Sloan, J. A. & Frank, T. E. (2023) Student self-assessment data: An instrument for program assessment. *Intersection; A journal at the intersection of assessment and learning, 4*(2).

Student self-assessment data: An instrument for program assessment

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The views expressed in this paper are those of the authors and do not necessarily reflect the official policy or position of United States Air Force Academy, the Air Force, the Department of Defense, or the U.S. Government. We have no conflicts of interest to disclose.

Intersection: A Journal at the Intersection of Assessment and Learning
Vol 4, Issue 2

Abstract: The ability to assess oneself is important in higher education, on the job, and throughout all aspects of life. Knowledge surveys (KS) are a self-assessment tool where students rate their ability to answer a knowledge question or perform a skills task. Previous research has shown that students are accurate self-assessors compared to instructor assessments when KS questions are specific and well-aligned with learning objectives and course content. Although it has been suggested as a use of KS in the literature, there are few data on the specific use of KS as a part of a continuous improvement process for program assessment. In this case study, KS were implemented in a Fundamentals of Engineering (FE) exam review course at an undergraduate-only civil engineering program in the western U.S. The paper will outline several components of our continuous improvement process, then compare KS with FE exam results from a cohort of students. The comparison demonstrates the utility of student self-assessment data as one artifact that helps to paint a more complete picture for program assessment. In addition, we will present several assessment benefits to implementing KS in courses and throughout an undergraduate program.

Keywords: *self-assessment, knowledge surveys, metacognition, continuous improvement, program assessment, lifelong learning*

Introduction

Self-Assessment

Self-assessment is a key component of learning and lifelong learning (Andrade & Valtcheva, 2009; Boud & Falchikov, 2005; Nilson 2013). Researchers as early as Sadler (1989) identified that students need to move beyond teacher-provided feedback to self-monitoring. Boud and Falchikov (2007) noted that a core purpose of education is to develop the capacity of students to make informed and accurate judgements about their own work. Boud et al. (2013) describe the learning process as a continuous refinement of student metacognition and self-assessment by stating:

> We posit that students learn by consistently making evaluations and relating these to the evaluations of others: reflecting on if their judgements were accurate or not, looking for

> reasons behind poor judgement and for ways to improve future judgements, wondering what they have missed in making their judgements that others have seen. (p. 943)

Self-assessment is a key self-regulated learning skill (Nilson, 2013) used by expert learners to deliberately select learning strategies to achieve learning goals (Ertmer & Newby, 1996). Wirth et al. (2021) note that self-assessment promotes both learning and self-directed learning through metacognitive processes. Accuracy in the self-assessments of one's knowledge and abilities is central to metacognition (Dunlosky & Metcalfe, 2009). Other research highlights that if students are unable to self-assess, then they will be ill-equipped for professional roles (Boud et al., 2013), while others emphasize the importance of self-assessment to career choice and success (Jaeger, 2018; Shulz & Thöni, 2016). For all these reasons, many researchers in this area argue that teachers are obligated to systematically teach students self-assessment skills as an overt part of any curriculum (Andrade, 2019; Boud & Falchikov, 2007; Sadler, 1989; Wirth et al. 2021).

Knowledge Surveys

Knowledge surveys (KS) are a self-assessment tool where students rate their ability to perform a given task, whether knowledge or skills-based (Nuhfer, 1993, 1996; Wirth & Perkins 2005). Questions should be specific (Nuhfer & Knipp, 2003; Sloan & Scharff, 2022), such as "I can solve for head loss in a pipe due using the Hazen-Williams equation" rather than general, e.g., "I can solve fluid mechanics problems." Rather than respond to the KS question with the knowledge or the skills required, students respond to the question by rating their ability to perform the required task by selecting one of several response options. A simple series of three response options might be "Yes, I can answer the question", "I can partially answer the question" or "I cannot answer the question." The specificity of the response options lends KS to be more descriptive than Likert-scale questions with "strongly disagree" to "strongly agree" response options. For example, the difference between a "strongly agree" and "agree" response is somewhat subjective. Although the Likert-scale questions certainly serve a purpose, KS are distinct from self-assessment questions using a Likert-scale since the nuanced, action-oriented response options have the potential to promote deeper metacognitive thinking in students. KSs also enable faculty to discern levels of student self-assessed understanding more granularly.

Faculty use student responses to calculate a normalized numerical score and compare the pre-post improvement in self-assessed ability, as well as compare post-KS with other assessment data, e.g., exams, projects, or writing assignments (Nuhfer & Knipp, 2003; Sloan & Scharff, 2022; Wirth & Perkins, 2005). Faculty typically administer a pre-KS early in a course or prior to a new block of instruction (Favazzo et al., 2014; Nuhfer, 1996; Nuhfer & Knipp, 2003). These data are helpful to determine the level of student self-assessed understanding of a given series of topics in a course (Nuhfer & Knipp, 2003). Faculty can then tailor course instruction and activities, spending less time or skipping entirely those topics where students already have a reasonable level of self-assessed understanding (Sloan & Scharff, 2022, Wirth & Perkins, 2005). Likewise, faculty administer a post-KS near an exam, project, or writing assignment which permits them to compare grades on a given assignment with each student's self-assessed ability (Favazzo et al., 2014; Nuhfer, 1996; Wirth & Perkins, 2005). Faculty can share student results anonymously along with group statistics such as the correlation between grades and student KS scores, and the average "error" of the cohort where error is calculated as the difference

between a KS score and grade (Nuhfer & Knipp, 2003; Sloan & Scharff, 2022; Wirth & Perkins, 2005). This comparison enables conversations with students collectively, such as the importance of metacognition and self-assessment to learning and how accurately the cohort is self-assessing.

Researchers have found that students can accurately self-assess their abilities compared to instructor assessments when questions are specific rather than broad or global in nature (Nuhfer et al., 2016a, 2016b, 2017; Watson et al., 2019; Wirth et al., 2021). When used in a course, student post-KS's compare well with scores on exams, design projects, and writing assignments (Bell & Volckmann, 2011; Favazzo et al., 2014; Sloan & Scharff, 2022; Sloan et al., 2022). Other research shows that better-performing students (as measured by their GPA) tend to be better self-assessors (Sloan & Scharff, 2022). Research also suggests that students improve their self-assessment abilities and achieve better alignment with instructor assessments with practice and feedback when a specific self-assessment mechanism is systematically incorporated into a course (Boud et al., 2013; Sloan & Scharff, 2022). Self-efficacy can be gained by practicing self-assessment (Ross, 2006) as students calibrate their self-assessment abilities over time, for example by comparing KS scores to direct measures of competency. Accuracy in self-assessment can empower students to become more self-directed learners, wherein students take ownership of their own learning by choosing what to learn, establishing goals, and seeking knowledge to meet those goals (Cheng et al., 2010).

Each student's individual data also reveal whether they are accurate in their self-assessments, or perhaps habitually over or underconfident (Watson et al., 2019). Faculty can then have a conversation with each student accordingly (Nuhfer & Knipp, 2003; Wirth & Perkins, 2005). For example, a low-performing student who accurately self-assesses their ability may lack motivation while a low-performing student who is overconfident may need assistance with utilizing appropriate study techniques given the nature of the course and the assessment. Additionally, viewing self-assessment data may enable a high-performing student with low self-assessments to build self-efficacy and better understand their competence in a subject. Lastly, faculty can discuss proper study habits with a student who self-assesses highly but performs poorly on a given assignment (Sloan & Scharff, 2022).

Over or under confidence of a student cohort may inform faculty about better teaching practices, misalignment of assessments, or student misperceptions about faculty expectations (Sloan et al., 2022). For example, overconfidence relative to performance on an exam could be because the exam questions were not in alignment with the course objectives upon which the KS was based. In an ideal case, faculty have well-designed courses with specific learning objectives that clearly communicate learning expectations, formative assessments that enable faculty to observe student performance and intervene as needed, and summative assessments that are well-aligned with the objectives and instruction of the course (Nuhfer, 1996; Nuhfer & Knipp, 2003; Wirth & Perkins, 2005; Wirth et al., 2021). In all cases, faculty have a tool to teach students not just about a given topic, but to teach students about self-assessment as a fundamental component of learning and to teach them how to think metacognitively (Andrade, 2019; Boud & Falchikov, 2007; Boud et al., 2013; Wirth et al., 2021).

In assessment, there is a "true" measure of student performance, or competence in the subject matter, the instructor's measure of student performance, and the students' self-assessed measure of

their performance (Wirth, 2017a; Wirth 2017b). In cases where a course is well-aligned (objectives aligned to instruction and assessment), and grading is unbiased, then the instructor's measure is perhaps as close to a true measure as we could hope for (Wirth & Perkins, 2005). However, in using new instructional techniques in the spirit of continuous improvement, faculty may not always have a well-aligned course (Wirth & Perkins, 2005). In those instances, students' perceptions about their own performance may provide valuable feedback to faculty on student misunderstanding of objectives, misaligned assessments, or a mismatch in faculty versus student expectations (Wirth & Perkins, 2005).

For example, Becker and Sloan (2023) and Sloan et al., (2022) describe the use of KS for technical writing. Students completed the same technical writing KS multiple times in a course and by using KS, the researchers learned that students had misplaced expectations. After realizing the students' under confidence in self-assessment of their technical writing abilities as a cohort, the researchers' conversations with students revealed that the students were judging their writing abilities against the expert level of technical writing they observed in their textbooks, official documents, and other professional writing samples. Meanwhile, faculty in the course graded the students on the technical writing capability the faculty would expect from a typical undergraduate student. KS illuminated the dichotomy of expectations and sparked conversations with students during the semester. As a result of these conversations and cycles of instruction, peer review, and instructor feedback on assignments and self-assessment accuracy, not only did the student scores and technical writing abilities improve through the semester, but the gap between student KS and instructor grades on the writing assignments narrowed as well (Becker and Sloan, 2023, Sloan et al., 2022). KS are thus a valuable tool for helping both students become better learners and faculty become better teachers (Nuhfer & Knipp, 2003).

Background

Continuous Improvement and ABET Criteria

The Engineering Accreditation Commission (EAC) of the Accreditation Board for Engineering and Technology (ABET) establishes criteria for the accreditation of undergraduate engineering programs (ABET, 2022). Programs are required to demonstrate that their graduates meet the seven ABET student outcomes or "SOs" given in Table 1. In demonstrating that their students achieve the ABET SOs, programs historically rely heavily on artifacts of student work such as performance on exams, design projects, laboratory exercises, technical writing assignments, and capstone experiences. Programs also sometimes rely on data from the Fundamentals of Engineering (FE) exam (e.g., Bowen, 2010; Guarino et al., 2013; Liaw et al., 2008; Sadowski et al., 2007), faculty-developed comprehensive exams (Lewis et al., 2010; Gnanapragasam et al., 2008; Schimmel et al., 2003; Terry et al., 2002; Varma, 2006) or concept inventories (Jorion et al., 2015).

Table 1

EAC-ABET student outcomes (ABET, 2022)

Number	Student Outcome
1	an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics

2	an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
3	an ability to communicate effectively with a range of audiences
4	an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts
5	an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives
6	an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions
7	an ability to acquire and apply new knowledge as needed, using appropriate learning strategies

Fundamentals of Engineering Exam

What it is

The FE exam is developed by the National Council of Examiners for Engineers and Surveyors (NCEES). The FE is a nationally normed summative engineering exam that students in many undergraduate engineering programs take in their final semester. The exam is 6 hours in length and students take the exam via computer at an established testing center. Students choose a discipline-specific portion of the exam based on their program of study, e.g., civil engineering or mechanical engineering (NCEES, 2020).

As one of the first steps in licensure as a Professional Engineer, along with graduating from an ABET-accredited engineering program, most civil engineering programs encourage students to take the FE exam in their final semester. As a further step, many programs require students to take the FE exam (Gnanapragasam et al., 2008; Liaw et al., 2008; Plantenberg, 2008; Roney et al., 2017), and a small cohort of programs require students to pass the exam as a graduation requirement for the program (Craver et al., 2003).

How it is used

FE results are used in part for program assessment by many engineering programs (Bowen, 2010; Doepker, 1999; Guarino et al., 2013; Koehn & Malani, 2005; Liaw et al., 2008; Sadowski et al., 2007; Stuart & Steinberg, 2005; Younis, 2005). Crawford et al. (2021) provide general guidelines for using the FE for program assessment among other tools. In one study, a slight majority of engineering schools were "in favor of the use of the modified FE as an assessment tool" (Doepker, 1999, p. 9). As such, it was encouraged that the current FE be modified so that "it can be used both as an educational assessment tool and as the first professional exam" (Doepker, 1999, p. 9).

Knowing the importance of the FE to professional licensure, and to some programs' continuous improvement processes, some engineering programs offer an FE review course for students (Khatib et al., 2020a, 2020b; Swenty et al., 2021). Crepeau et al. (2020) redesigned an FE review course tailored to Gen Z students (short videos, available problem sets) which shows promise for increasing student pass rates. In other cases, longitudinal FE data are used to either drive or evaluate the effects of curricular changes in courses (e.g., Melnyk et al., 2016).

FE and self-assessment

A few researchers have asked students to report metacognitive self-confidence ratings for the FE exam. Swenty et al. (2021) report a single global question about student self-confidence in passing the exam on a 5-point Likert scale. Pre-post self-confidence increased at all three universities studied in three distinct courses (FE review, reinforced concrete, and concrete materials). Notably, there was only a 6% increase in pre-post self-confidence in a three-semester-hour FE review course reported by Swenty et al. (2021). In a slightly more refined approach than the single global measure by Swenty et al. (2021), Khatib et al. (2020a, 2020b) used a pre and post student self-confidence rating on a Likert scale across eight major topic areas for the chemical engineering FE. Students showed a clear increase in confidence after completing the review course problem sets. Students also reported their level of metacognitive reflection in completing the review problems and in all subject areas. The results indicated a self-reported reflection level above a 3.0 neutral value on a 5-point Likert scale. Additionally, statistical analysis of the responses indicated students were consistently reflective across multiple topics throughout the course, thus, substantial levels of metacognitive reflection took place. Confidence was also correlated to performance on mock exams (Khatib et al., 2020a, 2020b). These two examples aside, there is little in the literature about self-assessment for the FE exam as a summative engineering exam.

Purpose and Research Hypothesis

Purpose

Given that KS have been used successfully in individual courses, we naturally had the research question: *are KS a useful tool for program assessment?* If so, *how might they be used successfully for this purpose?* Several researchers mention the utility of KS for program assessment conceptually (Favazzo et al., 2014; Nuhfer & Knipp, 2003; Wirth & Perkins, 2005), but there are few data in the literature to directly illustrate the value of KS data to assessing and improving an academic program.

In this paper, we will describe the program assessment framework that our department uses to demonstrate achievement of ABET student outcomes including Fundamentals of Engineering (FE) exam results, assessment artifacts, student exit surveys, and student advisory council inputs. We will then describe the use of knowledge surveys in the civil engineering program at the U.S. Air Force Academy (USAFA), particularly their use in the FE exam review course. We will compare pre and post-FE review course KS data with the students' performance on the exam as a cohort. Lastly, we will draw conclusions about how the use of knowledge surveys as a student self-assessment tool has informed program assessment and the program's continuous improvement process.

Research Hypothesis

The literature shows that self-assessment is an important skill to cultivate in students for lifelong learning. KS have been shown to be an effective tool to help students practice and calibrate their self-assessment skills within an individual course. They can also help faculty members better align their course objectives, activities, and assessments. In addition to the benefits at the course level for students and faculty, *the authors postulate that the lessons learned and benefits for both faculty and students from applying KS in individual courses will also apply at the program level*. Thus, we believe that KS can be a helpful tool for program assessment. USAFA's civil engineering program already has several assessment events that are collected and analyzed annually, and the use of KS alongside the comprehensive Fundamentals of Engineering Exam taken spring of senior year will be explored as an additional program assessment tool.

Institutional and Program Context

U.S. Air Force Academy

USAFA is a small undergraduate-only university in the western United States. The Department of Civil and Environmental Engineering has 14 full-time teaching faculty and graduates an average of 40-45 civil engineering majors annually. The institution has a large general education curriculum and students are required to declare a major in their third semester. Thus, at any given time, there are approximately 120-150 students enrolled in the civil engineering program.

As a military institution, USAFA has a large general education curriculum focused on the essential education for officership. Although it serves a valuable purpose, the large general education curriculum constrains the number of courses that can be offered in the major's curriculum. The overall curriculum consists of 93 semester hours of general education courses and 45 semester hours of major courses (United States Air Force Academy, 2022). Many of the general education classes are in math, basic science, engineering, or other topics that directly support the program in meeting ABET criteria for those courses.

Authors

Authors of this paper are the Department Head and Deputy for Curriculum of the Civil and Environmental Engineering Department at USAFA, who have been using KS in courses for approximately 5 years. We have used them successfully in individual courses and we are exploring their value and application in the broader context of program assessment.

Continuous Improvement Process

The program identifies three constituency groups: students, faculty (to include former faculty), and the civil engineering (CE) career field in the U.S. Air Force. Faculty and CE career field input is collected periodically in off-site meetings, former faculty and industry day forums, and in the annual Education and Training Review Committee (ETRC) hosted by the CE career field. The existing continuous improvement process includes several assessment tools used to maintain program accreditation, and recent success in applying KS lend themselves to consideration as an additional program assessment event. Since the focus of this paper is on student self-assessment, we will focus primarily on program assessment data collected through KS from students.

Assessment Culture

The department has a strong assessment culture as it pertains to EAC-ABET accreditation. Course directors complete a course assessment plan (CAP) at the beginning of the semester and a course assessment report (CAR) upon its completion. Faculty have identified artifacts (student grades on exams, projects, and writing assignments, for example) from selected major courses that help demonstrate that students in the program meet each of the seven ABET SOs (Table 1). Faculty summarize the data for each course in their CAR with particular attention to the pre-determined artifacts supporting the SOs. The Deputy for Curriculum collects data from the CARs and prepares an annual assessment report during the summer following each academic year. Faculty review and discuss the results of the report at an offsite in August with an eye for continuous program improvement.

In addition to student grade data on a variety of assignments in courses, the program uses results from the FE exam, a student exit survey, and a student advisory council roundtable to inform the annual assessment report and demonstrate achievement of the ABET SOs. The exit survey is conducted within the context of the FE review course that we will describe later. The exit survey consists of a series of Likert-scale questions that help the program show student achievement of the ABET SOs. Questions are targeted to assess areas that are more

difficult to directly measure (e.g., whether students can make informed judgements to incorporate economic or societal impacts in their designs).

The department's Deputy for Curriculum also leads an annual student advisory council of 12-15 students across class years that is representative of the students in the program. The faculty member leads an informal discussion around pre-determined topics of interest and summarizes themes of the discussion for other faculty to review as a part of the continuous improvement process. The student advisory council is a more informal approach to student feedback on the program which faculty use to guide their curriculum and program decisions, but they are not formally incorporated into demonstrating that students meet the ABET SOs.

Exit Surveys

Table 2 illustrates six Likert-scale questions that the CE program uses to support the achievement of the ABET SOs along with sample results from Spring semester 2022. The response options on the Likert scale are: 0 – Not applicable, 1 – Strongly disagree, 2 – Moderately disagree, 3 – Slightly disagree, 4 – Slightly agree, 5 – Moderately agree, 6 – Strongly agree. Notably, all six items have an average above 5.0 which puts all of them in the Moderately Agree to Strongly Agree range. Although the relative value of a numerical score on a Likert scale may be hard to quantify, the real value in the data comes from a longitudinal comparison where a significant shift up or down in each cohort of students compared to previous cohorts may provide an indicator requiring further investigation. The CE program has used similar questions dating back to 2003 through three ABET accreditation cycles with visits in 2008, 2014, and 2020. Although these are not KS, they have historically provided substantial value as the faculty assesses the efficacy of the overall program by providing student perspectives on their learning where collecting data on a given topic is somewhat difficult to do otherwise.

Table 2

Likert questions contained in the CE program exit survey

Question	Average 6-pt Likert Response (N = 30)
I can recognize professional and ethical responsibilities in engineering situations and make informed judgments in a **global** context.	5.30
I can recognize professional and ethical responsibilities in engineering situations and make informed judgments in an **economic** context.	5.03
I can recognize professional and ethical responsibilities in engineering situations and make informed judgments in an **environmental** context.	5.13
I can recognize professional and ethical responsibilities in engineering situations and make informed judgments in a **societal** context.	5.13
I have the **knowledge of contemporary issues** (e.g. Technical, environmental, societal, political, legal, aesthetic, and economic).	5.07
I have the **ability to acquire and apply new knowledge** as needed, using appropriate learning strategies.	5.33

Demonstrating Student Outcomes – Student Outcome #4 Example

As an example of how the program integrates artifacts from various sources to demonstrate SOs, Table 3 illustrates the artifacts used for SO #4. The artifacts include grades in general education classes, performance on various assignments in CE major courses, FE exam data, and Likert-scale questions that students complete at the

end of the program (Table 2). Together, these data tell a more complete story since they represent diverse sources that include course grades, FE exam results, and student self-reported Likert responses.

Combining different student assessment data, such as final course grades, homework problems, papers, FE exam results, and exit survey questions requires an effective means to compare data with different ranges and scales. Since 2007, the department has used a simple scaling technique that assigns a numerical rating to each of these assessment events. The approach mimics a grade point average scale with a maximum score of 4.0 and a "passing" score of 2.0. In this way, each assessment can be scaled and averaged to determine the cumulative level of SO attainment based on the various supporting assessment events. For example, in the academic year 2021-2022, the department assessed students' ability to meet SO #4 as 3.4 out of 4 as indicated at the bottom of Table 3. Quantifying the SOs with this single score provides an effective method for conducting longitudinal assessments and identifying courses, practices, and instructors that may be leading to positive or negative changes in the attainment of student outcomes.

Table 3

Data the CE program uses to demonstrate that students achieve ABET Student Outcome #4 (an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.)

Assessment Events	Performance Standard	AY21/22
4-1 Ethics general education course: Demonstration of an understanding of ethics and moral theory	GPA 2.0	3.10
4-2 General education classes in History, Economics, Law, Military and Strategic Studies, Political Science, and Social Science. Acquire knowledge in global, economic, environmental, and societal contexts.	GPA 2.0	3.11
4-3 Capstone Course: Reflection on professional and ethical responsibilities through case study review	70%	95%
4-4 Capstone Course: Demonstration of an understanding of economics in developing engineering solutions	70%	89%
4-5 Intro to Environmental Engineering: Demonstration of understanding the impact of engineering solutions as they relate to social injustice, environmental law, and the triple bottom line	70%	99%
4-6 FE Exam: Demonstration of an understanding of professional and ethical responsibilities on the Fundamentals of Engineering exam	%D from Nat. Avg.	14%
4-7 Senior Seminar: Civil Engineering Program Senior Questionnaire responses to a question related to recognizing professional and ethical responsibilities in a **global context**.	4 of 6	5.3
4-8 Senior Seminar: Civil Engineering Program Senior Questionnaire responses to a question related to recognizing professional and ethical responsibilities in an **economic context**.	4 of 6	5.0

4-9 Senior Seminar: Civil Engineering Program Senior Questionnaire responses to a question related to recognizing professional and ethical responsibilities in an **environmental context**.	4 of 6	5.1
4-10 Senior Seminar: Civil Engineering Program Senior Questionnaire responses to a question related to recognizing professional and ethical responsibilities in a **societal context**.	4 of 6	5.1
SO Assessment Rating:		**3.4**

Student Advisory Council

In addition to Likert surveys, the USAFA CE program also uses less formal feedback from students through a student advisory council held annually. Topics discussed in the spring 2022 council meeting included student development of communication skills, laboratory use, department culture, the honor code, and barriers to success.

The program incorporates student feedback from the student advisory council to augment other assessment artifacts. As an example, the department collected artifacts from technical reports or oral presentations in four major courses in support of ABET SOs that emphasized the importance of communication with a variety of audiences (Table 1). Student input augmented that data with comments such as:

- Getting critical feedback on a draft lab report in *Introduction to Geotechnical Engineering* that wasn't graded was very helpful and low threat.
- A briefing to a mock city board on an environmental topic in *Introduction to Environmental Engineering* was a positive communication experience because it added realism and provided a specific audience so the students could tailor their presentations.
- Construction management is a good fit to cultivate communication skills since it is a discipline where communication is critical to success and adding an extra paper or presentation to a structured course without cutting anything would make the workload too high.

Another topic where students provided meaningful feedback during the advisory council was the honor code, where faculty do not otherwise collect quantitative data. Students provided the following comments:

- Recommend faculty pay close attention to assignment due dates to avoid undue pressure to cheat. For example, if an individual effort project is due on Monday and the last bit of knowledge was learned on Friday, the students may not have the ability to receive instructor help over the weekend, and in a panic, may be tempted to cheat.
- When collaboration is not allowed, be clear on rules and restrictions. Specifically, before a quiz, the instructor said, 'no collaboration allowed,' but that was not written in the instructions online causing some confusion on what type of outside help was allowed.

Methods

To determine the viability of KS as a program assessment tool, they were administered in a FE review course in the Spring 2022 semester. Prior to delving into the details of the course, it is helpful to review the use of KS by the cohort of students.

Use of KS in Prior Courses

Consistent with the department's focus on the scholarship of teaching and learning (SOTL) and engineering education-focused research, several faculty have used KS as a self-assessment tool to help students become better learners. Results to date are reported by Beauregard et al. (2019), Becker and Sloan (2023), Sloan et al.

(2022), and Sloan and Scharff, (2022). Students in this study used knowledge surveys in at least one course prior to the FE review course, and many used them in two or more prior courses. This prior experience made this cohort an ideal one for a case study of self-assessment as a component of program assessment since they all had knowledge of an experience with KS, which reduced the chances of misunderstanding or dismissal due to unfamiliarity.

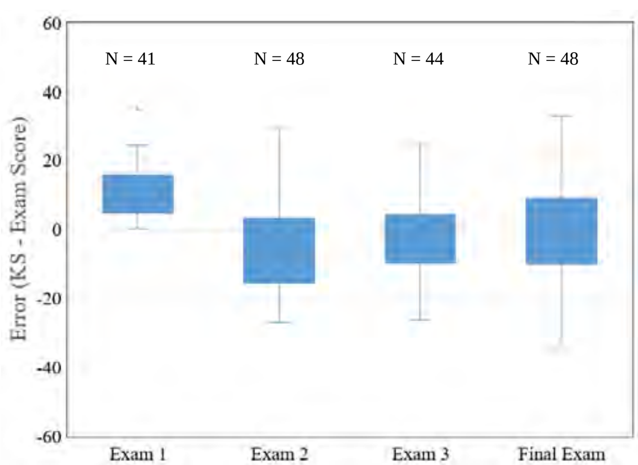
It is helpful to briefly review the accuracy of student self-assessment data in prior courses to establish a baseline for the accuracy of this cohort. Of the 49 graduates of the CE program in 2022, all 49 took the FE exam, and 48 of 49 used KS in *Fundamental Hydraulics*, a junior-level fluid mechanics course. These 48 students took the course in either the Fall 2020 or Spring 2021 semesters. A single instructor taught all sections of the course during that academic year. The course was conducted in a hybrid format due to the COVID-19 pandemic with one of about every four lessons meeting in person. The online lessons were taught with short 15-minute videos and the remainder of the lesson time was filled with practice problems. The in-person lessons consisted of “board work” problem sessions so the instructor could monitor progress formatively (Sloan & Scharff, 2022).

Figure 1 shows a box plot of the “error” defined as the student’s KS score minus the grade they received on each of the four exams in the course. Many students are within +/- 10 percent error which Nuhfer et al. (2016a) consider to be accurate, and most are within that range for the last two exams in the course: Exam 3 and the Final Exam. The statistically significant correlation for these 48 students with 181 data pairs of KS to instructor grade is 0.28 (p = 0.00014). It is also worth noting that the instructor offered an incentive for completing the KS by devoting approximately 5% of the exam points to completing the KS. This incentive resulted in a 94.3% completion rate of the KS in the course.

Further, 19 of the students used KS for technical writing assignments in a *Computer Applications* course, and two used them in *Structural Analysis*. In total, there are 262 data pairs of instructor grades with student KS resulting in a statistically significant correlation of 0.19 (p = 0.0019). In summary, the positive statistically significant correlation between student KS and instructor grades with a low p-value indicates that the students are accurate self-assessors compared to instructor assessments; many of the students have demonstrated accurate self-assessment via KS in two distinct courses.

Figure 1

Box plot of error by exam from 48 or the 49 students by exam in Fundamental Hydraulics, Fall 2020 and Spring 2021 semesters



FE Review Course

USAFA's FE review course is a required 0.5 semester hour course for CE majors given in the Spring of the senior year. The Department of Civil and Environmental Engineering administers the course which also includes students majoring in other engineering disciplines. The course is conducted on a pass/fail basis and enrolled students must take the FE exam. The institution reimburses students after they take the exam. The first part of the course is combined for all engineering students (discipline-agnostic) and focuses on the foundational topics of math and statistics, statics, dynamics, mechanics of materials, and materials (Table 4). Faculty in each engineering program then break students into subgroups by major for a discipline-specific review.

Use of KS in the FE Review Course

NCEES publishes exam specifications (number of questions by topic) for each discipline. We developed a KS consisting of 79 questions based on the FE civil engineering exam specifications (NCEES, 2020). Table 4 illustrates the number of FE questions by subtopic for the CE exam, the number of KS questions, and the number of 1-hour lessons by topic in the review course.

Table 4

Topics and number of questions for the civil engineering-specific FE exam (NCEES, 2020), KS data, and FE Review Course data

Topic	Number of FE Exam Questions	Number of KS Questions	Lessons Devoted to Topic in the Review Course
*Mathematics and statistics	8-12	4	2
Ethics and professional practice	4-6	4	0
*Engineering economics	5-8	4	1
*Statics	8-12	7	1
*Dynamics	4-6	4	2
*Mechanics of materials	7-11	4	2
*Materials	5-8	3	1
Fluid mechanics	6-9	4	2
Surveying	6-9	5	0
Water resources and environmental engineering	10-15	11	3
Structural engineering	10-15	8	4
Geotechnical engineering	10-15	11	2
Transportation engineering	9-14	5	2
Construction engineering	8-12	5	0
Total	110	79	22

Note. "*" indicates conducted in the discipline-agnostic review (all engineering majors together); all other topics are in the civil engineering-specific portion of the course.

Given the large general education curriculum and resulting constraints on the major's curriculum at USAFA, students have not had instruction, much less an entire course, in some of the FE topics. Two examples of this are

dynamics and transportation which are not covered at all in the civil engineering program but are covered briefly in the FE review course as shown in Table 4.

The KS questions were developed based on the CE exam specifications, which list three to eleven sub-topics for each major topic area shown in Table 4. In each case, we created one KS question for each sub-topic, typically by adding "I can" in front of each statement in the description from the exam specifications and in some cases adding an additional descriptive word. Students selected from one of five response options for each question: 0 - I am unable to perform the task, 1 - I can begin to perform the task but am quickly overwhelmed, 2 - I can make progress toward performing the task but fall well short of completing it, 3 - I can almost completely perform the task, 4 - I am completely able to perform the task for the exam. The Cronbach's alpha for the pre-and post-KS were 0.96 and 0.97 respectively, indicating that the KS has a very high degree of internal reliability, like results by Nuhfer and Knipp (2006) and others who also reported high reliability for KS. As examples of the KS questions, Table 5 illustrates the translation of FE specifications to KS questions for the topic of fluid mechanics, along with the response options for each question.

Table 5

NCEES FE exam specifications and corresponding KS questions and response options – fluid mechanics example

NCEES Specification – Fluid Mechanics	Corresponding KS Question
Flow measurement	I can measure fluid flow.
Fluid properties	I can interpret fluid properties.
Fluid statics	I can solve fluid statics problems.
Energy, impulse, and momentum of fluids	I can solve energy, impulse, and momentum of fluids problems.

After the discipline-agnostic portion of the FE review course and on the first lesson of the CE-specific review, the second author provided a brief explanation of KS as well as a description of their usefulness. Students were given time in class to complete the pre-KS and responses were captured via an online survey. Faculty explained that the KS was constructed directly from the NCEES FE Exam specifications. The KS were available online via the course's learning management system for reference by the students at any time. Students took the post-KS on the last day of the review course in class via an online survey. The students took each KS voluntarily as there were no incentives offered for completing them.

Students who completed KS in the FE review course

49 students took the FE exam in March or April 2022. 32 of these students completed the pre-KS and 22 students completed the post-KS. Table 6 shows the GPA of the entire cohort, the cohort who took the pre-KS, and the cohort taking the post-KS. Notably, the average GPA is similar in each case, increasing slightly among those who took the pre-KS and again for those who took the post-KS. From a program assessment perspective, the ideal case would include data from the full cohort of 49 students, however, the fact that the GPA is approximately the same and slightly increases with each smaller cohort indicates that each is a representative sample for both the pre- and post-KS.

Table 6

GPA Summary of the class of 2022 civil engineering majors

Cohort	N	Median GPA	Mean GPA	GPA Standard Deviation
Students who took the FE	49	3.21	3.15	0.36
Students who completed the pre-KS	32	3.22	3.17	0.35
Students who completed the post-KS	22	3.23	3.22	0.33

Results

Figure 2 shows the average pre- and post-KS data for the student cohort by each FE topic area. Note that a student-by-student comparison of results like the box plot in Figure 1 is not possible since FE Exam data from NCEES are based on the average performance of the students in the CE program. The scale for the pre/post-KS data is on the left side of Figure 2, from 0 to 4. Some topics in the discipline-agnostic portion of the FE review course generally do not show a substantial increase from pre to post, many changing less than one-tenth of a point (e.g., mathematics and statistics, statics, mechanics of materials). Note that students completed the pre-KS after the discipline-agnostic portion, and the lack of improvement in self-assessment scores may indicate that they did not put in much study time on those topics after those lessons in the course. Students did show an increase in self-assessed ability in a few of these early topics after they were covered in the review course (e.g., ethics and professional practice, engineering economics, dynamics, and materials).

Most topics in the CE-specific portion of the course show a substantial increase from pre- to post-KS of 10% or more, indicating the value of the review course and/or their own self-directed study to increase student confidence in their abilities leading up to taking the FE Exam. In some cases, this gain is small, such as with surveying, which was not a topic of the review course. In other cases, the increase from pre to post self-assessed ability was substantial as with transportation, which is not covered in any other course in the CE program but is covered in the FE Review Course.

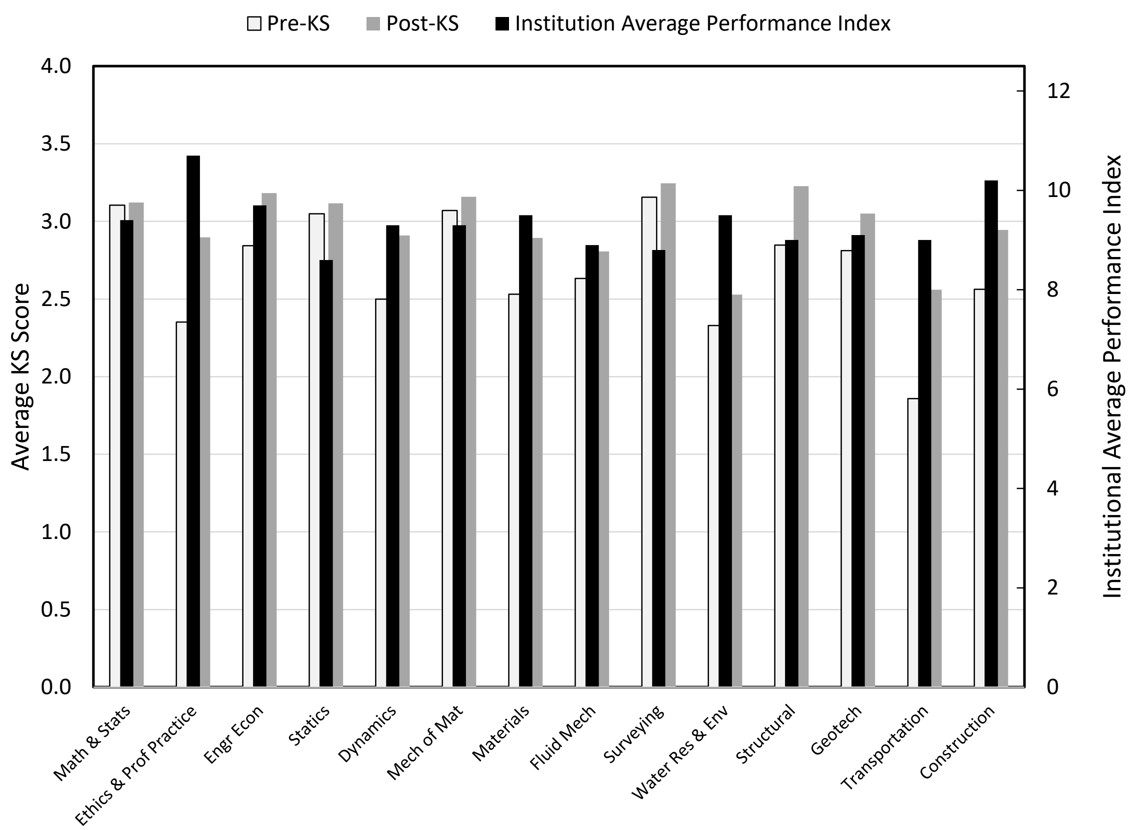
Figure 2 also shows the Institutional Average Performance Index (IAPI) by topic area with the scale on the right side of the figure. Although the scales for the KS and IAPA are different, the average post-KS score and the average IAPI occur at the same value on the graph, enabling a relative comparison of the data. The numbers above the bars for each topic area are the “scaled score” reported by NCEES and indicate whether this cohort performed above (positive number) or below (negative number) the national average and by what relative margin. Notably, a higher IAPI does not always correspond with a score above the national average if students nationally do well on a particular topic, for example. As a cohort, the pass rate for these 49 students was 78% compared to the national average of 64%.

Students’ self-assessed ability compares well with the IAPI for many of the topics such as math and statistics, dynamics, fluid mechanics, and geotechnical. In some cases, students performed well above their self-assessed ability, such as in ethics and professional practice. This is a point that faculty can emphasize in the FE review course for future cohorts of students. Students at USAFA have a strong foundation in ethics given the honor code and required honor lessons throughout the 4-year program. All students also take a three-semester hour ethics general education class taught by the Philosophy Department (United States Air Force Academy, 2022). Upon this foundation, students also receive instruction on ethics, professionalism, and licensure topics in their

CE courses. Reiterating to students that they have a strong foundation in this area might increase their confidence (and rightly so) for future cohorts of students.

Figure 2

Pre-KS, post-KS, and FE institutional average performance index



In other topics, students performed at a relative level below their self-assessed ability and below the national average, e.g., surveying and statics. CE majors spend three days (roughly 24 hours of instruction and practice) on surveying as one part of a field engineering course. Many other CE programs have an entire course that is primarily or fully devoted to surveying (e.g., Padmanabhan et al., 2013). Thus, it is not surprising that students performed below the national average in this area. The faculty may want to emphasize to CE majors that they have had less instruction on this topic than students in many other programs. A discussion that previous cohorts of students were over confident in this area may provide motivation for future students to work on more challenging practice problems in their preparation for the FE exam. Further, faculty may want to consider a minimum of a single surveying lesson in the review course as it is currently not covered (Table 4).

Other differences worth noting include the under confidence in the Water Resources and Environmental area. Faculty perceptions are that some students do not "enjoy" these classes as much as others, but it is worth emphasizing to the students that they have a strong background in this area by virtue of a required hydraulic design course, and they should be confident in their abilities even if this is not their favorite subtopic within the CE major.

Likewise, students underperformed compared to the national average and were also under confident in the Transportation area. Neither of these data points is surprising given the lack of a dedicated course in transportation. Yet, faculty may want to emphasize that even two review lessons and working on some example problems can still yield significant learning gains demonstrated on the FE Exam.

Finally, students were under confident in Construction but significantly outperformed the national average in this area. Construction Engineering is a strength of the program, and all students are enrolled in a construction-based capstone course during their final semester when they take the FE Exam (Stanford et al. 2020). The decision to not include review lessons on this topic is confirmed by student performance on the exam, and faculty can use this as a talking point with students as they discuss the relative strengths and weaknesses of the program.

Discussion

Use of self-assessment mechanisms for program assessment

The following subsections discuss the potential benefits for using KS as a tool for program assessment.

KS help demonstrate student abilities in learning to learn

Based on our experience using KS in several courses in the CE program (Beauregard et al., 2019; Becker & Sloan, 2023, Sloan et al., 2022; Sloan & Scharff, 2022), there is significant value to integrating a self-assessment component into individual courses. The metacognitive practice students get as they self-assessed, the accuracy they demonstrated, and the calibration of their self-assessment ability over time in the *Fundamental Hydraulics* course (Figure 1) reveals that we are teaching students more than mere academic content; *we are teaching them how to learn*. This has immediate and direct implications for program assessment given ABET SO #7 requires “an ability to acquire and apply new knowledge as needed, using appropriate learning strategies” (Table 1). Applying new learning strategies is not unique to engineering, however, and KS are expected to play a similar role in other disciplines given the literature on self-assessment as an integral component of the learning process (Andrade, 2019; Andrade & Valtcheva, 2009; Boud & Falchikov, 2007; Boud et al., 2013; Sadler, 1989). Although we have not formally adopted a student self-assessment component to demonstrate achievement of ABET SO #7, it would be a natural step to do so.

KS help confirm program strengths and weaknesses

Knowledge surveys may help faculty confirm or refute their perceptions about the strengths and weaknesses of the program. The individual KS data help a faculty member point out where students may have misaligned expectations or where they might have good intentions but poor study habits, for example. Doing this with students as a cohort at the program level helps to form a more complete picture of the strengths and weaknesses of the program that may drive changes to the program or can be useful to help describe the strengths and weaknesses of the program to students. In our program, comparing KS results during the FE review course to FE exam scores by topic area facilitated the program-level viewpoint.

KS enable program level discussions with students

The student self-assessment data from KS then provide a vehicle for discussion of program strengths and weaknesses compared to how students self-assess. From Figure 2, students in this cohort were under confident in both professionalism and ethics and in construction. Yet, both areas are strengths of the program. In the case of construction, students scored well above the national average in this area and are enrolled in their capstone

course based on a construction management competition (United States Air Force Academy, 2022) at the time they took the FE Exam, and yet they were under confident in their abilities.

Conversely, transportation and dynamics are not strengths of the program and Figure 2 illustrates that students seemed to be aware of this in their average self-assessed ability as a cohort. Surveying is a relative weakness of the program compared to other areas and data like that in Figure 2 enables a conversation with students and a caution not to be over confident in this area, either in preparation for the FE Exam or in executing their duties as an engineer after graduation. Thus, having the self-assessment data at a program level enables some of these deeper conversations and helps set expectations with students entering the workforce about how their educational experience may compare with the experiences of other students in a similar program from another university.

KS may yield insight into institutional trends

USAFA has a strong honor code and foundation of ethics. During the COVID-19 pandemic and online learning, there were instances of cheating and the institution embarked on an “honor reset” (United States Air Force Academy, 2021) that entailed discussions among faculty, students, and other leaders at the institution on how to best move forward given the events that had taken place. One of the initiatives involved a refocus on treating the honor code as an aspirational standard to live by rather than an “us vs them” (faculty vs students) mentality. The lower self-confidence in ethics/professionalism may be a consequence of an “us vs. them” or “though shalt not” mentality or perception of the honor code among students. This is insightful for the institution, continuing to reinforce that the honor code is not a weed-out tool, but an ideal to aspire to and live by.

As mentioned in the institutional and program context, the department was able to get student input specific to the CE program through discussing the topic of the honor code with the student advisory council. Additionally, positive results from this study showing how students can accurately self-assess at the course and program level is likely to translate outside of academics (Boud & Falchikov, 2005). KS could be an effective tool in inspiring metacognition toward one’s ability to live by the honor code, and multiple KS spanning several years could track the development of core values in individual students and in aggregate across the student body.

Recommendations for using self-assessment instruments for program assessment

Given the observations in this case study, student self-assessment data have the potential to serve as an incredibly valuable component of program assessment. KS help faculty set expectations, and students consider their abilities at any time facilitating self-regulation. Doepker (1999, p. 6) identifies student “surveys” and “student self-assessment” as two of at least 11 potential instruments for program assessment. As students are one of the three constituencies identified in USAFA’s CE program, it is appropriate to use both student self-assessment (Figure 2) and survey instruments (Tables 2 and 3) for program assessment. Other programs may not have a comprehensive exam to allow students to demonstrate learning across the comprehensive major’s curriculum and may find benefits in gathering student self-assessment data. Some keys to successfully using knowledge surveys for program assessment include:

- Following the same keys to successful KS implementation in a course which include specific/granular questions that are aligned with the course and program learning objectives (Nuhfer & Knipp, 2003; Sloan & Scharff, 2022).
- Introducing self-assessments to students in early courses. This includes providing feedback to students on the accuracy of their self-assessments. Prompt feedback on self-assessment accuracy and potential follow-on discussions to identify the root cause of inaccurate self-assessments will likely help students hone their accuracy and self-regulated learning abilities over time (Boud & Falchikov, 2005, Boud et al., 2013, Sloan & Scharff, 2022).

- Integrating KS into multiple courses in the program but not necessarily every course. Students should have multiple touchpoints with KS throughout the program. Along these lines, we would not recommend using KS for program assessment if students have not used KS in at least one prior course and perhaps as many as three (Boud et al., 2013).
- Using self-assessment data to complement or augment data from other sources; self-assessment instruments should not be the sole artifacts to demonstrate student achievement of a particular program outcome (Table 3).

There is tremendous value in making self-assessment an overt part of a curriculum (Boud & Falchikov, 2007, Sadler, 1989; Wirth et al., 2021) and where this is done, it is a logical next step to use some of these data for program assessment (Doppler, 1999; Favazzo et al., 2014; Nuhfer & Knipp, 2003; Wirth & Perkins, 2005).

Opportunities to extend KS throughout the program

Although we presented a summative program KS comparison in this paper (Figure 2), it would be straightforward to administer a similar KS at multiple points with the program to visualize students' self-assessed abilities as they enter the program and then over time as they navigate the curriculum. KS are easier for faculty to develop, administer, and review than other forms of assessment and are thus conducive to more frequent use. Most courses already have well-defined objectives and developing a KS may be as simple as adding an "I can" ability statement at the beginning of each objective.

KS also take less time for students than other forms of assessment and have the built-in advantage of serving as a program "guidebook" of sorts that helps faculty communicate key objectives of the overall program. Taking a comprehensive KS annually or even at the end of every semester could pinpoint where gains are made for students along their educational journey. A comprehensive or tailored KS could also help determine if students retain information from semester to semester, pinpointing knowledge or skills and where programs may want to repeat or re-emphasize key concepts to ensure retention over time (Ariel & Karpicke, 2018; Karpicke et al., 2009). KS themselves are a formative vehicle for repetition and the act of students repeating them over time, thinking metacognitively about key program concepts, may also be a vehicle to enable deeper learning (Andrade, 2019; Rushton, 2005).

Conclusion

Given that student learning is the goal of education, it is a natural step to include student input and feedback as a component of a program's continuous improvement process, whether generally through focus groups or survey question responses, or specifically by using student self-assessment data in comparison with other measures. This paper provided a case history of student self-assessment data using KS in an FE Exam review course where students demonstrated accuracy in self-assessment in at least one prior course. Along with faculty perspectives and student performance on a nationally-normed exam, student self-assessment data added another dimension to help form a more complete understanding of the program.

Comparing FE Exam results with student KS data has the potential for driving change in the program. Further, the self-assessment data enable conversations with students about the strengths and weakness of the program to help students align expectations of their own abilities with performance standards outside of their own localized experience in the program and helps them become more aware of their own abilities as they prepare to enter the workforce. Students' demonstrated accuracy in self-assessment is a potential source to show that students achieved ABET SO #7 and can acquire new knowledge using appropriate learning strategies. In short, systematically incorporating self-assessment into a program has benefits for both student learning and for continuous improvement of the program.

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