An Evaluation of the Numeracy Course "Numbers for Life" at McMaster University

Introduction

Numeracy is one of the most prominent transferable skills included in international indices (Nägele & Stalder, 2017). It has long been incorporated in assessments like the Programme for International Student Assessment (PISA) and the Programme for International Assessment of Adult Competencies (PIAAC) (Tout & Gal, 2015). Among the key skills identified by the PIAAC, numeracy is essential for individuals to "participate fully in society" and find success in different milieus, including education and work (Council of Ministers of Education, Canada & Employment and Social Development Canada, 2016).

Historically, instilling numeracy skills has been the responsibility of K-12 educators. Recent research, however, has pointed to the important role of postsecondary (PSE) institutions in students' numeracy development (Brumwell & MacFarlane, 2020). Despite increased attention to numeracy and the economic and social benefits of strong numeracy skills (Brumwell & MacFarlane, 2020; Durrani & Tariq, 2012), data on PSE students' numeracy skills in both BHASE (business, humanities, health, arts, social science, and education) and STEM fields are limited (Dion, 2014). Many colleges and universities assess students' incoming math skills, but they do not assess students' outgoing skill-levels. This has resulted in a considerable gap in understanding PSE students' numeracy development and proficiency.

The "Numbers for Life" course at McMaster University was designed to address the lack of research on learning experiences that advance PSE students' numeracy[1] knowledge and related skills. Over 12 weeks, students learn how to apply their numeracy skills in real contexts by focusing on topics such as human population dynamics, quantitative aspects of climate change, mortgages, taxes and tax brackets and consumer price index and inflation, with practical exercises such as calculating interest on a credit card debt.

This research project sought to answer the following question: To what extent does "Numbers for life" support students' numeracy skill development, including understanding numbers, logical reasoning, quantitative reasoning and communication[2]?

Methodology

The study included two cohorts of students enrolled in the "Math for Life" course at McMaster University in fall 2021 and 2022, with 688 students participating. Students' numeracy skills were measured at the start of the course (pre-test), the end of the course (post-test) and one year after they finished the course (delayed post-test) (see Appendix A for survey details). In addition

[1] The project team has defined numeracy as involving reasoning about numeric information (data), which can be presented in a variety of ways (such as narrative, graphic or dynamic forms). Numeracy also includes critical, evidence-supported thinking, common sense and logical reasoning in situations and/or contexts that might not explicitly or implicitly involve numbers or quantitative information. The key difference between mathematics and numeracy is in their approach to numbers: whereas mathematics is a study of numbers, and often in abstraction, numeracy requires thinking *with* numbers, always about authentic, meaningful and real-life contexts.

[2] In the context of numeracy, communication skills refer to the ability to explain what a numerical answer represents, provide a logical argument and/or create a narrative about a situation involving numbers.

to the pre- and post-test surveys, the project team developed and used the following tools to address the research question:

- rubrics to evaluate students' open survey responses (see Appendix B for evaluation rubrics);
- students' course assessments at the end of the fall 2021 and fall 2022 terms; and
- semi-structured interviews with a small sample of students in winter 2022 and winter 2023.

Findings

Through the "Numbers for Life" course, students showed improvement in their ability to understand numbers, use logical reasoning and engage with multiple-step problems that required quantitative reasoning. Table 1 shows students' mean scores on numeracy skills before and after the course. Rubric scores ranged from 0 to 5, with higher scores indicating stronger skills. Students' ability to understand numbers and work with numeric information was high before taking Numbers for Life (pre-test), but researchers observed skill improvement across all six questions. Even greater skill improvement was observed in students' logical reasoning scores.

Table 1

Students' Numeracy Skills Before and After Participating in the "Numbers for Life" Course

Question	Topic	Pre-test	Post-test
1	Ability to understand numbers	4.54	4.84
	Working with numeric information	4.52	5.00
2	Ability to understand numbers	4.54	4.86
	Working with numeric information	4.58	4.90
9	Ability to understand numbers	4.01	4.12
	Working with numeric information	4.27	4.47
10	Ability to understand numbers	4.46	4.83
	Working with numeric information	4.23	4.25
11	Logical Reasoning	3.49	4.40
	Ability to Communicate	3.45	4.94
12	Logical Reasoning	3.32	3.99
	Ability to Communicate	3.24	3.45

Note. This table shows mean rubric scores before and after the "Numbers for Life" course on questions about understanding numbers, working with numeric information, reasoning logically and communicating. See Appendix B for rubrics. The post-tests scores were normalized based on the average time students spent on each of the pre-test and post-test as a proxy; students spent 17.6% more time on the pre-test than on the post-test.

Students who had weaker backgrounds in numeracy, evidenced by pre-test scores, had the most pronounced skill gains. For instance, 70 students received a lower rating (between 0 and 3 out of 5) on question 10 on the pre-test. In many cases, their calculations were correct, but the interpretations were vague or incorrect. On the post-test, this number dropped to 44. Students' communications skills (in questions 11 and 12), considering non-normalized scores, showed the least improvement. Normalized post-test scores, in questions 11 and 12, assumed that a student would make a serious effort to answer these questions. Students' detailed post-test

explanations and/or calculations were similar to (and sometimes of lower quality than) their pre-test responses.

Table 2 outlines the percent of students with the correct multiple-choice responses before, after and 12 months after completing the numeracy course to explore skill retention over time. A year after completing the course, fewer students responded correctly to the questions than at the start or at the end of the course. While students did not often demonstrate improvement in terms of correct answers, their written justifications demonstrated improved numeracy skills. For example, in response to question 9 (see Appendix A), one student wrote in their pre-test, “The relative change is different.” In the same student’s post-test, they wrote, “Relative growth of X=(200-100)/100=100%, relative growth of Y=(1100-1000)/1000=10%; although they have the same absolute growth, island X has 100% relative growth while island Y only has 10% relative growth.” The key difference in the responses is the added technical skill of using a relative change formula, adding language such as “absolute growth” and “relative growth”, and the use of percentage change to interpret key difference between the population changes.

Table 2

Students Who Responded Correctly to Multiple-choice Questions on the Pre-test, Post-test and Delayed Post-test

Question	Topic	Pre-test (%)	Post-test (%)	Delayed post-test (%)
3	Reasoning about fractions: how the change in the numerator affects the value of a fraction	97.92	94.66	89.92
4	Comparing chance events when probabilities are given in the form “a in b” (as in 2 in 100)	88.02	89.97	73.95
5	Reasoning about the relative change when data is presented in a bar chart	42.97	54.01	53.78
6	Distinguishing between correlation and causation in the case of disease and symptoms	58.59	66.58	54.62
7	Venn diagram representation of a relationship between two populations	90.89	90.11	86.55

Note. The table shows the percentage of fall 2021 students who responded correctly to multiple choice questions before, after and a year following the “Numbers for Life” course. Three hundred eighty-four students completed the pre-test in September 2021, 374 students completed the post-test in December 2021 and 119 students completed the delayed post-test, a year after the course in December 2022.

Discussion and Conclusion

This project reveals that a university course can successfully improve some students’ numeracy skills. It is particularly encouraging that students who had weaker numeracy skills at the beginning of the course improved the most (this was not surprising, however; there was more room for students to improve). The researchers observed a great deal of improvement in logical reasoning in particular. This skill is not generally taught (except possibly implicitly) in high school. Directly teaching students how to understand numbers and reason logically is essential to ensuring students have the skills they need to navigate the workforce and their day-to-day lives (Otasowie & Dalporto, 2023).

Some adjustments to the survey design may be useful in future research on numeracy development. Students' lack of improvement in communication skills, as well as low scores on the assessment taken a year after the course, can be attributed in part to survey fatigue. Students spent 17.6% more time on the pre-test than the post-test and they did not answer the questions near the end of the survey instrument, or a year after taking the course, as carefully and thoughtfully as those at the start. Simper et al. (2018) similarly found that student motivation was a significant concern when using tests to assess skills. When replicating the study, researchers could add a grading component, increase incentives and make the results available to students, which may encourage participants to give their best effort on assessments (Simper et al., 2018).

While numeracy is often taught at the elementary and secondary school levels, it can be explicitly taught and reinforced at postsecondary institutions. Researchers have outlined a number of approaches to creating effective numeracy tasks that can be used in the classroom (Boaler, 1993; Hoogland & Pepin, 2016). This research supports the call for more meaningful numeracy tasks (e.g., how students can apply numeracy to real-life and authentic experiences) and more involved critical reasoning, rather than procedural, algorithmic questions, to develop students' numeracy skills (Gaze et al., 2014).

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Appendix A: Pre-Test, Post-Test and Delayed Post-Test

Question 1a) Given Pre-test Fall 2021 and Post-test Fall 2021

A sweater costs S dollars. As the price tag offers a 13% discount, you decide to buy it. At the counter, the 13% sales tax is added to the discounted price. How much will you pay for the sweater: S dollars, less than S dollars, or more than S dollars? Explain how you arrived at your answer to this question.

Question 1b) Given Pre-test Fall 2022, Post-test Fall 2022 and Delayed Post-test Dec. 2022

You are thinking of buying a sweater, and you look at the price tag. Next to it, a sign says that there is a 13% discount on all sweaters, and you decide to buy it. At the counter, the 13% sales tax is added to the discounted price. Will you pay more, less, or the same as the price seen on the price tag? Explain how you arrived at your answer.

Question 2) Given Pre-test Fall 2021, Post-test Fall 2021, Pre-test Fall 2022, Post-test Fall 2022 and Delayed Post-test Dec. 2022

The table below states the nutritional facts for a container of milk.

Nutrition Facts

Serving size 1 cup (220 g)
Servings per container 3.5

Amount per serving	
Calories 140	Calories from Fat 60
	% Daily Value
Total Fat 8 g	12%
Saturated fat 2g	9%
Trans fat 0 g	
Cholesterol 10 mg	4%
Sodium 235 mg	10%
Total Carbohydrate	10%
Dietary Fibre 0 g	
Sugars 12 g	
Protein 20 g	36%

If you drink the entire container, how many calories would you consume?

Question 3a) Given Pre-test Fall 2022, Post-test Fall 2022 and Delayed Post-test Dec. 2022

The energy demand a person needs for its cardiovascular system to function normally is computed by multiplying their cholesterol level by 9.5 and then dividing by their heart rate. Person A and Person B have the same heart rate, but person A has lower cholesterol level. What is the relationship between Person A's and Person B's energy demands? Show your reasoning.

Question 3b) Given Pre-test Fall 2021 and Post-test Fall 2021

The energy demand that a person needs for its cardiovascular system to function normally is computed by multiplying their cholesterol level by 9.5 and then dividing by their heart rate. Person A and Person B have the same heart rate, but person A has lower cholesterol level. Select the correct statement.

- ◯ Person A's energy demand is larger than Person B's energy demand
- ◯ Person A's energy demand is smaller than Person B's energy demand
- ◯ Person A's energy demand is equal to Person B's energy demand

Question 4) Given Pre-test Fall 2021, Post-test Fall 2021, Pre-test Fall 2022, Post-test Fall 2022 and Delayed Post-test Dec. 2022

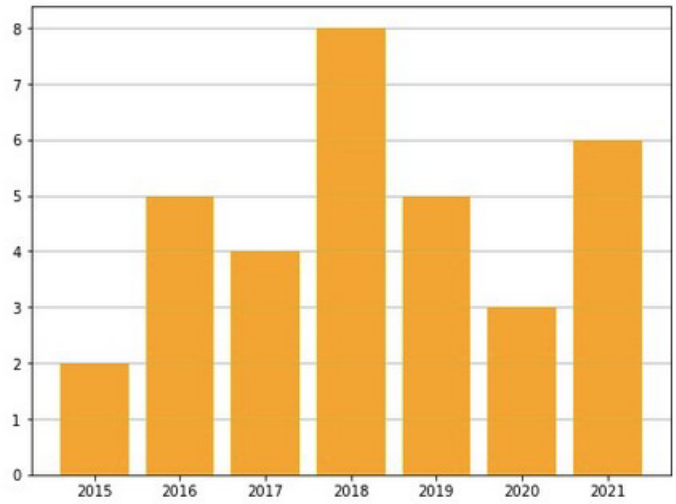
The chances of four events occurring, during a winter storm day in Ontario, are given below. Which event is the *most likely* to occur?

- ◯ 1 in 45,000 of injury in a car crash
- ◯ 10 in 400,000 of injury from slipping and falling
- ◯ 2 in 50,000 of mild to medium hypothermia
- ◯ 10 in 500,000 of injury from an exploding fireplace

[note: changed from *least likely* in 2021 to *most likely* in 2022 and in the delayed post-test]

Question 5a) Given Pre-test Fall 2022, Post-test Fall 2022 and Delayed Post-test Dec. 2022

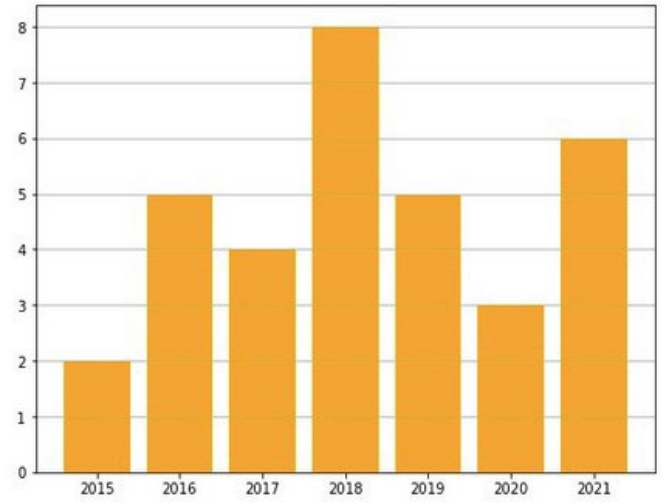
The diagram below shows the net profit (in $ thousand) of a small family-owned company.



True/False: The company experienced the largest relative growth from 2017 to 2018. State your answer as true or false, and explain your reasoning.

Question 5b) Given Pre-test Fall 2021 and Post-test Fall 2021

The diagram below shows the net profit (in $ thousand) of a small family-owned company.



When did the company experience the largest relative growth?

- ◯ from 2015 to 2016
- ◯ from 2017 to 2018
- ◯ from 2020 to 2021

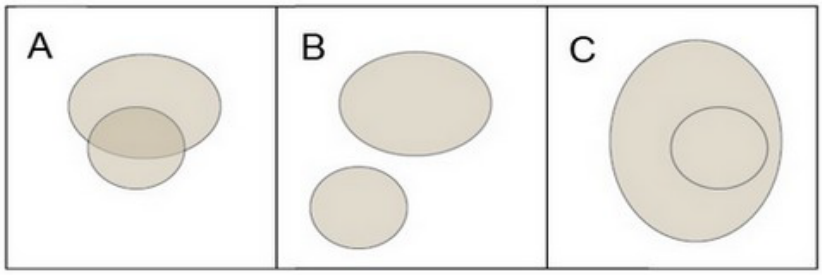
Question 6) Given Pre-test Fall 2021, Post-test Fall 2021, Pre-test Fall 2022, Post-test Fall 2022 and Delayed Post-test Dec. 2022

The sentence "The symptoms of meningitis are high fever, neck pain, and seizures" expresses a

- ◯ correlation between meningitis, and high fever, neck pain and seizures
- ◯ correlation between high fever, neck pain, and seizures
- ◯ causation, with meningitis being the cause
- ◯ causation, with high fever, neck pain, and seizures being the cause

Question 7a) Given Pre-test Fall 2022, Post-test Fall 2022 and Delayed Post-test Dec. 2022

"Some animals with thick fur are mammals, and some mammals have thick fur." Which diagram represents the relationship between animals with thick fur and mammals?



Answer by stating one of A, B, or C, and justify your reasoning.

Question 7b) Given Pre-test Fall 2021 and Post-test Fall 2021

[Question 7 deleted; above are the two versions administered]

Question 8) Given Pre-test Fall 2021, Post-test Fall 2021, Pre-test Fall 2022, Post-test Fall 2022 and Delayed Post-test Dec. 2022

You are in New Zealand, using your Canadian phone. Assume that a roaming charge for the usage over your plan is $6 per 80MB (megabytes) of data, and assume that you have reached the limit of your plan, meaning that you have to pay for extra data you use. You decided to watch a movie, whose size is 1.6 GB (gigabytes). How much will you pay in roaming charges for watching this movie?

Question 9) Given Pre-test Fall 2021, Post-test Fall 2021, Pre-test Fall 2022, Post-test Fall 2022 and Delayed Post-test Dec. 2022

Estimate the area of the part of the wall shown in this picture. (Not the area of the picture, but the area of the actual, real, wall shown below). Explain your reasoning.

Question 10) Given Pre-test Fall 2021, Post-test Fall 2021, Pre-test Fall 2022, Post-test Fall 2022 and Delayed Post-test Dec. 2022

Last year, there were 100 monkeys on island X and 1000 monkeys on island Y. This year, there are 200 monkeys on island X and 1100 monkeys on island Y. Thus, on both islands, the populations of monkeys increased by 100. How would you describe what is different about the change of two populations?

Question 11) Given Pre-test Fall 2021, Post-test Fall 2021, Pre-test Fall 2022, Post-test Fall 2022 and Delayed Post-test Dec. 2022

Consider the statement "In my neighbourhood there are 10 dogs and they all bark at night." What would you have to do to prove that this statement is not true?

Question 12) Given Pre-test Fall 2021, Post-test Fall 2021, Pre-test Fall 2022, Post-test Fall 2022 and Delayed Post-test Dec. 2022

The statement "If you do not study, you will not pass the test" can be reinterpreted as "If you study, you will pass the test." Is this a correct conclusion? Why or why not?

Question 13a) Given Pre-test Fall 2022, Post-test Fall 2022 and Delayed Post-test Dec. 2022

This ad for Harvey's burgers claims that there are *8 million ways to top your burger*.

You are suspicious of this fact, and decide to investigate. You discover that to customize your burger, you have to pick one of the three options for a bun (white, multigrain, or no bun), and then you can choose as many toppings as you wish among: 3 premium toppings, 10 other toppings and 10 sauces; for instance, you can have 2 premium toppings, 8 other toppings and 7 sauces. Based on this information you calculate the number of ways to top your burger. Does your estimate match Harvey's estimate of 8 million? Explain your reasoning.

Question 13b) Given Pre-test Fall 2021 and Post-test Fall 2021

Postal codes in Cook Island have the format LL-dddd where L is an uppercase letter and d is a digit; for instance, DX-3402. The first letter must be one of A, B, C, D, E, F, or G, and there are no restrictions on the second letter. The first digit in dddd cannot be 0 and cannot be 9, and there are no restrictions on the remaining three digits. What is the maximum number of postal codes available? Show how you arrived at your answer.

Appendix B: Grading Rubrics for Narrative Responses

Table 3

Rubric for Category A: Understanding and Working with Numbers and Numeric Information

	Level 1	Level 2	Level 3	Level 4	Level 5
Ability to Understand Numbers	Student skills are emerging in this trait.	Student can identify relevant numeric information but does not show interpretation in context.	Student can identify relevant numeric information from few or no distractors and shows attempt to interpret it's meaning in context.	Student can identify relevant numeric information, sometimes from other plausible distractors, and shows a valid attempt to interpret its meaning in context.	Student can identify relevant numeric information regardless of the presence of distractors, and correctly interpret its meaning in context.
Working with Numeric Information	Student skills are emerging in this trait.	Student attempts to employ an inappropriate quantitative reasoning skill but attempts to address the numeric information in the question with their answer.	Student attempts to employ an appropriate quantitative reasoning skill to work with presented numeric information in context, but makes three or more minor errors (e.g., calculation errors), or one major error (e.g., selecting an inappropriate computation).	Student attempts to employ an appropriate quantitative reasoning skill to work with presented numeric information in context, but perhaps makes one or two minor errors (e.g., calculation errors).	Student can employ quantitative reasoning skills to work with presented numeric information correctly within its context, and in a variety of forms.

Table 4

Rubric for Category B: Using Logical Reasoning and Recognizing Logical Fallacies

	Level 1	Level 2	Level 3	Level 4	Level 5
Correlation/Causation and **Logical Structures**	Student skills are emerging in this trait.	Student attempts to use an inappropriate choice of logical structure to evaluate the truth value of a statement and describe methods of proving or disproving a statement, OR attempts to use the correct logical structure with two or more logical errors.	Student attempts to use the correct logical structures to evaluate the truth value of a statement and describe methods of proving or disproving a statement but uses them with a minor logical error (e.g., correctly identifying the use of the contrapositive, but misinterpreting the meaning).	Student can correctly use logical structures to evaluate the truth value of a statement and describe methods of proving or disproving a statement.	Student can clearly articulate and correctly use logical structures to evaluate the truth value of a statement and describe methods of proving or disproving a statement.

Table 5

Rubric for Category C: Multiple Step Problem Solving Using Quantitative Reasoning

	Level 1	Level 2	Level 3	Level 4	Level 5
Engaging with Multi-step Problems	Student skills are emerging in this trait.	Student selects at least one correct step in reasoning or computations to solve the problem.	Student selects some correct steps in both reasoning and computations, or most correct steps in either reasoning or computations to solve the problem.	Student selects mostly correct steps in both reasoning and computations to solve the problem.	Student selects all correct steps in reasoning and computations to solve the problem.
Computational Proficiency	Student skills are emerging in this trait.	Student is unable to construct mathematical formulae or arrive at a final solution, OR constructs formulae and arrives at an unreasonable solution without addressing the issues with their solution (e.g., having a negative number of postal codes in a combinatorial problem).	Student attempts to construct mathematical formulae and arrives at reasonable values for all aspects of problem solving, OR constructs inappropriate mathematical formulae and recognizes the unreasonableness of their solution (e.g., recognizing a negative number of postal codes in a combinatorial problem is an issue).	Student constructs correct mathematical formulae and arrives at problem solving or recognizes the unreasonableness of a given solution.	Student constructs correct mathematical formulae and arrives at correct solving.

Table 6

Rubric for Category D: Ability to Communicate Answers to Problems with Quantitative Reasoning

	Level 1	Level 2	Level 3	Level 4	Level 5
Communication of Solutions	Student skills are emerging in this trait.	Student can communicate using at least one correct definition of terms and concepts, or mostly correct description of terms and concepts, in their communication of solutions.	Student can communicate using some correct definitions of terms and concepts, or mostly correct description of terms and concepts, in their communication of solutions.	Student can communicate using mostly correct definitions of terms and concepts, or mostly correct description of terms and concepts, in their communication of solutions.	Student can communicate using either correct definitions of terms and concepts, or correct description of meaning of terms and concepts, in their communication of solutions.
Explanations of Quantitative Reasoning	Student skills are emerging in this trait.	Student attempts to justify their choice of computational practices, or their quantitative reasoning practices, or why their final answer is reasonable based on the context of the question.	Student attempts to justify their choice of EITHER their computational OR quantitative reasoning practices with reference to the context of the question, and where necessary, explain why their solution is a reasonable one based on the context of the question.	Student can justify their choice of EITHER their computational OR quantitative reasoning practices with reference to the context of the question, and where necessary, explain why their solution is a reasonable one based on the context of the question.	Student can justify their choice of computational and quantitative reasoning practices with reference to the context of the question, and where necessary, explain why their solution is a reasonable one based on the context of the question.