



Work in Progress: Developing a Multi-dimensional Method for Student Assessment in Chemical Engineering Laboratory Courses

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Introduction:

The impetus for this project came from the desire to continue to improve the quality of learning that our students experience in the unit operations laboratory course. With input from the entire chemical engineering faculty, course changes are under consideration. As with most unit operations laboratory courses, this course lives at the end of the 4-year curriculum and serves as the culmination of the student's prior coursework. Chemical engineering faculty at Rose-Hulman Institute of Technology (RHIT) perceive that students appear to lose motivation and excitement for doing high-quality work in the laboratory course, potentially diminishing student outcomes; these attitudes are motivating the desired change to the curriculum.

Before making changes, we first needed to assess the gains in student learning, engagement, and skills in the existing course to verify instructor perceptions. Therefore, our goal was to benchmark a broad snapshot of the current laboratory course sequence before implementing any course changes. Due to the complexity of the course learning objectives, the authors took a multi-dimensional approach. By using both self-assessment and direct assessment methods with various tools in each of these categories we sought to capture the effects of our current pedagogical practices while creating a platform to assess future changes to the laboratory curriculum. The four outcomes of interest were developments in knowledge, laboratory skills, attitudes, and writing skills.

Table 1: Proposed assessments that cross multiple dimensions of the learning process. Included are the instrument name and types of outcomes associated with each instrument. (*No results are presented on the writing skills assessment in this preliminary study.)

Student Self-Assessment		Direct Assessment	
instrument	outcomes	instrument	outcomes
URSSA	knowledge, skills	Skills Test	knowledge, skills
MUSIC	attitudes	VALUE Rubric [1]*	writing skills*

Methods:

Student Self-Assessment Development:

By asking the students to judge their own performance via self-assessment, we were better able to identify current weaknesses in the organization and content of the course. Self-assessment by students can produce mixed reviews [2], but employing validated instruments, such as the URSSA survey [3] and MUSIC Inventory [4], [5], provide added confidence in our assessments. The URSSA survey was developed within the Life Sciences community [3] and was recently validated as a tool for assessing undergraduate research programs [6]. Although the original survey contained significant overlap with the learning objectives for this chemical engineering laboratory course, it lacked questions on teaming, safety, and accepting responsibility. An additional 12 questions were written to address these topics, consistent with the associated modification instructions. By adding 12 new questions and removing research oriented-questions, the survey consisted of 36 multiple-choice questions with a Lickert scale. The

inventory aims to capture students' perception of their own skills and knowledge in the laboratory course.

To assess students' attitudes, we adopted another validated instrument, the MUSIC (eMpowerment, Usefulness, Success, Interest, Caring) Inventory. This survey was established to measure student motivations and has been validated [7], [8]. It has been used to study motivations of engineering students [9]. We administered this 20-item inventory to capture how students view the usefulness of the course, their sense of success in the course, their interest in the course material, and as potential validation of instructor observations about student attitude. We omitted the caring theme for two reasons: it falls outside the scope of our proposed changes, and students do not have one instructor throughout the entirety of the course sequence.

Student Laboratory Skills Test Development:

Questions for the laboratory skills test were modeled after those present in the AIChE Concept Warehouse [10]. The test directly assessed student knowledge and skills related to specific learning objectives in chemical engineering laboratory courses. Discussions with eleven chemical engineering laboratory instructors at RHIT led to identifying these skills and objectives. These skills included: safety practices, data acquisition skills, data analysis skills, connecting theory with experimental results, troubleshooting (data and/or equipment), knowledge of equipment, knowledge of instrumentation, management skills, application of concepts to new scenarios, and communication.

The skills test comprised 22 questions drawn evenly from the skill topics. Question types included multiple choice with one or more correct response, image labeling, content matching, numerical data entry, and short free response. Several of the questions within each skill category were variations on a similar theme. For example, students are asked to assess if a plotted data set is accurate, precise, both, or neither to demonstrate mastery of drawing conclusions from data and statistics. Chemical engineering faculty at RHIT reviewed these questions. Questions were revised for clarity and content. A second iteration of the skills test saw 9 of the 22 questions replaced with variant questions considered topically equivalent. The authors changed these questions from test-to-test to minimize predictability while still permitting comparisons between different versions of the skills test.

Assessment Deployment:

Data were collected from students on the first and last day of the Lab II course during the academic year 2017-2018. Data collected include the student self-assessment (URSSA and MUSIC) and the skills test. Students were instructed to complete the self-assessment first then the skills test. They were told the self-assessment would take approximately 10 minutes and the skills test would take approximately 20-30 minutes. (All students completed both instruments within 45 minutes.) Students were provided with a link from their course management system for each instrument and taken online. Assessments were hosted by the authors' institute office for planning and research. This ensured no instructor could gain access to student responses until after grades were submitted. Student responses did not affect students' grade in the course, however participation was required to pass the course and a good faith effort was expected.

Preliminary Results:

Student Self-Assessment:

The self-assessment administered to students comprised a 36-item section (URSSA) that measured knowledge and skills and a 20-item section (MUSIC) that measured attitudes. For both sections paired-samples t-test were conducted to compare scale differences for items or categories on pre- and post-surveys. The average student response changed ($p \leq 0.1$) for 19 of the 36 items on the URSSA survey. Of note, significant differences ($p \leq 0.001$) with large effect sizes ($D \geq 0.5$) emerged (see Table 2). Positive effect sizes indicate students rated themselves higher at the end of the course compared with their rating at the beginning. The authors observed that the learning objectives associated with these questions are connected to structured elements in the existing laboratory curriculum, and ones that some faculty members emphasize to their students. For example, students develop two experimental plans and receive instructor feedback on each (one for each project). Some instructors encourage or require students to re-write their experimental plans incorporating this feedback.

Table 2: Subset of results from URSSA survey (5-point scale) reporting student self-assessment of knowledge and skills related to their laboratory experience. Mean (M), standard deviation (SD), p -value, and effect size (D) are given. $N = 66$.

ITEM	PRE		POST		p	D
	M	SD	M	SD		
how to formulate an experimental objective that can be answered with data.	3.70	0.66	4.33	0.54	≤ 0.001	1.06
how to figure out the next step in a lab experiment.	3.52	0.64	4.11	0.59	≤ 0.001	0.96
how to identify limitations of experimental methods and designs.	3.47	0.66	4.03	0.70	≤ 0.001	0.82
how to explain the chemical engineering principles within a lab project.	3.67	0.75	4.21	0.67	≤ 0.001	0.76
how to relate experimental data to theoretical phenomena.	3.70	0.74	4.08	0.62	≤ 0.001	0.56
enthusiastic about working in the chemical engineering laboratory.	3.56	0.98	3.32	1.13	≤ 0.05	-0.23

Three items showed negative effect sizes ($D < 0$), one of which was significant (see Table 2). Some of the least significant items (not shown) pertain to students' level of enthusiasm and their interest in discussing concepts with non-chemical engineers. This is consistent with results of the MUSIC assessment. As seen in Table 3, student interest in the course did not change significantly.

Table 3: Results of MUSIC Inventory (6-point scale, theme of caring, “C”, not included) reporting self-assessment of student attitudes related to their laboratory experience. Mean (*M*), standard deviation (*SD*), *p*-value, and effect size (*D*) are given. *N* = 66.

CATEGORY	PRE		POST		<i>p</i>	<i>D</i>
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>		
eMpowerment	4.34	0.88	4.58	1.05	≤0.1	0.3
Usefulness	4.80	0.81	4.68	1.03		-0.1
Success	4.99	0.62	4.79	0.73		-0.3
Interest	4.28	0.80	4.38	1.02		0.1

We observed significant shifts ($p \leq 0.05$) with positive effect sizes ($D > 0$) in students’ sense of empowerment, suggesting students perceive a larger sense of autonomy at the end of the course. Student perception of the usefulness of the course material, students’ perceived ability to be successful in the course, and student interest in the course did not show a significant change between pre- and post-course assessment.

Laboratory Skills Test:

To analyze the skills test, the questions were divided into the ten constituent categories (Safety, Acquire Data, etc.) Each category was scored individually. Scores were recorded as a percentage of possible points earned by the student. These percentages were averaged for each category and are presented below with standard deviation in Figure 1. Although these data are for a relatively small sample size, students do not appear to score significantly differently on the post-test when compared to the pre-test in the majority of categories. Several of the categories that showed no significant change, including data analysis, troubleshooting, and concept application, contained at least one question that was substituted between pre- and post-test. In general, students scored the highest in the Safety and Acquire Data categories; most students received full credit for these questions which skewed some error bars above 100%.

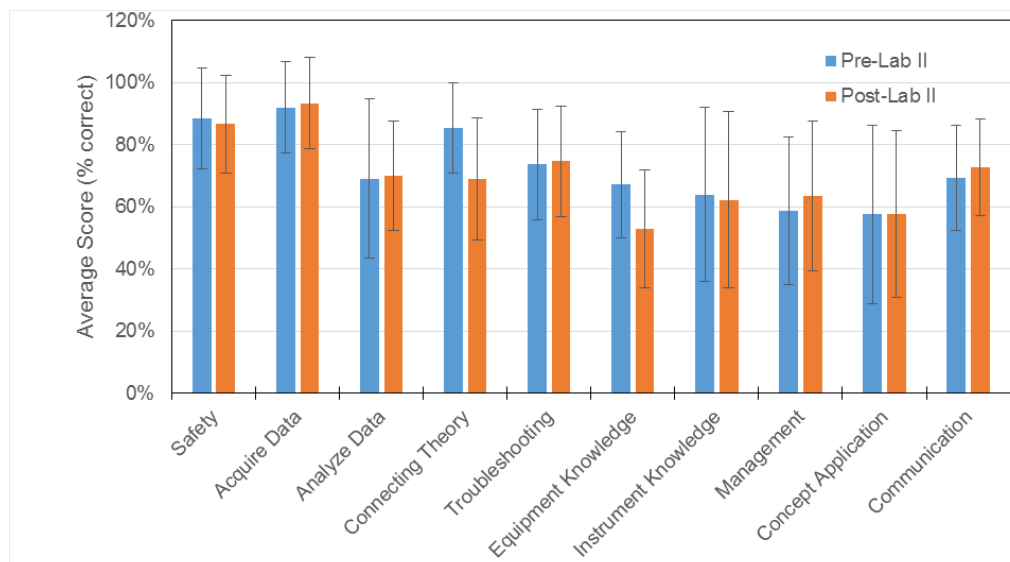


Figure 1: Average student score for each category of the Skills Test administered before and after the Lab II course. Error bars represent standard deviation of 66 scores (pre-test) and 65 scores (post-test).

Observable decreases were seen in the categories of connecting theory with experimental data (a 16 percentage point drop) and knowledge of laboratory equipment (a 14 percentage point drop). Each of these categories contained one new question within the post-test that was not present on the pre-test. These new questions received considerably lower scores than their equivalents on the pre-test, while the scores for the unchanged questions in these categories did not significantly change. For instance, 95% of students answered the question related to operating a ball valve correctly on the pre-test; however, only 39% of students answered its “equivalent” variant question related to correct manipulation of a globe valve on the post-test. Another difference between these questions in particular was a switch from a simple “Choose one” response style for the former vs. a “Choose one or more” style for the latter. This change made it harder for students to earn full credit on the globe valve problem on the post-test. These results indicate that more care should be taken when designing variant questions, to both assure that topical overlap and question complexity remain the same between each variation of a question.

Conclusions & Future Work:

A preliminary, high-level analysis of shifts in student’s self-assessment and skills test scores show students tended to feel more confident about experimental and procedural topics after taking Lab II, but a general assessment of laboratory skills did not show a significant change overall. Themes the authors would like to explore further include the following: deeper analysis of qualitative responses, instrument validation, evaluation of the student technical writing, and identifying future uses for these instruments. For example, the authors plan to identify common themes found in the qualitative responses given to the open-ended questions related to abilities and skills students perceived as gaining in the laboratory. The authors would also like to determine if there is consistency between common themes in the self-assessment instruments and the skills test.

An assessment vector that is unavailable at the time of publication is the student writing assessment. Student writing samples were collected electronically during each laboratory offering during the 2017-2018 academic year. The results and discussion portions of the collected reports will be submitted for assessment by other chemical engineering faculty at RHIT. Context, content development, and language use will be assessed using the VALUE rubric for written communication [1]. Assessment of the initial reports will begin in the summer of 2018, and the data are unavailable at the time of publication.

Another area of work anticipated to be completed in the future is further development and validation of the skills test. We anticipate that, within the next year, another set of questions will be developed, allowing for greater question options to be included in future offerings of the test. Furthermore, we hope to have the questions externally evaluated by other chemical engineering faculty and educational researchers to assure that the questions are phrased clearly and accurately capture understanding of the intended skills. Once validated, we hope to use all three instruments to assess the impact of the changes being made to the laboratory curriculum.

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