2023 Annual Conference & Exposition
Baltimore Convention Center, MD | June 25 - 28, 2023
The Harbor of Engineering Education for 130 Years
Paper ID #39694

Student Self-Assessment of Knowledge to Encourage Individual Understanding of Strengths

Dr. Megan Prygoski, Purdue University at West Lafayette (Polytechnic)

Dr. Prygoski has been teaching Mechanical Engineering Technology at Purdue University's South Bend campus for nine years. She has her B.S. in Mechanical Engineering from the University of Arizona and a M.S. and Ph.D. in Mechanical Engineering from the University of Notre Dame.

Student Self-Assessment of Knowledge to Increase Understanding of Strengths

Introduction

It has long been known that there is much to be learned from failures in engineering. Engineering content aside, we can also learn from the primary causes of these failures. A 1976 study by Matousek and Schneider involving 800 cases of structural failure resulting in 504 deaths and 592 injuries found that when engineers were at fault, 36% of the failures were due to insufficient knowledge on behalf of the engineers [1]. In most circumstances, this source of error should be avoidable. Students in engineering and technology are exposed to a vast range of topics in their given discipline making complete mastery of all topics difficult. As instructors it is important to know that it is unrealistic to expect that 100% of the students leaving the classroom will be well versed in all topics covered. It is possible, however, to expect each student to have a strong grasp on which concepts they fully understand. Or more importantly, to understand where they should seek assistance to potentially avoid future failures due to their own lack of knowledge.

In the field of psychology, there have commonly been considered to be four stages of competence [2, 3] which can be applied to engineering education in a fairly straight forward manner. Within this conscious competence learning model, there is a progression within a particular skill from incompetent to competent. For each of these skill classifications, we can also consider the individuals' awareness of their incompetence or competence. That is, are the unconsciously or consciously aware that they do or do not know something. The theory follows that students start out unaware of their lack of understanding then as individuals recognize their incompetence, they consciously seek out a skill, then use it. Eventually, the skill is mastered such that it can be utilized without it being consciously thought through; at this point the individual is said to have acquired unconscious competence [2].

The stages of competence (Figure 1), start out with unconscious incompetence where the individual does not possess an understanding and does not know they lack this. As a result, many individuals in this stage may not see the usefulness of a skill. Before moving on, the individual must first acknowledge their incompetence and then acknowledge the utility in a skill or knowledge set before advancing to the next stage. Some individuals will only be in this stage for a short time, while others may

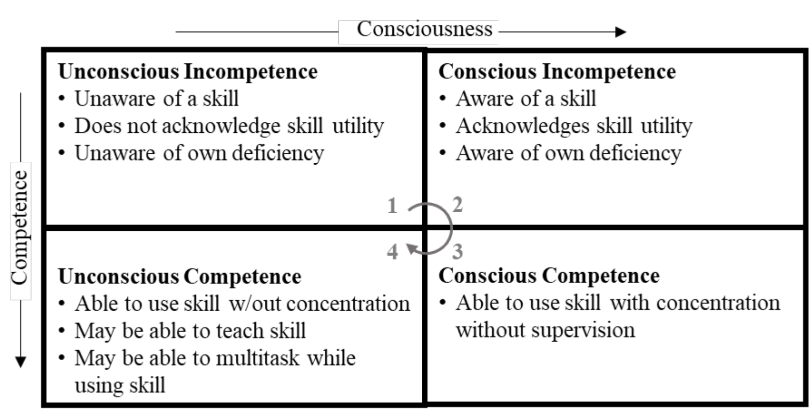

Figure 1: Conscious Competence Matrix

stay here indefinitely. The leading factor determining the amount of time an individual stays here is the strength of the motivation to learn a concept or skill [2].

In the next stage, conscious incompetence, the individual recognizes their deficit, though they still do not understand the concept or know how to use the skill. At this point the individual may start to make and recognize mistakes from which they can learn. Once the individual knows how to do something, they become consciously competent; they know how to do something, but doing so requires concentration, such as breaking the skill down into steps [2]. With sufficient practice with the skill they begin to unconsciously use it. The skill becomes second nature and can be executed easily. Individuals at this level have mastered the skill and may even be able to teach others the skill.

The ultimate stage for anyone is to reach unconscious competence. The most dangerous stage to be in is arguably unconscious incompetence. Guiding individuals away from unconscious incompetence towards unconscious competence often times includes helping them to identify what they don't know, which can be considered a part of the Johari window, which deals with self-awareness and is designed to help individuals better understand their relationship with others [3]. From an educational standpoint, it can also be thought of as a way for individuals to assess their relationship with educational concepts- both understood concepts (strengths) and misunderstood or unknown concepts (weaknesses). There are again four stages, or quadrants, within this technique (Figure 2).

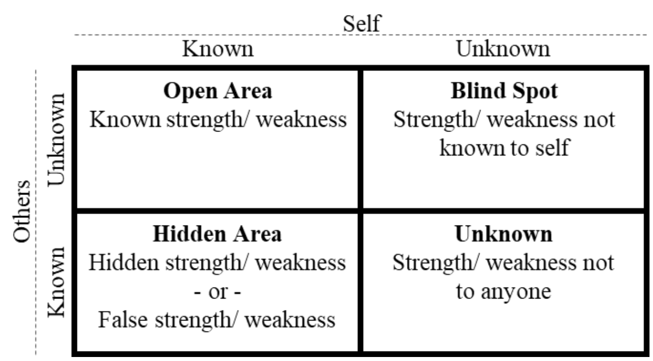

Figure 2: Johari window for strengths and weaknesses. Adapted from *[3]*.

The four quadrants within the Johari window are open, hidden, blind and unknown. To frame this analysis from an educational skill standpoint, you could think of taking a group of students that are familiar with one another on an academic level. If you then had everyone select from a list of skills which they think they possess, the list could then be compared to the skills the subject's peers or instructor might select. Strengths or weaknesses known to the individual and observed by their peers would fall within the open window. Strengths or weaknesses known to oneself but not known by others could potentially be hidden, or could represent a false sense of ability or inability on the part of the individual. Strengths or weaknesses not known to anyone would be unknown. And lastly, strengths or weaknesses known by peers but not by oneself would be blind spots. In guiding students, the instructor could then help students to identify blind spots.

The blind spot identification by the professor can be thought to occur in multiple forms of feedback, which can be one of the most powerful tools for learning [4, 5]. Unfortunately, not all feedback is productive and many students do not view feedback without prompting. True productive feedback will not only enhance student learning within a course, but will also ready students for lifelong learning [6].

In order to gauge student competencies, some form of assessment must be carried out, the feedback from which can be crucial. These assessments can be completed at the student level, course level or instructor level and can be quantitative or qualitative. Student level assessments evaluate how well a single student has mastered a given topic or skill and can include things like exams, homework assignments, projects, and laboratory assignments. For the purposes of this paper, course level assessment will refer to the culminative findings for all students on a given assessment as it relates to the course learning outcome(s) which are a critical tool in evaluating how well the necessary material within a course is being delivered to and received by the students. Both student and course level assessments should be considered when evaluating the impact of changes made within a course. These types of assessments will be the focus of this paper as a means to measuring students' ability to consciously assess their competence in real time during exams. Instructor level assessments refer to those performed by students at the end of the semester. While these are vital to course improvement they do not always reflect student understanding and for that reason are not included in this paper.

Methods

From the spring 2020 semester, to the fall 2022 semester four unique courses were selected for a rolling integration of a modified examination style according to Table 1. The first time the modified exam format was utilized was in Applied Thermodynamics on the final exam. This information is included in Table 1 to illustrate the timeline of implementation of the exam format, but data from the spring 2019 offering of the course is not included in the analysis since there was a mix of testing formats utilized.

Table 1: Number of course offerings with each exam format

Course Name	Semesters Taught	Number Offerings (n=total students)	Exam Style (Traditional or Modified)
Applied Thermo. (MET 32000)	S: 2015-19*	4 (27)	Traditional
	S: 2019*-22	4 (14)	Modified
Applied Statics (MET 11100)	S: 2015-19	3 (31)	Traditional
	S: 2020-22	3 (47)	Modified
Heat and Power (MET 22000)	F: 2015-19	5 (26)	Traditional
	F: 2020-22	3 (11)	Modified
Dynamics (MET 21300)	F: 2016-19, S: 2021	5 (26)	Traditional
	S: 2022	1 (2)	Modified

Traditional style exams consisted of multiple questions, typically worth varying points based on difficulty and length. With this exam style all questions were required of all students. Modified exams consisted of multiple questions, all similar in difficulty and length, worth the same number of points. With this style, the exam is intentionally written to be too long to complete in the given time period and students are typically told to select one problem to "opt out of". The intent is that students will practice a self-assessment of knowledge during the exam in order to determine which problems they wish to complete for a grade. In some cases, students may work quickly enough to be able to complete all questions. Those students still must indicate which problems they want to be evaluated on, which in turn indicates which problem they are least comfortable with.

The number of questions on each of the exams included in this study can be found in Table 2. In a few instances, as noted in the table, exams were broken into two sections. This has been done for two reasons. Firstly, in lower-level classes there are some foundational concepts that each student needs to comprehend to be successful in multiple subsequent courses in their field of study. In these courses, exams were broken into a required section with short answer or quick calculation problems and a section with longer more in-depth problems where students could "opt out" of one problem. This two-part format allows the instructor to compare all students on foundational concepts and determine if material needs to be reiterated to the class on the whole. The second reason for a two-part exam comes when there is sizeable difficulty developing a sufficient number of problems both equal in difficulty and time required. In these instances, problems were grouped into two parts based on difficulty and time required to complete, and students were allowed to "opt out" of one problem in each section.

Table 2 breaks down the number of sections on each modified exam, whether all questions within the section were required, the percentage of points in each section and how many questions needed to be completed by each student in sections where all questions were not required. Information for Applied Dynamics is included, however data for that course was not considered since the modified exam format has only been used one time, during a semester with only two students, giving little weight to any findings.

To encourage students to acknowledge their individual incompetence and then work towards gaining the associated competence, after graded exams are returned students are asked to complete related problems for an increase in their exam grade, typically 10%. In some instances, students that struggle significantly are asked to setup a meeting with the instructor to review areas of confusion and get practice problems to work on. This overall approach has been in place with both the traditional and modified exam formats. With the traditional format semi-individualized review problems were developed for students to complete for a grade increase. Typically, 5-8 problems were developed per course per exam, and they were then assigned to students based on areas of deficit observed on the exam. With the modified exam, all students were asked to complete the skipped problem(s).

Table 2: Number of questions per exam with point values and number of sections included.

Course Name	Year (n)	Exam #	Multiple Parts?	Part 1			Part 2		
				All required?	Number of Questions	% of Points	All required?	Number of Questions	% of Points
Applied Statics	2020 (9)	1	Y	Y	4	33%	N	4 of 5	67%
		2	Y	Y	4	40%	N	3 of 4	60%
		3	N	N	5 of 6	100%			
	2021 (16)	1	Y	Y	4	32%	N	4 of 5	68%
		2	N	N	5 of 6	100%			
	2022 (6)	1	Y	Y	4	32%	N	4 of 5	68%
		2	N	N	5 of 6	100%			
		3	N	N	5 of 6	100%			
Dynamics	2022 (2)	1	N	N	4 of 5	100%			
		2	N	N	4 of 5	100%			
		3	Y	N	4 of 5	40%	N	2 of 3	60%
Heat and Power	2020 (5)	1	N	N	4 of 5	100%			
		2	N	N	5 of 6	100%			
	2021 (4)	1	N	N	4 of 5	100%			
		2	N	N	4 of 5	100%			
	2022 (2)	3	N	N	4 of 5	100%			
		1	N	N	4 of 4	100%			
		2	Y	N	3 of 4	33%	N	2 of 3	67%
Applied Thermo	2020 (10)	3	Y	N	2 of 3	25%	N	3 of 4	75%
		2	Y	N	3 of 4	60%	N	1 of 2	40%
	2021 (5)	1	N	N	3 of 4	100%			
		2	Y	N	1 of 2	10%	N	3 of 4	90%
	2022 (4)	1	N	N	3 of 4	100%			
		2	Y	N	3 of 4	60%	N	1 of 2	40%
		3	Y	N	1 of 2	25%	N	2 of 3	75%

From 2015-2020 these meetings and additional problems were required for any student receiving an exam grade of less than 80%. Anyone receiving a grade of 80% or higher could still complete the problems though their final grade could not exceed 100% on the exam. This was wildly unpopular with many of the very low scoring students, with most never meeting with the instructor or submitting the required problems despite an associated grade reduction. As a result, the extra points were made optional to all students in the spring of 2021 with those scoring less than 80% strongly encouraged to complete the problems. As the problems shifted to optional for everyone, there was a decrease in the participation. It is worth noting, that most students refusing to complete the required review problems from 2015-2020 did not pass the course; a phenomenon which was not a direct result of grade reductions. Consequently, a shift back to requiring these problems is being considered.

Course level assessments are compiled department-wide to assess teaching effectiveness and identify areas in need of change. For each course learning outcome objective (CLOO), student performance in multiple activities are assessed. Each CLOO evaluation typically consists of multiple assignments (homework, labs, projects) and exam questions. A sample CLOO assessment is below to illustrate the type of data that would be compiled for each course every time it is offered. From this data, CLOOs with any assessments with average scores of less than 80% are typically reviewed for potential changes, with scores below 70% prompting more significant evaluation or restructuring of the material and assessments. Shown in Table 3 is data for a single offering of Heat and Power with four students.

Table 3: Sample CLOO assessment for Heat and Power.

CLOO	Assessment Used	Points Possible	Student Scores				Averages	
			S1	S2	S3	S4	Assessment	CLOO
Analyze fixed mass and steady flow control volume systems and devices.	HW 6 (closed sys.)	30	30	30	30	27	98%	81%
	Exam 2, P1 (closed sys.)	25	8	10	22	22	62%	
	Exam 2, P4 (closed sys.)	25	14	6	20	20	60%	
	Exam 3, P3 (closed sys.)	25	23	-	12	22	76%	
	HW 7 (open sys., Q1-3)	55	52	50	55	50	94%	
	Lab 5 (open sys.)	100	100	100	100	100	100%	
	Exam 3, P1 (open sys.)	25	17	18	19	16	70%	
	Exam 3, P4 (open sys.)	25	25	16	-	25	88%	

To assess the impact of the change in exam format, course level assessments for the CLOOs were compared. Due to low student enrollment in the courses as can be seen in Tables 1 and 2, data for the end of semester course assessments was pooled to increase the size of the data pool. To do this, assessments for a single CLOO were compiled for all semesters under a given exam format- modified or traditional- and were compared to identify if any changes were occurring at the course level as a result of the exam format shift. For the courses with the traditional exam style, typically from 2015-2019 only years 2017-2019 were considered as less complete exam score records were kept prior to 2017 making inclusion of those years unfeasible.

Additionally, after each exam, data was collected to find averages for each question on the exam and the percentage of students opting out of each question was tracked to identify areas of confusion and look for trends. Topics particularly difficult were reviewed and reassessed on a subsequent exam where possible to evaluate the effectiveness of the review. Data was also analyzed regarding the rate at which questions were skipped as they related to associated course CLOOs to look for trends. Potential trends that were watched for are below:

- Consistent skipping of multiple questions associated with the same CLOO either within a semester or by a given student. This could indicate that the material was not be sufficiently covered or explained in a manner that resonated with the students.
- High rate of students within a class opting out of the same question. This could indicate that a given question was unclear, or perceived as being more difficult than the rest of the questions on an exam.

Data

Data was compiled for three courses, and comparisons were made between the average course CLOOs across all semesters of a given exam format. Due to small class sizes, and the wide variation among students, there is no statistical significance to the data presented, which was expected. The data provided is the average of all activities associated with a single CLOO (homework, labs, projects and/or exam questions). High and low stakes assessments were weighted equally. As is reported in Tables 1& 2, there were varying numbers of students in each offering of the course. Since each student was counted equally, semesters with larger class sizes were weighted more heavily as a result.

Highlighted are CLOOs where the overall performance increased or decreased by 5% or more, indicating that there may be some associated impact of the exam structuring. Seven of the twelve course CLOOs for Applied Statics have higher average assessments under the modified exam with a decrease of 3% occurring in only one CLOO (Table 4). In Heat and Power and Applied Thermodynamics there was an increase of 5% or more in assessments for one of three and three of ten of the CLOOs, respectively (Tables 5 & 6).

Reasons for the observed increases are considered to potentially be due to two reasons:

1. As students become able to identify areas of incompetence, the graded exam questions should represent the more competent students in the course, giving rise to higher grades. This indicates an increase in conscious incompetence.
2. As students then realize their weaknesses, and are encouraged to review the material-with an associated grade benefit- they tend to perform better on subsequent exam questions over similar material, indicating the students are moving towards conscious competence.

Also found in Tables 4-6 is the most commonly skipped exam question by associated CLOO for all three years. In Applied Statics, there was one occurrence where a large majority (83%) of the class skipped a single question which had portions related to two CLOOs (5 and 8). Included in the table for those two CLOOs is the second most commonly skipped question that same year which shows that during that same exam students were still evaluated on that concept. Over the course of the semester, there were four distinct questions on the three exams to make sure assessment was being done multiple times. The high number of students skipping the same question then suggests this may have been due to a lack of clarity on the question phrasing.

In Heat and Power, 100% of the four students skipped the same question on Exam 2 in 2021, again suggesting a potential issue with the question. On that same exam there were five questions with portions related to CLOO 2, where students scored an average of 64% on those questions. The topic was reviewed and on the next exam there were four questions with portions related to this CLOO with an equal distribution of students skipping each question (25%). The average for these problems was an 81%, showing an increase in comfort and/or understanding on the topic.

Table 4: Average CLOO assessment for Applied Statics

CLOO	Year	# of Related Exam Questions	Most Skipped Question	% of Students Skipping	"Traditional" Exam Assessment	"Modified Exam" Assessment
1	2020	2	E1, P8	25%	88%	85%
2	2022	2	E1, P5	33%	**80%**	**85%**
3	2021	2	E1, P3	6%	80%	82%
4	all	0	HW & lab only	NA	**82%**	**87%**
5	2022	4	E2, P1a	83%	**70%**	**85%**
			E2, P3a	0%		
6	2021	3	E2, P5	20%	**64%**	**86%**
7	2021	2	E1, P9	25%	74%	71%
8	2022	4	E2, P1b	83%	**77%**	**83%**
			E2, P2c	0%		
9	2022	1	E3, P2	67%	**55%**	**88%**
10	all	0	HW & lab only	NA	93%	93%
11	2020	2	E3, P4	22%	87%	88%
12	2020	1	E3, P2	22%	**67%**	**87%**

Table 5: Average CLOO assessment for Heat and Power.

CLOO	Year	# of Related Exam Questions	Most Skipped Question	% of students skipping	"Traditional" Exam Assessment	"Modified Exam" Assessment
1	2021	4	E3, P4a,b,d	25%	**86%**	**94%**
2	2021	9	E2, P5a-b	100%	84%	88%
			E2, P2a-b	0%		
3	2021	4	E3, P2c	50%	94%	93%

Table 6: Average CLOO assessment for Applied Thermodynamics.

CLOO	Year	# of Related Exam Questions	Most Skipped Question	% of students skipping	"Traditional" Exam Assessment	"Modified Exam" Assessment
1	all	0	Project only	NA	92%	90%
2	2020	3	E1, P4a	40%	**84%**	**93%**
3	2021	5	E2, P2a-d	100%	**84%**	**91%**
			E2, P5	0%		
4	2022	2	E2, P5c	50%	87%	86%
5	2022	5	E2, P3	50%	90%	88%
6	2020	1	E2, P6a-c	80%	89%	89%
7	2020	3	E2, P4a-b	90%	84%	88%
			E3, P3a-b	30%		
8	2022	1	E3, P4a-c	50%	83%	86%
9	2020	1	E3, P5a-3	40%	84%	85%
10	all	0	Project only	NA	**80%**	**88%**

In Applied Thermodynamics there was a single instance of all four students in a course skipping the same question. However, there were five questions that semester over the same CLOO with each student being assessed on the topic on the same exam. At completion of the exam it was noted that there was a discrepancy between the written problem and the schematic provided, making the reason behind the high skip rate clear.

The data provided is just a snippet of the data collected, with the average percentage of students skipping each optional question being 12% in Applied Statics, 17% in Heat and Power and 31% in Applied Thermodynamics. Questions in Applied Thermodynamics are typically longer, so fewer questions are on each exam as is seen in Table 2, giving rise to a greater percentage of students skipping each question.

Discussion

Data collected as well as personal observations suggest there is some benefit to be had with the modifications in exam as can be seen in the increase in overall assessment scores for the course learning outcome objectives. The expectation was that this would be more beneficial in upper division courses were students were believed to have greater metacognition, however this was not the case, with the greatest improvement being found in a second semester course- Applied Statics. In all three courses, there were no significant decreases in CLOOs that were worth noting, indicating that if students and instructors prefer this exam format there does not appear to be any harm to course outcomes by continuing to use it.

While the exam format may help students identify blind spots and drive them towards conscious incompetence, without student assistance in closing of the loop by completing additional problems for an increase in their exam grades, it is hard to enforce the reiteration of the material necessary for students to achieve conscious or unconscious competence. One approach being considered is to again require all students to complete these questions. Starting in the spring 2023 semester, students are now allowed to increase their exam grades above 100%, giving higher performing students incentive to increase concept competence.

Where possible, students were re-evaluated on concepts that were skipped by more than half of the students either on subsequent exam questions or in homework or laboratory activities as discussed where applicable. This could not be done instances where questions were commonly skipped on the final exam.

It should be noted that there is a substantial time commitment to grading these review problems after the exam which cannot be overlooked in large courses. With small class sizes this has been manageable and appears to be worth the time. Due to the small class sizes, data was also pooled across multiple courses. Additionally, CLOO assessments came from a mix of exams, homework assignments, lab reports and projects. The combining of data from both high stakes (exams) and low stakes (homework, labs, projects) assessments, appears to have greatly increased the spread of the data. This is due to greater observed variation on high stakes exam scores across classes, than is typically seen on homework assignments. The class sizes also meant that in a course with four students, having only two students opt out of the same question resulted in a skip rate of 50%, which may not hold true for larger courses.

As for an increase in metacognition, in each course, engineering failures are frequently discussed, with an emphasis on people making decisions they should not be making that result in failures. This is tied back to the instructor's strong desire for students to fully understand their weaknesses, and to know when and where to seek outside help- be it through a colleague or their own research. In each course there is an atmosphere where it is reiterated to students that it's ok to not know. And that it can be dangerous to pretend you know what you don't or to have no idea how to learn what you need to. While the impact of this classroom environment is not measured in the data presented here, the hope is that this sort of environment will help students to feel comfortable in critically assessing their shortcomings related to engineering concepts or skills. This, combined with practice in assessing competence in real time during exams, is intended to increase the students' problem-solving mindset and carry with them as they enter the workforce and will undoubtedly be faced with problems they never experienced during their educational career.

Informal discussions with graduating seniors suggest they like the format, but admit it takes some adjustment as they were initially unsure of how to decide which problems to do. As these are discussions directly with the instructor there is the potential that students are not being fully transparent in their like or dislike for the exam format. In anonymous end of the semester evaluations, however, there have been no negative comments made about the format of the exam suggesting there may be some truth to the opinions shared. On these same evaluations, students have, on multiple occasions, reported liking the opportunity to complete review problems to increase their exam grades, suggesting there is incentive to revisit difficult topics. To better gauge whether or not there is any perceived benefit to the exam formatting, work is being done to develop surveys to administer to students at the start and end of each course, as well as after graduation.

References

[1] M. Matousek and J. Schneider, "Untersuchungen zur Struktur," Birkhäuser, Basel, Switzerland, 1976.

[2] M. Broadwell, "Teaching For Learning (XVI.)," *The Gospel Guardian,* vol. 20, no. 41, pp. 1-3, 1969.

[3] P. R. a. P. W. W. Curtiss, The Dynamics of Life Skills Coaching. Life Skills Series., Saskatchewan NewStart, Inc.,, 1974.

[4] J. Flower, "In the Mush," *Physician Executive,* vol. 25, pp. 64-66, Januray 1999.

[5] J. Luft and H. Ingham, "The Johari Window," *Human relations training news,* vol. 5, no. 1, pp. 6-7, 1961.

[6] C. Evans, "Making Sense of Assessment Feedback in Higher Education," *Review of Educational Research,* vol. 83, no. 1, pp. 70-120, 2013.

[7] J. Hattie and H. Timperley, "The Power of Feedback," *Review of Educational Research,* vol. 77, no. 1, pp. 81-112, 2007.

[8] D. Hounsell, "Towards More Sustainable Feedback to Students," in *Rethinking Assessment in Higher Education*, Milton Park, Routledge, 2007, pp. 101-113.