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Enhancing Knowledge Surveys with an Intellectual Humility Scale

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Abstract

As engineering education and related research evolve, it is also important for assessment tools and research methods to evolve. This Work in Progress paper focuses on evaluating student knowledge surveys in conjunction with instructor knowledge surveys about student learning and a validated intellectual humility scale. Knowledge surveys have been used as an indirect, self-report measure of assessing knowledge mastery within courses and across engineering programs to triangulate direct assessment results and inform continuous improvement of teaching and learning, but they have yet to be leveraged in other ways. For example, in engineering education student knowledge survey results are rarely compared to an external perspective nor combined with validated instruments. In this study, knowledge surveys (pre- and post-) were completed by both students and instructors in a 3rd year undergraduate Control Systems and Instrumentation course and used in combination with the limitations owning intellectual humility scale (Haggard et. al.) to gauge the accuracy of perceived growth of learning by students. Student responses were compared against the instructors' initial expectations for student knowledge in the context of the departmental curriculum as well as growth targets upon course completion. Our guiding research questions were (1) What do knowledge surveys reveal about student perceptions in their knowledge compared with instructor perceptions?" and (2) "What insights do we gain in comparing student intellectual humility scale results with their knowledge surveys?" Preliminary findings for research question 1 show that student self-assessments are generally higher than instructor expectations and targets in both pre- and post- surveys which indicates that there are knowledge areas where major gaps still exist in students' perceptions of growth. The gap is greater at the end of the course, indicating that after a preliminary course experience they overestimate their knowledge gains. Instructors can leverage this data in future course iterations to manage student perceptions by providing broader context in targeted knowledge areas. While findings for research question 2 did not show a significant relationship between student perception of self-knowledge and their intellectual humility, this is likely due to limitations of this study design. Incorporation of intellectual humility and assessment thereof in engineering education holds promise because intellectual humility is associated with a mastery approach to learning that fuels lifelong learning and is a characteristic employers value in engineers.

Introduction

Knowledge surveys (KS), as introduced by Nuhfer and Knipp [1], are intended to provide instructors feedback on student learning through self-assessment of mastery of topics and types of questions (i.e. Bloom's taxonomy). While there have been varying reports on the correlation of student self-assessment through knowledge surveys and student performance [2], [3], there are clear benefits for students by highlighting course objectives/content, serving as a learning guide, and strengthening self-assessment skills and for instructors as a course improvement tool, aiding in course organization and design, providing a knowledge baseline for students entering a course (pre-survey), providing a measure of content mastery, are generally more comprehensive than exams, and can be used to evaluate new pedagogies [4]. Specifically, in an engineering context, knowledge surveys have also been used across engineering programs to triangulate direct assessment results and inform continuous improvement of teaching and learning [5-8]. <u>This study seeks to further leverage knowledge surveys for instructor course improvement with particular focus on whether or not topical information is presented appropriately in the broader context of the field.</u> This is akin to Carter and Dunning's [9] concept of an "informational environment" which is the understanding of what information exists related to a particular topic. Student awareness of a given subject can be limited to topics covered in a course, and by restricting the informational environment to core subject matter without appropriate context the informational environment does not allow students to understand the course in the context of the broader subject landscape. If the informational environment is incomplete, or too narrow in focus, then a student will not necessarily be aware of their limitations related to that topic. By not providing an appropriate informational environment, students will only be aware of what they have been taught and not "know what they don't know", fueling the Dunning-Kruger effect [10]. A student in an introductory course who performs well would be expected to rank their mastery of that specific course content high. However, in the context of a broader informational environment, not confined to the course itself, students should be aware that the material is introductory and rank their mastery lower. In an advanced course on a particular topic, the student has more mastery of the entire informational environment and a higher ranking would be appropriate. To assess this, student knowledge surveys are evaluated against a target attainment as set by instructors. In other words, the instructors define where they believe that this course content falls in the broader informational environment, setting a baseline for comparison of student responses. If students rank themselves higher than this target, it may be prudent for the instructor to highlight the broader context to enrich the students' understanding of the informational environment. Conversely, if the students rank themselves lower, then the instructor may need to highlight the relevance and applicability of the material within the informational environment.

Knowledge surveys have also been used as a lens to view student confidence, identifying cases where self-assessment does not align with measured or observed performance [11]. This could be low self-assessment with high performance, or vice versa. This can be problematic when students perform self-assessments as it can introduce bias into the results. To account for this, we consider student confidence as a gauge of the virtue of intellectual humility (IH). Porter, et. al. [12] succinctly define Intellectual Humility as "a meta-cognitive ability to recognize the limitations of one's beliefs and knowledge". Intellectual Humility has been identified as a character trait sought by employers [13], [14] and is an indicator of lifelong- learning [15], [16] and mastery approach to learning [17] which is identified as a student outcome for ABET Accreditation [18]. While knowledge surveys can provide some insight, Intellectual Humility itself can be assessed on a continuum from servile (underestimated confidence) to arrogant (overconfident) [19]. By coupling an intellectual humility survey instrument with a knowledge survey gauging student learning over a course, this study seeks to assess whether instructors are providing a complete informational environment to their students. The specific research questions addressed through this study are:

> RQ 1a. To what extent do students' knowledge surveys improve pre/post (i.e., do they think they learned in the class)?

RQ 1b. To what extent do the knowledge survey tools show a convergence between student perception of their content mastery and the instructors' perceptions of student mastery. Is there a significant change between the student-instructor pre-gap and post-gap?

RQ 2a. How and to what extent do individual students' IH scores change over the course of the semester?

RQ 2b. To what extent do the students' IH scores correlate with accuracy of a self-reported knowledge survey?

Engineering Education Context

This study was conducted over two semesters in a junior level undergraduate course titled "Control Systems and Instrumentation". This is a core course in a general engineering undergraduate program that covers a large swath of topics pertaining to electrical, computer, and control systems. In a discipline specific degree program, these topics are traditionally spread across many courses such as Circuits, Analog Electronics, Digital Electronics, Power Systems, Embedded Systems, and Controls, many of which often have a separate associated lab. This is a hands-on course and laboratory exercises are integrated into almost every class alongside the lecture component [20]. For labs and larger projects, students work in groups of two or three with each group having access to their own benchtop instrumentation consisting of a power supply, a digital multimeter (DMM), an oscilloscope, and a function generator. Additionally, each student has their own electronics kit consisting of a handheld DMM, wire, wire strippers, needle nose pliers, wire snippers, a breadboard, a resistor booklet, an Arduino Uno, and various electrical components (capacitors, inductors, and a selection of integrated circuits, sensors, and semiconductors). This is used in class for lab activities as well as outside of class for pre-lab exercises and course project work. With the broad course coverage, the content is broken into modules (Figure 1) which form the basis for the knowledge survey.

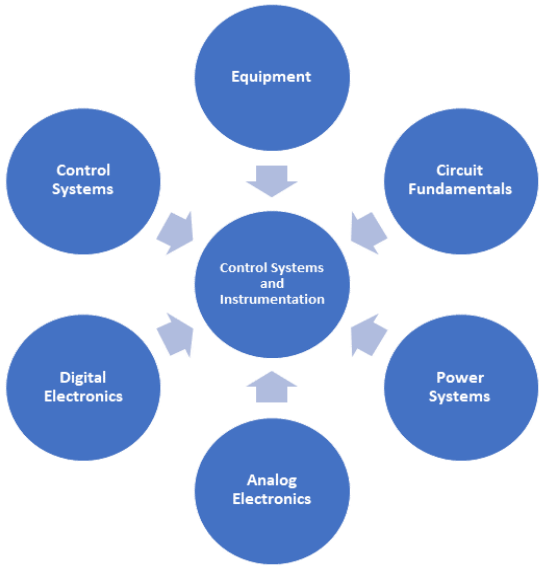

Figure 1 Modular breakdown of topics in the Control Systems and Instrumentation course

In turn, each module is broken down into five to ten subtopics. For example, "Circuit Fundamentals" is composed of:

- Ohm's Law (Voltage, Current, Resistance)
- Ground
- Voltage Division
- Kirchoff's Voltage Law
- Kirchoff's Current Law
- Equivalent Circuits (Norton and Thevenin)

For this study, there were two instructors for both semesters that data was collected. While there are some variations in the course from instructor to instructor, this course was largely team-taught. During one semester, there were two different sections, which were closely coordinated by instructors, mirroring each other in terms of schedule, lab activities, homework, exams, projects, resources, and even lecture slides. The second semester was a single course split between the same two instructors who alternated teaching over the course of the semester by module.

Study Context

This study is part of a larger research program focused on infusing character education into engineering. Intellectual humility is one of the target character virtues being investigated as it has implications in teamwork, lifelong learning, identifying limitations, and seeking and accepting external feedback. These are all skills relevant in engineering practice, however, it is important to better understand the virtue of intellectual humility and characterize how it acts as a vice in absence as well as in excess. Other studies focus on intellectual humility specifically in the context of engineering design reviews.

Methods

This study was conducted over the course of two semesters. Students were asked to complete the general knowledge survey and the limitations-owning intellectual humility scale [15] at the beginning and end of each semester. The instructors of the course also completed the general knowledge survey with their expectation of where students would rank prior to the course as well as after the course. Student responses to the knowledge survey and the intellectual humility scale are analyzed to determine changes over the course of the semester. The student knowledge survey responses are also compared to the instructor ratings. Lastly, student variations with respect to instructor targets are compared to intellectual humility scores.

Sample Population

This study was conducted in the undergraduate general engineering program at a small liberal arts college in the United States. Twenty-seven students enrolled in a required third year Instrumentation and Controls Course participated.

Data Sources

<u>Knowledge Survey (Appendix A)</u>
A knowledge survey was designed in Qualtrics based on the module breakdown of the course as discussed in the engineering education context and depicted in Figure 1. Each broad module is presented along with its sub modules. Students are asked to rank each sub module using a Likert scale of 1 to 9, with 1 being "No Familiarity" and 9 being "Mastery". They are also asked to assess their overall understanding of the high-level module.
Instructors also completed the knowledge survey based on their expectations of student knowledge both pre and post course. Instructor averages were used as a criterion comparison for student scores [21].

<u>Limitations Owning Intellectual Humility Survey (Appendix B)</u>
Students completed the Haggard Intellectual Humility Scale [19] through the course Canvas site. The twelve-item survey addresses three sub-constructs, four questions each: Love of Learning, Appropriate Discomfort with Intellectual Limitations, and Owning One's Own Intellectual Limitations. Likert scale responses ranged from 1 to 9, with 1 being "Strongly Disagree" and 9 being "Strongly Agree". This survey has not yet been validated for Engineering undergraduates.

Data Analysis

<u>Research Question 1a</u>: To what extent do students' knowledge surveys improve pre/post (i.e. do they think they learned in the class). To answer this question, student pre and post scores were compared using a two-sample *t-test* for each knowledge survey question. A second *t-test* was run using averages calculated for each student in each of the knowledge survey content areas (Equipment, Electronics Fundamentals, Power, Analog, Digital, and Controls).

<u>Research Question 1b</u>: To what extent do the knowledge survey tools show a discrepancy between student perception of their content mastery and the instructors' perceptions of student

mastery, was explored using a one sample *t-test* comparing students data set against the target instructor score. This analysis approach is known as an independent means comparison, wherein the mean of students' self-reported knowledge survey scores are compared with a mean criterion score (in this case determined by the instructors) to provide insight into the direction and magnitude of student inaccuracy [21].

Research Question 2a: How and to what extent do individual students' IH scores change over the course of the semester. To answer this question, student pre and post scores were compared using a two-sample *t-test* for overall Intellectual Humility scale scores as well as scores on the subscales: Love of Learning, Appropriate Discomfort with own Limitations, and Owning One's own Intellectual Limitations.

Research Question 2b: To what extent do the students' IH score correlate with accuracy of the knowledge survey. Compare the deviation of student KS scores from instructor scores with IH scores using Pearson correlation, the hypothesis being that higher IH scores indicate smaller deviation. Additionally, the change in IH scores from T1 to T2 with the change in student deviations from instructor scores from T1 to T2 were compared using Pearson correlation, with the hypothesis being that larger increase in IH would correlate with a decrease in deviation from instructor scores.

Results and Discussion

RQ2: Results from the Knowledge Surveys

RQ 1a. To what extent do students' knowledge survey improve pre/post (i.e., do they think they learned in the class)

Table 1 Comparison of student self-reported pre/post Knowledge Survey (KS) scores

	Pre-KS		Post-KS					
	M	SD	M	SD	*df*	*t*	*p*	Cohen's D
Equipment	3.37	1.41	7.53	0.65	26	-13.89	<0.01	3.789
Electronics Fundamentals	3.78	1.61	7.93	0.69	26	-12.31	<0.01	3.351
Power	2.77	1.56	6.23	1.20	26	-9.10	<0.01	2.486
Analog	2.63	1.32	7.17	0.74	26	-15.63	<0.01	4.243
Digital	2.80	1.19	7.15	1.03	26	-14.30	<0.01	3.909
Controls	1.94	1.22	6.09	0.95	26	-13.89	<0.01	3.796

Student perceived growth was assessed using a T-test of the pre and post rankings of the knowledge survey. As indicated in Table 1, all topics in all categories demonstrated significant change in outcome except for one: the “Soldering” subtopic under the “Equipment” category. This is not a surprising outcome as soldering was not a topic that was explicitly taught in the class, rather it was only introduced to a subset of students if needed to support the implementation of course projects. Otherwise, this self-report data indicates that students perceived significant knowledge growth in all other areas.

RQ 1b. To what extent do the knowledge survey tools show a convergence between student perception of their content mastery and the instructors’ perceptions of student mastery. Is there a significant change between the student-instructor pre-gap and post-gap?

The baseline instructor expectation for the knowledge survey was developed based on input from both instructors of this course. The pre and post expectations for both are shown in Figure 2. The instructors were more in line with one another in the pre assessment than the post assessment. Post assessment shows variation up to two points with the expectations of instructor A higher than those of instructor B by one to two points in all areas except for digital electronics. This is not a surprising outcome given biases implicit to each instructor given their own academic background and experiences as well as interactions with students in follow-on courses. An example is that instructor B did not feel that the students had enough exposure to all of the capabilities of the lab equipment to rate them higher overall. This was corroborated through experiences with students in capstone courses and technical electives that needed assistance using more advanced equipment features. Given that these disparities are low, the instructor expectation scores are averaged for comparison with student self-assessment data.

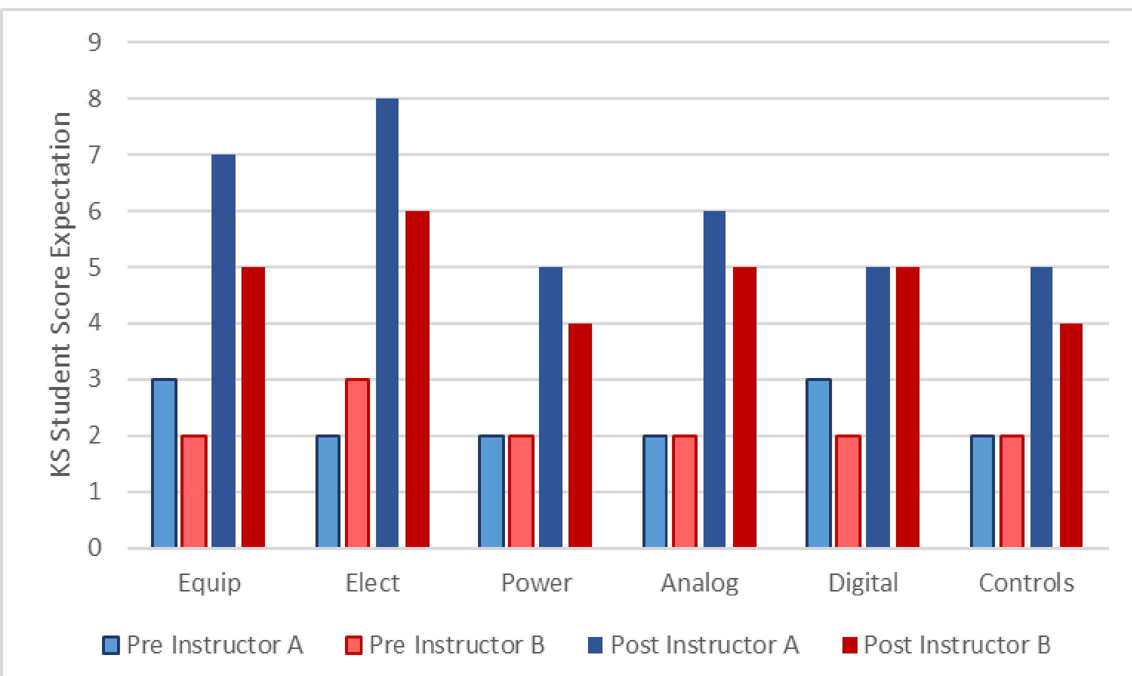

Figure 2 Instructor expected Knowledge Survey ranking for both pre and post course surveys as evaluated by both course instructors (A and B).

As shown in Figure 3 (student/instructor average pre/post), students were more conservative than instructors regarding their pre-Controls knowledge and their post-Electronics

Fundamentals knowledge. This was the sole case of students rating their understanding lower than instructors and could be caused by students having such a limited informational context of the topic that they were uncomfortable ranking this topic at all. In all other regards, students rated their knowledge higher than their instructors' estimation, and this gap grew at the end of the semester when the post-scores were collected. This change in gap is exemplified by evaluating the average change in rating as shown in Figure 4 (Student vs Instructor Changes in average pre/post Knowledge Survey Scores).

A possible explanation for the consistently higher self-rankings from the students is that their information environment [5] is largely based on the context of this course. In other words, the students do not know what they do not know in the broader context of topics studied in this course. For example, in this course, student exposure to controls is limited to proportional, integral, derivative control (PID), addressing overshoot, stability, and settling time for first order and second order systems. There is only brief mention of controls beyond this context, so there is little introduction to the broader controls ecosystem that includes digital controls, multivariable controls, state-space controls, or adaptive controls.

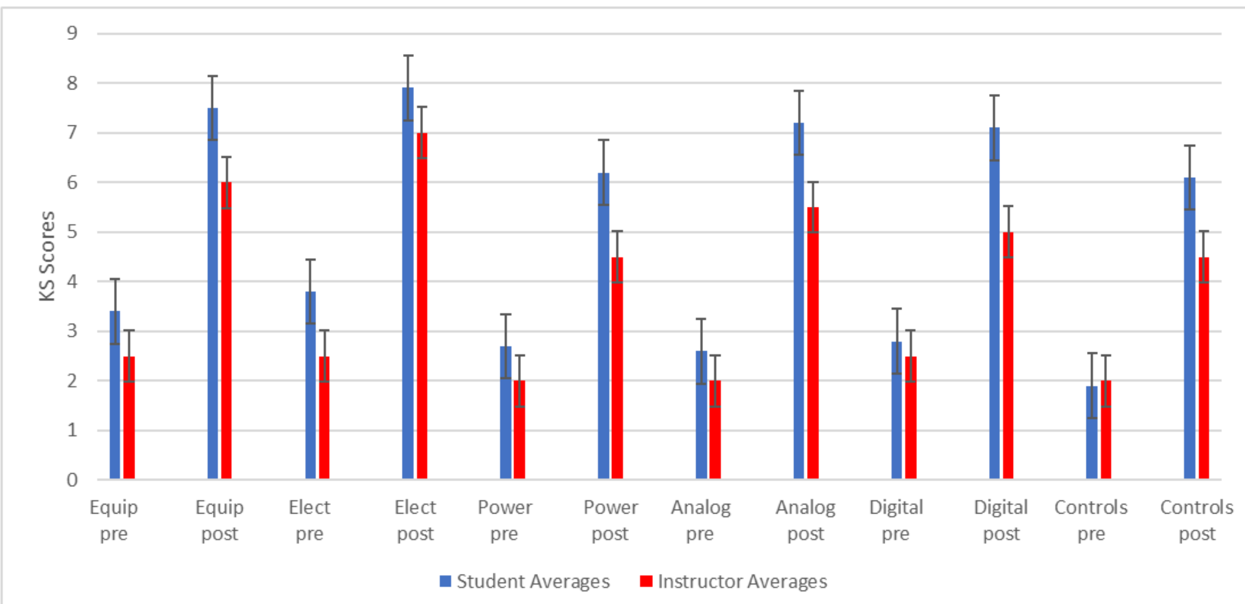

Figure 3 Student vs instructor average pre/post Knowledge Survey Scores

Across measures, students generally ranked their understanding of topics higher than instructors except for the Digital and Controls categories (Table 2). Students in this course had previously been exposed to basic electronics in an introductory 100-level general engineering course, where students use fundamental electrical equipment such as DMMs and power supplies and cover basic electric fundamentals such as Ohm's law. Before the course started it is possible that students considered themselves to have limited, but substantial, understanding of electronics due to the limited information environment they had at that time. However, the fundamentals students had previously been exposed to made little mention of Digital signals and no mention of controls, perhaps influencing their KS scores for these categories.

Table 2 Statistical significance measures of student responses vs. instructor expectations for the pre-Knowledge Survey.

	Pre-KS Student N = 27	Reference Mean*		
	M	M	*t*	*p*
Equipment	3.37	2.50	3.209	0.0035***
Electronics Fundamentals	3.78	2.50	4.114	0.0003***
Power	2.77	2.00	2.543	0.0172**
Analog	2.63	2.00	2.474	0.0202**
Digital	2.80	2.50	1.309	0.2019
Controls	1.94	2.00	-0.2419	0.8108

* Pre-KS Instructor average
** $p < 0.05$
*** $p < 0.01$

Upon completing the course, students reported significantly higher scores compared to instructor mean (Table 3) for all groups. In all cases, students reported higher scores than instructors, and this difference is statistically significant (Table 4), indicating that students may not have fully contextualized the course material in the scope of electrical engineering.

Table 3 Statistical significance measures of student responses vs. instructor expectations for the post-Knowledge Survey.

	Post-KS Student N = 27	Reference Mean*		
	M	M	*t*	*p*
Equipment	7.53	6.00	12.345	<0.0001***
Electronics Fundamentals	7.93	7.00	7.046	<0.0001***
Power	6.23	4.50	7.461	<0.0001***
Analog	7.17	5.50	11.730	<0.0001***
Digital	7.15	5.00	10.804	<0.0001***
Controls	6.09	4.50	8.727	<0.0001***

* Post-KS Instructor average
** $p < 0.05$
*** $p < 0.01$

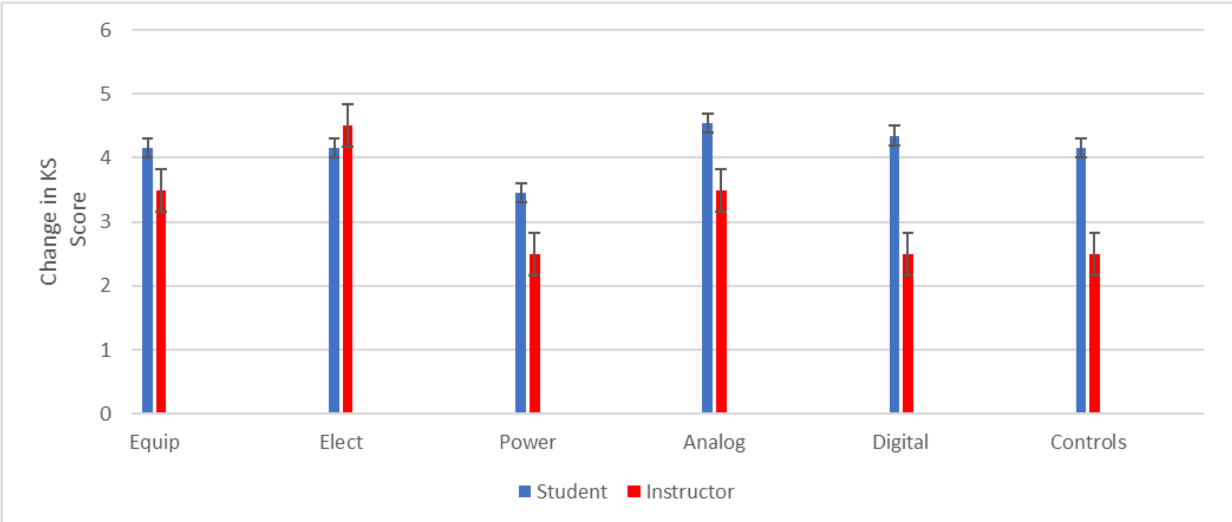

Figure 4 Student vs instructor changes in average pre/post Knowledge Survey scores.

Table 4 Pre/Post change in Deviation of student vs instructor Knowledge Survey scores.

	Pre-KS		Post-KS					
	M	SD	M	SD	*df*	*t*	*p*	Cohen’s D
Deviations from instructor	0.52	0.94	1.61	0.69	26	-3.95	0.0003	1.322

RQ2: Results from the Intellectual Humility Scale

RQ 2a. To what extent do individual students' IH improve over the course of the semester?

Student IH survey results were analyzed (Table 5) between their pre and post rankings. The results indicate no significant change in any of the dimensions of intellectual humility.

Table 5 Statistical significance of changes in Intellectual Humility subscale self-report from beginning to end of the semester.

	Pre		Post					
	M	SD	M	SD	*df*	*t*	*p*	Cohen's D
Intellectual Humility (full scale)	6.87	0.82	6.95	0.68	17	-0.35	0.727	0.106
Owning Intellectual Limitations (subscale)	6.96	1.08	7.22	1.06	17	-0.74	0.464	0.243
Love of Learning (subscale)	7.79	0.72	7.65	0.69	17	0.59	0.559	0.199
Appropriate Discomfort with Limitations (subscale)	5.85	1.48	5.99	1.43	17	-0.29	0.776	0.096

RQ 2b. To what extent do the students' Intellectual Humility score correlate with accuracy of self-knowledge survey

Correlation between the Knowledge Survey and Intellectual Humility subscale scores are reported in Table 6. Red indicates a negative correlation between KS results and Intellectual Humility scores (i.e. lower Knowledge Survey associated with higher self-reported Intellectual Humility). The darker the red, the stronger the correlation. Blue indicates a positive correlation between KS results and Intellectual Humility scores (i.e. higher Knowledge Survey associated with higher self-reported Intellectual Humility). The darker the blue, the stronger the correlation. Several relevant observations can be made based on this data. While none of the correlations were statistically significant, several of the correlations were trending toward significance and should be investigated further. Students who reported in the post survey that they own their limitations were found to have scored themselves more closely with instructor expectations (i.e. lower) in the pre-course Knowledge Survey. These students may have had a more reasonable evaluation of their topical understanding upon entering the course because of a higher propensity to see their personal limitations. However, students who reported higher comfort with their limitations in the post IH survey were found to deviate from instructor expectations more in both the pre and post Knowledge Surveys, potentially pointing to some further investigation needed around differences between comfort with limitations and ownership of them in this context. Further, the nearest correlation to significance was found between the change in a student's ownership of limitations score and the change in deviation from the instructor's scores. In this case, students whose ownership of limitations score increased over the course also appeared to deviate more from the instructor's scores more at the end of the course.

Table 6 Pearson correlations comparing student KS deviations with Intellectual Humility (IH) scale and subscale scores. N = 18.

	pre KS dev	post KS dev	change KS dev
pre IH avg	0.001998	-0.06974	-0.06625
post IH avg	-0.00376	0.107467	0.10311
change IH avg	-0.00691	0.221522	0.211337
post own lim	-0.37417	-0.09204	0.381008
change own lim	-0.04294	0.420225	0.438249 (*p = 0.0689**)
post love learn	-0.14668	-0.16328	0.032873
change love learn	-0.21926	-0.15749	0.128262
post comf with lim	0.344398	0.300301	-0.15324
change comf with lim	0.135211	0.146127	-0.0344

*All correlations, except for change in Knowledge Survey deviation compared to change in Owning Intellectual Limitations, had a p-value of 0.1 or higher, so significance is otherwise not reported in this table

Conclusions

Broadly, the goal of this work is to consider the link between knowledge survey scoring and intellectual humility in the context of this undergraduate level instrumentation and controls course. While perceived student growth is desirable, it is also important to understand the context of that growth. Upon completion of a course, do students have an appropriate appreciation for where their knowledge on course topics lies within the broad context of that field? Do they even have an appropriate informational environment in which to properly self-assess? Understanding these questions can provide valuable information to instructors to guide focus in future course iterations.

To answer these questions, a broad knowledge survey was issued in conjunction with a validated intellectual humility scale. Does the outcome of the IH assessment indicate how students will self report on a knowledge survey? The knowledge survey implemented here considered the self-report levels of students with respect to course topics in a broad context compared to the instructor(s) estimate of where they should rate themselves. Initial results do not indicate significance in correlation between KS deviations from instructor(s) targets and intellectual humility scores, but there are trends towards significance that should be further evaluated. Specifically, students who rank themselves higher in owning limitations deviated more from instructor targets at the end of the course. Further evaluation is warranted addressing limitations in the study.

Limitations

- This study uses a broad knowledge survey, meaning that it does not focus on performance estimates on particular types of questions, rather it asks the student to rate their understanding of a topic. Doing so may artificially limit the informational environment, which is the very thing that is being examined. Student instructions state that the evaluation is not limited to the context of the course. Even so, it may be difficult to think beyond the immediate context of the course. The advantage of a question-based Knowledge Survey would be that the informational context is less open to interpretation by the respondent.
- The intellectual humility scale is self-report and there may be bias based on how a student ranks the statements. It may be better to conduct a 360-degree evaluation of intellectual humility. The drawback is that this may be difficult to achieve over the course of a single semester. Students may also be misinterpreting statements and there is at least one case where it appears that a student applied the ranking backwards for their post evaluation when compared with the pre.
- There are cases of incomplete data where the knowledge survey was completed, but not the intellectual humility scale. This has been addressed by combining the instruments into a single survey.

Future Work

Moving forward with this work in progress, focus will be placed on addressing the identified limitations by:

- Assessing the design and content of the knowledge survey,
- Clarifying rating instructions for the knowledge survey,
- Examining knowledge survey and intellectual humility results alongside graded material,
- Expanding this work to a larger scale evaluation of IH in the context of ABET accredited undergraduate engineering education.
- Validating the limitations owning intellectual humility scale for an undergraduate engineering student population,
- Conducting a long-term study that follows students across multiple courses or even the entire curriculum.
- Perform additional statistical analysis with a larger sample size.

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Appendix A: Knowledge Survey

The following topics are all technical concepts related to equipment you will use in this course. Remember, 1 is "no familiarity" and 9 is "mastery".

	No Familiarity (1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	Mastery (9)
Practical use of DC power supplies	o	o	o	o	o	o	o	o	o
Practical use of arbitrary function generators (AFGs)	o	o	o	o	o	o	o	o	o
Practical use of digital multimeters (DMMs)	o	o	o	o	o	o	o	o	o
Practical use of oscilloscopes	o	o	o	o	o	o	o	o	o
Practical use of breadboards	o	o	o	o	o	o	o	o	o
Practical use of wire strippers	o	o	o	o	o	o	o	o	o
Practical layout and wiring of circuits (layout only, not functional design)	o	o	o	o	o	o	o	o	o
Soldering	o	o	o	o	o	o	o	o	o
OVERALL Equipment Rating	o	o	o	o	o	o	o	o	o

The following topics are all technical concepts related to electronics fundamentals. Remember, 1 is "no familiarity" and 9 is "mastery".

	No Familiarity (1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	Mastery (9)
Ohm's Law	o	o	o	o	o	o	o	o	o
Ground	o	o	o	o	o	o	o	o	o
Voltage Division	o	o	o	o	o	o	o	o	o
Kirchoff's Voltage Law	o	o	o	o	o	o	o	o	o
Kirchoff's Current Law	o	o	o	o	o	o	o	o	o
Equivalent Circuits (Norton and Thevenin)	o	o	o	o	o	o	o	o	o
OVERALL Electronics Fundamentals Rating	o	o	o	o	o	o	o	o	o

The following topics are all technical concepts related to electrical power. Remember, 1 is "no familiarity" and 9 is "mastery".

	No Familiarity (1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	Mastery (9)
Direct (DC) and Alternating (AC)	o	o	o	o	o	o	o	o	o
Power generation	o	o	o	o	o	o	o	o	o
Power transmission	o	o	o	o	o	o	o	o	o
2 and 3 phase power	o	o	o	o	o	o	o	o	o
Transformers	o	o	o	o	o	o	o	o	o
OVERALL Power Rating	o	o	o	o	o	o	o	o	o

The following topics are all technical concepts related to analog electronics. Remember, 1 is "no familiarity" and 9 is "mastery".

	No Familiarity (1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	Mastery (9)
Capacitors	o	o	o	o	o	o	o	o	o
Inductors	o	o	o	o	o	o	o	o	o
Impedance	o	o	o	o	o	o	o	o	o
Filters	o	o	o	o	o	o	o	o	o
Diodes	o	o	o	o	o	o	o	o	o
Transistors	o	o	o	o	o	o	o	o	o
555 Timers	o	o	o	o	o	o	o	o	o
Operational Amplifiers (different configurations)	o	o	o	o	o	o	o	o	o
Sensors	o	o	o	o	o	o	o	o	o
OVERALL Analog Electronics Rating	o	o	o	o	o	o	o	o	o

The following topics are all technical concepts related to digital electronics. Remember, 1 is "no familiarity" and 9 is "mastery".

	No Familiarity (1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	Mastery (9)
Binary	o	o	o	o	o	o	o	o	o
Basic logic gates	o	o	o	o	o	o	o	o	o
Combinatorial logic	o	o	o	o	o	o	o	o	o
Sequential Logic	o	o	o	o	o	o	o	o	o
Microcontrollers (e.g. Arduinos)	o	o	o	o	o	o	o	o	o
Computer Programming (not language specific)	o	o	o	o	o	o	o	o	o
Communication Protocols	o	o	o	o	o	o	o	o	o
OVERALL Digital Electronics Rating	o	o	o	o	o	o	o	o	o

The following topics are all technical concepts related to control systems. Remember, 1 is "no familiarity" and 9 is "mastery".

	No Familiarity (1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	Mastery (9)
First order systems	o	o	o	o	o	o	o	o	o
Second order systems	o	o	o	o	o	o	o	o	o
Open-Loop control	o	o	o	o	o	o	o	o	o
Closed-loop control	o	o	o	o	o	o	o	o	o
Proportional Integral Derivative (PID) control	o	o	o	o	o	o	o	o	o
OVERALL Control Systems Rating	o	o	o	o	o	o	o	o	o

Appendix B: Haggard Intellectual Humility Scale

(1 - strongly disagree; 9 - strongly agree)

Constructs within the Haggard scale (Haggard 2018). *scored in reverse

I. Love of Learning

1. If I don't understand something, I try to get clear about what exactly is confusing to me.
2. When I don't understand something, I try hard to figure it out.
3. I love learning.
4. I care about truth.

II. Appropriate Discomfort with Limitations

1. I focus on my intellectual weaknesses too much.*
2. When I know that I have an intellectual weakness in one area, I tend to doubt my intellectual abilities in other areas as well.*
3. When I think about the limitations of what I know, I feel uncomfortable.*
4. I tend to get defensive about my intellectual limitations and weaknesses.*

III. Owning Intellectual Limitations

1. I have a hard time admitting when one of my beliefs is mistaken.*
2. When someone points out a mistake in my thinking, I am quick to admit that I was wrong.
3. I am quick to acknowledge my intellectual limitations
4. I feel comfortable admitting my intellectual limitations.