re-evaluated based on new evidence or perspectives, or the availability of new tools of inquiry		

Study Context

Participants were given five short essay assignments, each covering three weeks of the semester, in which they identified the most important elements of knowledge that they had learned, what it meant to them, and where else they could apply it. Each essay consisted of responses to the following prompts:

- What was the most important item of knowledge that you learned in this course over these three weeks?
- Why was it important for you to learn it? Please use a specific example, except for an immediate need to use it in our design project, or to pass the course.

- How could you use this knowledge somewhere outside of this course, such as in another course, a job, at home, etc.? Please be specific and tell me something that I am not likely to already know.
- What did you encounter over these three weeks that you still find difficult to learn?

The last question was not graded, but was included to provide feedback for formative assessment of course topics and how students responded to them. The same questions and grading rubric were used for each assignment throughout the semester, except for the final assignment. The final assignment's questions were modified in view of the intent to reflect on the entire semester, rather than on a particular three-week period. In all cases, the grading rubric was made available to the students along with the assignment description.

Grading was based largely on the specificity of responses for clarity and depth, as identified by Niewoehner [10] as attributes of critical thinking. These attributes were aligned with intellectual development and reflective judgment, as shown in Table 1 above.

Participants

The participants were sixty-nine first year engineering students among eight sections of an introductory engineering design course over two semesters. The course is the second in a two-course sequence; therefore, these participants were not first-semester students. A briefing was given at the beginning of the semester to introduce reflection as a way to identify the meaning of specific knowledge. Additional lessons, focused on reflection, were not included, in view of resource constraints to cover existing technical and design course content. Since the same rubric was used for all assignments, students further learned about the value of reflection by fulfilling the rubric's requirements for specificity and uniqueness of their responses.

Data Collection

The reflective essays were graded as homework assignments, on a scale of 1-15. Because student progress in employing reflection was of interest, homework submittals were collated by participant, marked with grade, and de-identified in accordance with IRB stipulations. A total of 325 homework submittals by 65 participants was available for analysis.

Data Analysis

While the responses to the first question in each assignment were of interest as feedback about the course content, they were expected to be mostly narrative, with little to no reflection. Therefore, we focused on the responses to the second and third questions for evidence of reflection, and categorized responses according to stages of the Perry and King and Kitchener models.

We were also interested in the relationship between assignment grades and extent of reflection for each participant, given that two thirds of the total grade were based on the responses to two largely reflective prompts. Since the prompts stipulated specific examples, was specificity also an indication of reflection? Therefore, each participant's combination of reflection stages (i.e., lowest to highest stages exhibited) was compared to their average grades and standard deviations to determine how well specificity was linked to reflection.

Limitations to this Study

This is a qualitative research study, in which applicable aspects of quality include the relationship between the research question and data collection and analysis, relevance of the results to the research question (a form of overall warrant), and ability to inform or improve practice [12]. Improving methods of guided practice in reflection serves our overall course intent to provide students with methods to solve ill-structured problems.

Meaningful reflection requires both practice and experience. First-year students are more limited than upper-class students in their prior knowledge for comparison to recent knowledge. The ability to reflect for the expansion of knowledge is not included in our course objectives, although the ability to exercise critical thinking is implied. Therefore, we are limited in our exploration of reflective judgment and intellectual development.

Verification is also important, especially for transferability and more widespread acceptance of our recommendations. Procedures which apply include prolonged engagement with participants' written responses, clarifying researcher bias (being clear about our own assumptions and biases), and peer review prior to any form of publication. At the same time, researcher bias can interfere with objective analysis, and resolved through inter-rater reliability, whereby another researcher would also analyze the data.

We also relied on two theoretical frameworks instead of just one, because strict adherence to only one theory can also lead to bias through the exclusion of alternative views [13]. While we rely on the validity of two theoretical frameworks for this study, they are not independent, as the work of King and Kitchener used the Perry Model as its basis [6]. However, the Niewoehner model was also useful as a way to describe and measure critical thinking ability [10].
Finally, because the same grading rubric was used throughout the course, and was available to the students before each assignment, no variations in performance were due to changes in the rubric. Therefore, the rubric provided a set of standards for more consistent measurement than if the rubric had evolved according to responses in the individual assignments.

Results

Combinations of several stages of reflective behavior are shown in Table 2, as shown below. The majority of participants exhibited Stage 4 reflective behavior in their early responses, where most knowledge is unknown and idiosyncratic beliefs may exist. These participants often exhibited Stage 5 in later responses, where judgments are based on context but are still subjective. The second and third highest groups progressed from Stage 4 or 5 to Stage 6, where judgments are based on consideration of multiple contexts and acceptance of uncertainty, yet grounded by individual values. Participants exhibiting Stage 7 reflective behavior had provided highly credible evidence for their views, and recognized how their views might change in light of new information. Table 2 also shows the progression among intellectual development and reflective judgment stages, correlated with grading rubric criteria for the second and third reflective prompts.

Table 2: Progress from Lowest to Highest Level			
Lowest	Highest	# Responses	%
3	6	1	1.5
3	7	1	1.5
4	5	22	33.8
4	6	15	23.1
5	5	4	6.2
5	6	14	21.5
5	7	8	12.3
	Totals	65	100.0

Overall progress among stages was sporadic in general, meaning that that a response might show Stage 3 or Stage 4 reflection in the first assignment, then progress to Stage 5 or 6 in a subsequent assignment, then revert back to Stage 4 or 5 in later responses. In addition, the only participant group attaining Stage 7 were those who began at Stage 5.

Comparison of average assignment grades with attainment of one or more intellectual development/reflective judgment stages revealed that grading was more dependent on specificity of responses and the presence of evidence to support a position, rather than on the recognition of multiple sources of information or uncertainty in predicting a future outcome. In addition, although we had correlated certain grading rubric criteria to Reflective Judgment Stages 3, 5 and 6 (see Table 1), a perfect assignment score did not necessarily mean that the student had submitted any Stage 7 responses. In general, longer responses contained richer descriptions and additional evidence for a particular position, but a small number of shorter responses contained equally thoughtful impressions.

Sample responses for each Table 2 stage combination appear in Table 3 on the next page. Responses in Stages 4 and 5 indicated participants' beliefs, often limited or idiosyncratic, and lacking an indication of a path forward to achieving their aspirations. In general, Stage 6 and 7 responses contain more detail and descriptions of specific phenomena than responses in Stages 4 or 5, and were distinguished for recognition of alternative contexts and lifelong learning skills.

Table 3: Samples Responses for Stages 4-7 of the Perry Model or the King and Kitchener Reflective Judgment Stages

Participant	***Response showing Stage 4***	***Response showing Stage 5***	***Response showing Stage 6***	***Response showing Stage 7***
John	Learning a CAD program is important to me because I will be using it for the rest of my academic and professional career. Inventor, or similar CAD programs, are used to fabricate parts for mechanical creations. It is an essential program to be able to use.	By understanding MatLab, codes could be written with certain parameters given specific inputs. Having an understanding of MatLab will greatly benefit you when trying to learn other coding languages, because, while they're not the same, they are similar in certain ways.		
Jeremy		When working on a new/difficult assignment, there will almost always be points where you have to come up with an alternative way of approaching the problem, and using previously successful methods can be a good way to get past the problem.	Chemistry lab reports normally take much longer time than estimated. If I consistently allocate more time, I will write more efficient and higher quality reports. Allowing a little extra time to get somewhere also makes every day flow a little smoother and prevents me from being late if something unexpected happens.	
Emily	This will be very beneficial to me when reading or sketching designs in the future. By understanding the formatting of orthographic sketches, I will be able to visualize the final product more easily.	I have already begun using CAD to help my dad design a shed for our back yard. By using CAD, I have been able to send him his designs back in 3D so that he can visualize what he is trying to build more easily.	Abiding by the NSPE Code of Ethics can ensure that any problems with a product can be solved a reasonable manner. Knowing different ethical frameworks can help to predict what somebody else may choose to do regarding a project.	
Trevor		Simplicity is the key when seeking innovations or efficiency in the workplace. With specific methods to use under certain conditions, work efficiency is consistent and the project is completed without overlap. For example, when building a house, having designated methods for construction groups prevents overlap, since each worker has a designated role.	The data analysis methods that we used in MatLab could be applied to simulations that test adjustments to large-scale projects, such as aircraft equipment analysis, without the need to collect flight performance data. The simulated data could also be analyzed using the MatLab statistical functions.	Accuracy in dimensioning is a measure of how much variation/uncertainty is acceptable in satisfying an outcome. In terms of drug dosages to an organism, a difference of 0.0004 mL could result in a lethal dose if the organism's concentration tolerance was exceeded. Making sure that the dimensions of a design fit prior calculations ensures an expected and controllable outcome.
Peter	I am planning on studying aerospace engineering. In my field, I will be designing and modeling parts, assemblies and processes with CAD-style programs. Hence, understanding CAD is very important for my career.	By understanding the engineering design process, I will have a fuller understanding of what will is expected in the workforce. As an aerospace engineer, assigned to research a topic, when I prepare a report about the topic, the quality of the report will be higher.	Knowing about the design process makes it possible to re-define a complex problem in different terms to make finding a solution easier. At the same time, redefining a problem in different terms by different parties could lead to different solutions.	People work better and feel better when they feel included in the process of learning, such as learning how to learn. This is where the Common Core math system has failed: it teaches students how to learn, but fails to provide sufficient practice in fundamental skills that enable higher level learning.

Discussion

Our results indicated that guided practice in reflection was beneficial for certain participants in prompting them to reflect on their impressions of course content and its importance to them. In designing the grading rubric, our stipulation for specificity was intended to provoke well-reasoned responses as well as rich yet concise descriptions of supporting evidence. The presence of supporting evidence is an indicator of the ability to think critically [10]. Critical thinking, though, might or might not involve reflection, because it can be exercised using logic, but without beliefs.

Certain participants readily provided alternative contexts in their responses, and approximately 14% of all participants attained the highest level of intellectual development/reflective judgment at some point during the semester, in which they combined multiple contexts with changes in their own thinking. However, reaching Stage 7 did not occur at the end of the semester, but during the middle stages.

In the responses, most participants used at least some reflective judgment or higher-level thinking in the form of metacognition about the nature of their knowledge and the possibility of uncertainty. However, many of these participants also gravitated toward one familiar or nearly familiar context in their responses to the third question, ("where else could you use this knowledge?"), which could explain why the majority of participants advanced by only one development/judgment stage.

The highly sporadic behavior in the assignment grades for approximately one third of the participants indicates additional factors affecting the willingness to exercise reflective judgment and include supporting evidence in responses. These factors include time available to the participant to answer the questions, their energy level for thinking at that time, and the demands of concurrent assignments in their other courses. Responses from these participants also contained wide variations in the levels of development/judgment categories identified, although none of their responses could be considered as Stage 7. These participants were also more likely to use sweeping statements, such as "I am sure that I will use this skill as an engineer", but not explain how they expected to do so. Here is another case where limited exposure to the engineering workplace might be a factor in limiting knowledge about it. Preconceived notions about the nature of engineering may also influence this type of response. This insight reflects on the identity of the profession as seen by its future practitioners.

The participants found the prompts to be mostly straightforward and directly related to the course content over a specific time period, making each assignment relatively easy to complete. In addition, many of the participants readily shared their knowledge, beliefs and assumptions with little reservation.

Conclusions and Recommendations

While incorporating context into responses to reflective prompts led to convincing evidence for participants' positions in homework assignments intended for reflection, many of our participants limited their responses to one or at most two alternative contexts. Some would occasionally include more than two contexts or sources of information for their positions, and/or acknowledge that their sources of knowledge were reliable, but not perfectly accurate. We also found that progress toward higher stages of intellectual development/reflective judgment was sporadic. In a future study, it might be useful to identify the type and quantity of alternative contexts mentioned in the responses in order to more fully understand the participants' frames of reference.

Another option would be to convert our assignments to a continuous reflective "journal" structure, where students would add successive entries to the same document, and would submit the entire document in five periodic assignments. In the way, students could then reflect on their previous submittals when writing subsequent ones, or even revise earlier journal entries in light of new knowledge. We emphasize "could" rather than "would", based on our experience in working with first year students and recognizing their tendencies.

We would also offer additional guidance in reflection, such as sharing examples of reflective responses corresponding to the higher stages of the intellectual development and reflective judgment models. Many of our students infer their knowledge inductively rather than deductively, in that they learn from examples more easily than from theory. Another way to use examples would be to present the same topic or theme according to each reflective judgment/intellectual development stage.

Our current method for guided practice, with the same questions and grading rubric for each assignment, does not necessarily promote continuous improvement in reflection over the course of one semester. We would continue to offer reflective learning assignments as guided practice in reflection, but would vary some of the questions from one assignment to the next. This attempt at variety might also prevent resentment from students who take a dim view of reflection and its value in an engineering course, by making the prompts more novel and therefore interesting. Instructors could also address this skeptical view by providing more substantial and convincing evidence that reflection provides value in the practice of engineering.

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