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Qualitative Analysis of Skills in a CHE Laboratory Course

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Qualitative Analysis of Lab Skills in CHE Lab

Abstract

To better understand the change in student perception and abilities in a CHE laboratory course, a multi-dimensional survey was administered to two different student cohorts: one with a traditional lab structure and one with a revised lab structure. While quantitative data from the self-assessment and lab skills test has been analyzed [1], this work presents analysis of one of the open-ended responses questions on the lab skills test. This study was motivated by the desire to understand the impact curriculum revisions have on student experience and abilities. The data set for this project consists the text responses to one open-ended question. Open-ended responses were read and sorted based on key themes related to research questions, such as:

How well can students connect known principles with specific experiments? How does their equipment familiarity and use of technical terminology improve over time?

To assist in reviewing the quality and range of responses, we developed an analytic scoring rubric loosely modeled on the Design Quality Rubric [2]. This work explores student performance on one of several open-ended skills test questions. Overall trends from these research questions will be discussed.

Background

This study was born out of a desire to systematically track student experiences, knowledge, and abilities through their time in a multi-course chemical engineering laboratory sequence, as well as the desire to assist in making informed decisions about the efficacy of curriculum revisions. Prior work analyzes quantitative results from a 22-item laboratory skills test (LST) coupled with two self-assessment instruments [1, 3, 4]. Questions were developed based on relevant objective themes identified in literature on laboratory skills [5]. Key aspects of the revised curriculum included online engagement in the form of pre-laboratory modules paced with the laboratory sessions throughout a 10-week course. The traditional curriculum included twice weekly lecture sessions that met in-person for the first half of the course. Moderate revisions to the laboratory sessions included working with one more equipment station in the unit operations laboratory and giving students a more scaffolded and exploratory experience. The focus of this work is not to draw conclusions about the efficacy of each curriculum model, as there are many compounding factors and relatively small number of student responses to analyze. Instead, the goal is to unpack themes from open-ended responses on the LST in effort to create a more complete picture of student laboratory experience and to further inform teaching practices.

Among the 22 items in the LST were multiple-choice questions, image labeling, content matching, numerical data entry, and three open-ended questions. The aim of the open-ended questions was to provide students an opportunity to demonstrate their abilities and awareness associated with topics in the CHE laboratory course, specifically those that are more difficult to assess through close-ended questions. While these topics were included in the self-assessment survey, we acknowledge the limitations of self-assessments presented by other scholars [6] and desired a way to more-directly observe students' abilities by reviewing these open-ended responses. The responses analyzed in this work are from one question associated with themes of connecting prior knowledge of fundamental course topics to a piece of equipment, student's familiarity with equipment, and their proper use of appropriate technical terminology.

Methods

Survey Administration and Course Placement

For details regarding survey development and deployment, the reader is directed to prior literature [1, 3, 4]. Briefly, students completed the online LST in approximately 20-30 minutes on the first day of the course, prior to instruction. The same students took the LST on the first day of the subsequent lab course after successfully completing the course and a summer term break. Three laboratory class sections were offered on three different afternoons: two traditional (N = 29, N = 18) and one revised (N=18). Students worked in teams of two or three, with three or four teams per faculty advisor (student:faculty ratio between 9:1 and 11:1) for all sections. The traditional course contained two 50-minute lecture sessions a week for six weeks, while the revised course engaged with online lecture modules and pre-lab activities throughout the course. Students were placed in a section based on schedule availability and did not self-select into the traditional vs revised course.

The question prompt associated with this analysis is given in Figure 1. The prompt was accompanied with image of a shell and tube heat exchanger.

The heat exchanger picture below illustrates the location of the hot and cold streams. Please indicate the chemical engineering principle(s) that govern the analysis of a heat exchanger. Select one or more:

- Heat Transfer
- Fluid Dynamics
- Reactions
- Mass Transfer
- Separations
- None

Based on your section to the previous question, explain your reasoning for choosing each chemical engineering principle in 1-2 sentences.

Figure 1: Direct Skills Test question with open-ended follow-up question related to connecting CHE concepts to heat exchanger operation.

Rubric development

Draft rubrics were loosely based on Design Quality Rubric [2]. Draft rubrics were revised based on feedback from colleagues, applied to several sample responses, and revised further to reduce ambiguity. The final rubrics, shown in Table 1, were then applied to whole data set (N=60). Only students that successfully completed pre and post responses were included. It should be noted that the rubric development and application was a step toward assessing general trends over time in these categories to allow for refined analysis of student abilities as documented in their responses, while the rankings themselves were not the end goal. The goal was to unpack themes that emerged from reading students' responses to the open-ended question and use the rubric rankings as a guide for assessing shifts in students' abilities over time.

Table 1: Rubrics developed for guiding evaluation of qualitative responses to open-ended question about connecting concepts to heat exchanger operation.

Metric	**Definition**	**Ranking***
Connecting knowledge	The response identifies chemical engineering concepts and correctly relates them to the given system.	3 = Outstanding, 2 = Acceptable, 1 = Poor
Equipment familiarity	The response indicates an understanding of how the equipment functions.	3 = Outstanding, 2 = Acceptable, 1 = Poor
Technical terminology	The response uses technical terminology appropriate in the chemical engineering discipline.	3 = Outstanding, 2 = Acceptable, 1 = Poor

*NA = Not Applicable, may be chosen if the response fails to provide enough evidence to rank.

Assessment method

The authors of this paper (three CHE faculty) used the rubrics in a set of evaluations. All three evaluators served as laboratory instructors of the traditional course offering in the past. One of the evaluators served as a lab instructor of the traditional course at the time students were a part of this IRB-approved study, however all survey response data were held by a separate office until after final grades were submitted. Furthermore, all names were removed and replaced with arbitrary identifiers for the evaluation of responses. Evaluators considered all pre-course responses, then evaluated post-course responses with the ability to view the companion pre-course responses to allow more accurate assessment of the change in the response with respect to three categories: connecting knowledge, equipment familiarity, technical terminology. Each response was evaluated by two independent evaluators. All evaluator discrepancies were reviewed between evaluators. Less than 10 rankings differed by more than one point; all were resolved. Many differed by one point, and all but three were resolved. Finally, by comparing pre- and post-rankings, each student's experience was labeled "improvement," "no change", or "regression". These results were compared across the two cohorts (traditional vs. revised laboratory course). Key phrases that exemplified themes or student experience were noted.

Representative Examples of Student Responses

Of all the pre and post responses (60 each), student explanations ranged in length from 6 to about 100 words, with an average near 35 words for both pre and post responses. There were brief explanations justifying only on concept (i.e., heat transfer) "*It is a heat exchanger, it is designed to transfer heat*," and more detailed responses that included justification of multiple concepts (i.e., heat transfer, mass transfer, fluid dynamics, and separations).

It should be noted that ratings of student responses from their first day in the course are summarized in Table 2. Averages of ratings in each category among the two cohorts differed by not more than 0.4 on the 3-point scale, and the standard deviation for each category ranged from 0.6 to 0.8. Based on this data we have no reason to believe the cohorts on average exhibited noticeable differences in their incoming aptitudes and thus proceeded to compare shifts in responses across cohorts. While one limitation of this study is the relatively small number of students, this, in part, motivated a qualitative approach to understanding the student experience.

Table 2: Summary of guiding evaluations from first day responses from both cohorts.

	Connecting Knowledge		**Equipment Familiarity**		**Technical Terminology**	
	AVG	STDEV	AVG	STDEV	AVG	STDEV
Revised (N=16)	2.5	0.6	1.8	0.8	1.8	0.6
Traditional (N=44)	2.4	0.8	2.2	0.7	1.7	0.8

Using the guiding evaluations shown in Figure 2, we observe that most students showed no major shifts in the quality of their responses for the three categories: connecting knowledge, equipment familiarity, technical terminology (60%, 47%, 65%, respectively). One student with acceptable to outstanding responses used clear direct language to support their answer before the course: "…*flow conditions can impact the total heat transfer coefficient and would therefore impact the heat transfer rate*" and after "*Fluid dynamics are important as they dictate heat transfer coefficients of the baffled system*." They specifically refer to the "baffles" in the heat exchanger, indicating some higher degree of comfort using technical terms and an awareness of heat exchanger features. Another student with consistently poor responses justified the concept of mass transfer (among other concepts) by stating "*A mass is moving through the heat exchanger*," and after the course, similarly uses simple language with insufficient support, and without any technical terms "*Mass moves, it's a heat exchanger and fluids are what is flowing.*"

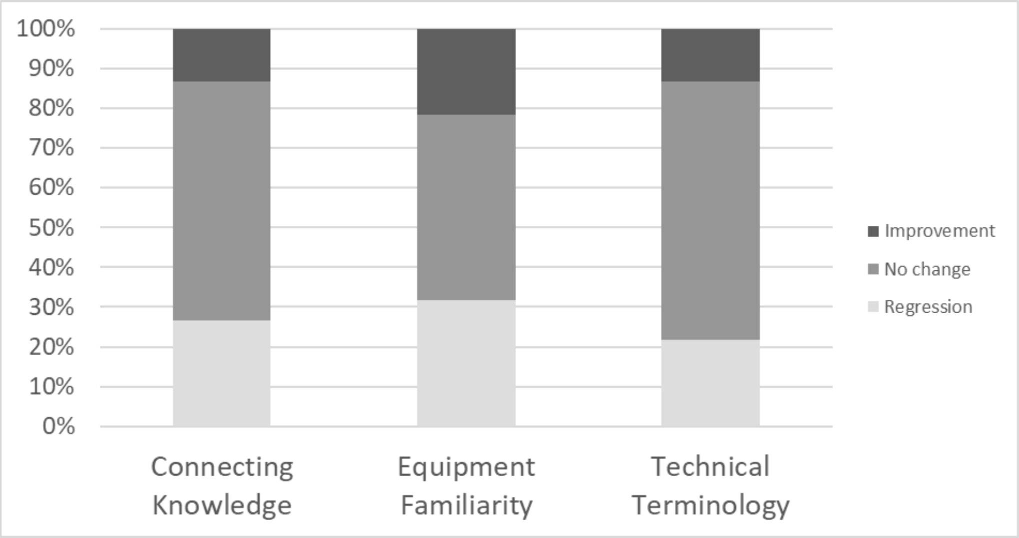

Figure 2: Overall shifts based on guiding evaluations for all students combined. (N=60)

Based on the guiding evaluations, trends were similar among both cohorts, with the largest improvement observed in their level of familiarity with equipment (22% of all students showed improvement). This positive shift was slightly more pronounced for students in the revised course as seen by comparing dark shaded regions in Figure 3 for Equipment Familiarity (31% vs 18%). One student who initially gave a simple, yet correct justification of relevant concepts made clear connections to the operation of a heat exchanger in their response after course completion. In their second response they mentioned "*liquid is being cooled with cooling water,*" and went on to confirm that neither a reaction nor separation was occurring. While they did not show noticeable shifts in the correctness of their answer nor their use of technical terms, they included specifics related to the operation of the heat exchanger. Another student's initial response correctly identified heat transfer and fluid dynamics yet offered little justification beyond "*a heat exchanger is all about the transfer of heat*" and "*fluid dynamics are involved with any process in which fluid is flowing through.*" In their post-course response, the student specifically mentions that in this system fluid dynamics "*deals with the flow of liquid through pipes, and the corresponding effects on the exchange of heat*" and that "*heat is being physically transferred from one stream to the other throughout the heat exchanger."* The student provides more context specific to this system in their response.

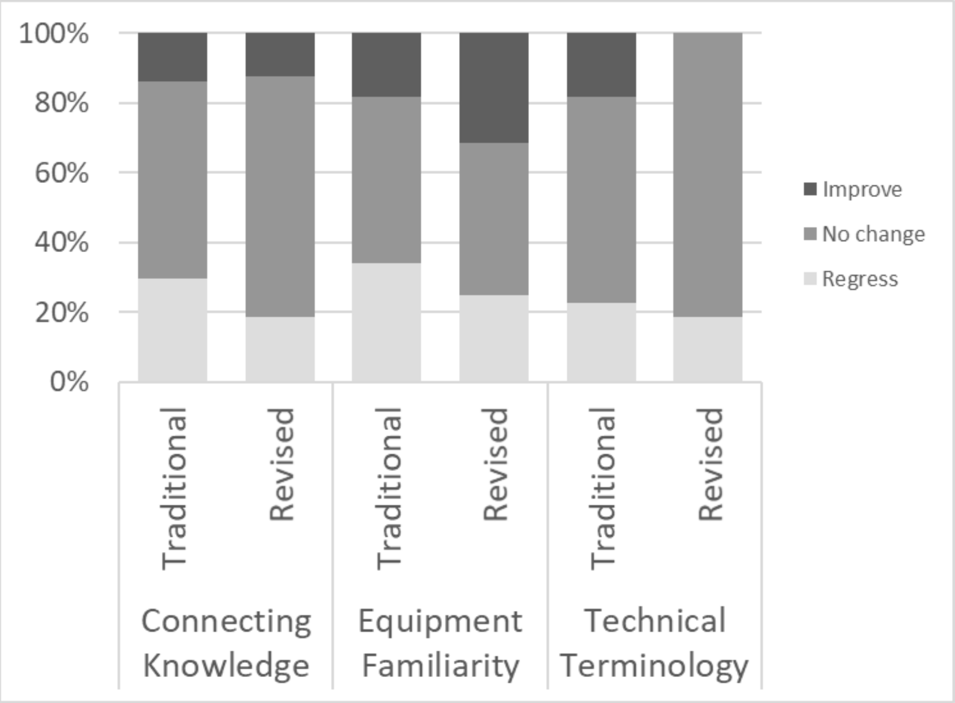

Figure 3: Overall shifts based on guiding evaluations for students in the traditional (N=44) and revised (N=16) courses.

Student usage of technical terminology improved slightly more for the students in the traditional course (18% vs 0%). Examples of technical terminology used include ‘distribution plate’, the mention of ‘hot stream’ and ‘cold stream’ or ‘inlet and outlet streams’, referring to ‘heat transfer coefficients’, ‘surface area’, or ‘flow regimes’ as they pertain to affecting rates of heat transfer. One student initially articulated that heat transfer can be “*maximized using heat transfer principles*” and in their post-course response specified that fluid flow should be *“in the turbulent flow regime to maximize heat transfer*.” The technical terminology, when used appropriately like in this instance, often strengthened the justification. However, we did not observe large shifts for most students in this, or any other, category.

Discussion of Themes

There appeared to be relatively **few large shifts** in the quality of student responses. Given this documented change across the first course in a three-course sequence (and the following summer), this seems reasonable. Furthermore, with a prompt that invited simple 1-2 sentence responses, we did not anticipate observing transformative experiences conveyed in student responses.

When reviewing the student responses, we observed many **students missed an opportunity** to use the technical terms they learned in previous courses. Although we were expecting terms like “heat transfer correlation”, “flow regimes”, it was interesting that many students didn’t refer to the dimensionless parameters such as Reynolds, Prandtl, etc. More often students attempted to give broad-reaching explanations that, although perhaps the student thought they were well reasoned, repeatedly fell flat in meaning.

We tend to see this same phenomenon in students' final laboratory reports as well, even in the final course of the laboratory sequence. There is often a disconnect between what the students write and the actual meaning of their project results. Rarely do students attempt to begin with the fundamental observations and draw conclusions, supporting their ideas in a logical progression. The observations in this work indicate that this practice is not reserved for final reports, where space may be limited, but a common practice. Perhaps by coaching students earlier in their student career, giving them ample opportunities to practice, receive feedback, revise their work, one would hope to see succinct cogent technical response to these types of questions.

It was apparent that many **students misclassify "mass flow" as "mass transfer".** In reflecting on the student's exposure to these concepts, heat transfer and mass transfer often taught together using analogies to link the similarities in driving force equations, it may not seem surprising that these terms are often conflated. However, proliferation of this misconception caught all the evaluators unawares. Approximately 20% of all students wrote in their post-course justifications something like "*mass transfer: there is movement of mass throughout the system*" or "*Mass transfer determines the amount of flow of material through the heat exchanger*." One evaluator remarked that they will be asking more conceptual questions in their core classes to try and tease out this information earlier in the curriculum so that these misconceptions don't continue to stay with students into their upper-level courses.

Results from close-ended questions on the LST related to equipment familiarity indicated that a high percentage of students (roughly 50-70%, depending on the question) improved after completion of all courses in the laboratory sequence [1]. Clearly students are learning about these equipment aspects over time but articulating what they know in a given context is not the same thing.

Conclusions

In conclusion, by analyzing student responses to an open-ended question about CHE principles, students connect their knowledge of principles to the equipment reasonably well right from the start. Over the first course in the sequence, this ability remains constant for most students. Their ability to use technical words accurately and relate to specifics of the equipment of an example unit operation follows a similar trend. There are relatively more students who improve in their use of technical terminology from the traditional course, and more who improve in their familiarity with equipment from the revised course. One key theme worth noting is that students struggle with defining the concept of mass transfer accurately, while they seem to appropriately define and apply concepts of heat transfer and fluid dynamics.

Building on the themes that were discovered in this study, this rubric can be applied to subsequent cohorts of students to help identify knowledge gaps. Similar rubrics can be developed and applied to remaining open-ended items on the LST. This qualitative study will also allow for future investigations to produce evidence of student response movement after course changes are made. As mentioned above, there is an immediate opportunity to address some of the misconceptions that the students wrote about which are topics found in the prerequisite courses.

There is also evidence that students could benefit from more guidance and practice constructing and supporting arguments with precise technical terms.

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