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Work in Progress: Studying Loss of Long-Term Knowledge Retention in Chemical Engineering Undergraduate Courses

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Introduction:

Previous literature has shown that active learning techniques and knowledge retention are closely correlated. For short-term (i.e., during the timeframe of the course) retention is enhanced by rest breaks[1], scaffolding, and multi-part practice that takes complex problems and breaks them down in shorter steps.[2] Knowledge retention is also enhanced by team-based learning techniques.[3] However, comparatively less research is dedicated to how long-term knowledge retention can be enhanced as well. For core courses that are taken by all chemical engineering undergraduate students, it is imperative that the knowledge is retained across multiple semesters. In this work in progress, a study is undertaken of how students retain knowledge delivered in the course taught by the instructor.

The instructor's course "Modelling and Simulations in Chemical Engineering" is a core course taken by all chemical engineering undergraduate students in their second year, in the spring term. The average class size ranges from 45-60 students. The learning objectives of the course are as follows:

1. Convert the physical problem into a set of mathematical equations, identify appropriate techniques and make an informed choice of one of these techniques.
2. If analytical, find the analytical solution (often from another class).
3. If numerical, write a well-structured computer program that solves the problem.
4. Recognize the role of base knowledge onto more complicated numerical analysis.
5. Relate methods learned in this course to other problems outside of traditional chemical engineering.
6. Communicate numerical solutions back into physical or social terms.

The course is designed to teach undergraduates math, numerical methods, MATLAB as a coding language, and analytical and numerical techniques applied to chemical engineering and other engineering disciplines. The materials taught in the class range from basic mathematical concepts such as matrices, to advanced materials such as partial differential equations. Alongside the mathematical knowledge, the students learn different numerical techniques to approximate solutions to complex equations and how to code these solutions using MATLAB. All of this is taught using chemical engineering-based examples and questions.

The materials taught in this course are utilized throughout future chemical engineering core courses. For example, the knowledge of partial differential equations features heavily in the fluid dynamics and mass and heat transfer courses, and non-linear regression analysis is featured in the reaction engineering course. In addition, MATLAB is available as a coding language for the students to solve any of the numerical problems that feature in the subsequent courses. Therefore, the students will require long-term retention of the acquired knowledge over the next two years, if not for longer, depending on their future path. It is thus imperative to assess how much knowledge the students retain, so that they can minimize the required amount of time and energy to relearn the material to succeed in subsequent courses.

Methodology:

To understand how long term knowledge retention can be obtained, first a study of what knowledge is retained long term must be assessed. In this work in progress, a series of surveys are undertaken after the students pass the instructors course, to understand knowledge retention of the materials as students progress through the chemical engineering program. The course “Modelling and Simulations in Chemical Engineering” is a core course taken by the undergraduate students almost exclusively in their second year (4^{th} semester). The follow up surveys are designed to be given to the students every semester afterwards (Semesters 5-8), at the beginning of the semester, to study the self-reported retention of the material (**Figure 1**). The full class is asked to participate in the surveys in semesters 5-8, but commonly, 50-80% response rate has been obtained from the students, compared to the number of students who passed Modelling and Simulations in Chemical Engineering in semester 4.

The students are asked to take the survey at the end of the first week of each semester, at the end of the lecture in a core course, to ensure maximum participation. The students are asked to take the survey anonymously as to have a blinded study, and the author of this paper is also not present during the time the survey is taken. The students are notified about the time required for the survey (5-10 min), and that the survey is optional.

The survey asked a short set of questions on the student’s self-rated skills in various aspects covered in the course. The questions were designed in consultation with the Center for Teaching Excellence at the University of Virginia, in order to focus on whether the mathematical knowledge is retained after taking the class. The first set of questions asked how the students understood the analytical techniques of solving equations, including partial differential equations (PDEs). The second set of questions asked the students to rate their skills in numerical techniques, and the final set of questions asked the students to rate their skills with MATLAB. The survey was designed to be anonymous to obtain truthful responses. This anonymity also precluded individual tracking of the scores, and thus, only population-level data could be obtained. Although the approach is biased towards students judging their own abilities, it was expected that this bias may be less important due to the population level study, and that the same groups would be surveyed every semester from semester 5-8, and thus the bias should be consistent across semesters.

Along with the survey, a short ‘priming quiz’ is also included. The current purpose of this priming quiz is to relate the materials that were taught in the earlier course with the materials that will be taught in the current course. An example of the priming quiz, for the course Transport Processes I: Momentum Transfer, is included here (**Figure 2**). The quiz is taken after the survey, as it was not intended for the priming quiz to test the knowledge of the students, and instead to foreshadow that the materials from Modelling and Simulations in Chemical Engineering is relevant in the current course as well.

Indicate how confident you feel about the following: (**1=not confident at all, 7=absolutely confident**) (based on your current confidence)

Analytical:

1. I can convert a set of equations into a matrix formulation.
2. I can find analytical solutions using ordinary differential equations.
3. I can find analytical solutions to transient partial differential equations.
4. I can find analytical solutions to steady state partial differential equations.
5. I can convert mass based chemical engineering problems to mathematical equations.
6. I can convert heat based chemical engineering problems to mathematical equations.

Numerical:

1. I can find out if an analytical or numerical solution is a better choice to solve a problem.
2. I understand the tradeoffs between accuracy and computational time/space.
3. I can solve matrix based numerical problems.
4. I understand regression analysis beyond linear regression.
5. I can find solutions to a set of equations using numerical approximation using Matlab.
6. I can code my own numerical solution to algebraic equations.
7. I can find solutions to ODEs using Matlab.
8. I can code my own numerical solution to ODEs.
9. I can code my own numerical solutions to PDEs.

Matlab:

1. I can write logically correct blocks of code using Matlab
2. I can use built-in functions that are available in Matlab
3. I can write a small Matlab program given a small problem that is familiar to me
4. I can write a reasonably sized Matlab program that can solve a problem that is only vaguely familiar to me
5. I can organize and design my program in a modular manner.
6. I can debug (correct all the errors) a long and complex program that I had written, and make it work
7. I can find ways of overcoming the problem if I get stuck at a point while working on a programming project.
8. I can come up with a suitable strategy for a given programming project in a short time.
9. I can mentally trace through the execution of a long, complex, multi-file program given to me.
10. I can rewrite lengthy confusing portions of code to be more readable and clear.

Figure 1: Survey given to undergraduate students at the beginning of each semester afterwards (semesters 5,6,7).

Part 2: These questions are here to help me see how much you remember, as well as guide your learning about how you can use knowledge for ChE2216 in your current course. This part is also not graded. Please answer “I don’t know” instead of leaving it blank!

1. My fluid flow can be modeled as a linear ODE. Given that I have access to Matlab, I would solve it using the built in function:

2. Navier Stokes equations seem to give me a transient diffusion PDE! This PDE has the general form:

3. And if I need to solve this PDE numerically, I would ___

Figure 2: Example of the priming quiz given to the undergraduates in a course with the survey in semesters 5-8.

Results:

The study is not complete, and the results are still inconclusive. The datasets were collected for a cohort of students, but due to the pandemic-induced break in classes, followed by the move of classes online for two semesters, the study had to be suspended as the class modality had shifted. The currently limited dataset has already proved useful as a guide to modify the course to better serve student areas of weakness in long-term retention. **Table 1** shows selected questions from the survey, where it is clear that as the students progress through their third year, they lose the knowledge previously learned about using numerical techniques to solve ordinary differential equations (ODEs) and partial differential equations (PDEs), while gaining the skills required to code and understand complex programs. These results were surprising, as the higher-level chemical engineering classes feature the use of analytical techniques to solve problems more heavily than the utilization of coding techniques.

A few reasons could explain the results. One, as the students spend a disproportionate amount of time using analytical solutions, they are more likely to recall instances where their knowledge was limited. Conversely, good programming technique is not utilized heavily in the core curriculum, so they do not have the chance to continuously struggle with new material, and thus have an inflated sense of knowledge concerning the material. Another reason could be that, it is possible that the coding-heavy nature of the course enabled the students to remember good programming practices, and this is reflected in the subsequent semesters.

The lowest self-rating was given to the question "I can code my own numerical solutions to PDEs." Therefore, one direction of improvement would be to strengthen this section in the coding class, and in addition, include more PDE coding-oriented problems in future core chemical engineering classes, so that they continue keeping the knowledge in their working memory. The rest of the datasets are currently being analyzed for a full study in the future.

	Semester 5		Semester 6			
Questions (1 = poor, 7 = excellent)	Average	St. Dev.	Average	St. Dev.	Avg. Diff.	P-value
I can find solutions to a set of eqns. using num. approx. using Matlab.	5.62	1.30	5.00	1.29	-0.62	0.01
I can find solutions to ODEs using Matlab.	5.58	1.46	5.07	1.74	-0.51	0.07
I can code my own numerical solution to ODEs.	5.02	1.51	4.38	1.59	-0.64	0.03
I can code my own numerical solutions to PDEs.	4.04	1.48	3.33	1.66	-0.71	0.02
I can mentally trace the execution of a long, complex, multi-file program.	5.00	1.53	5.55	1.52	0.55	0.04

Table 1: Data collected from undergraduate students showing decrease or increase of knowledge in certain areas.

Future work:

These results have shown that self-rated surveys, following the cohort through their school years, can provide data about retention of the materials through the undergraduate years. This knowledge will be used in the future for course improvement after conversations with Instructional Designers, and for the improvement of subsequent core courses, to provide multiple points of learning retention.

For better implementation of the survey, a class activity or a graded quiz might reflect the students' knowledge retention in an unbiased manner. Similarly, the quiz could be given before the survey to jog the students' memories. However, care must be taken to not unduly burden the students with additional work. Finally, the future applicability of this knowledge can be used in the program to create an integrated body of courses to help students become successful engineers.

References:

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