Transfer of Learning from Mathematics to Engineering in Upper Division Sensors and Systems Course

Mehrube Mehrubeoglu[a], Lifford McLauchlan[b], David Hicks[b], Maria Vasilyeva[c]

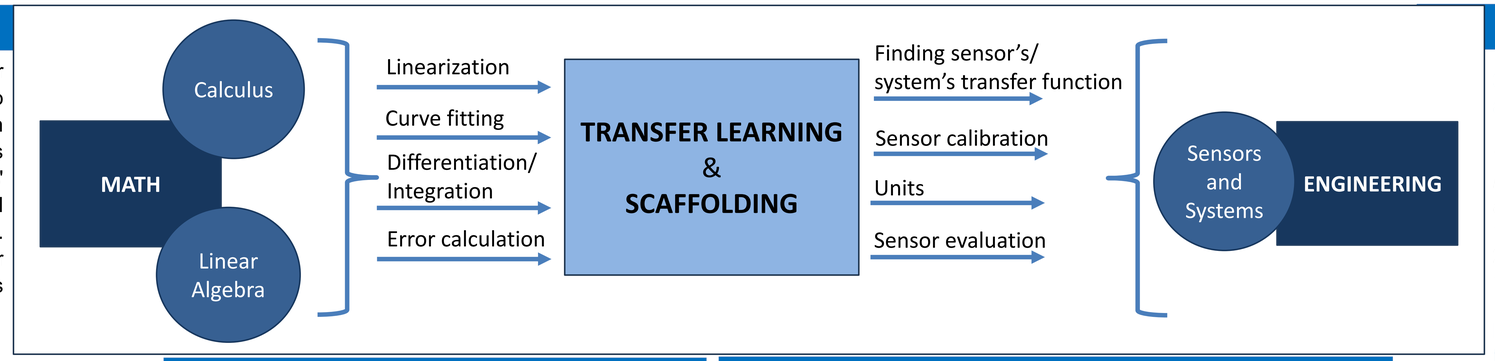
[a]Texas A&M University-Corpus Christi, Department of Engineering
[b]Texas A&M University-Kingsville, Department of Electrical Engineering and Computer Science
[c]Texas A&M University-Corpus Christi, Department of Mathematics and Statistics

ABSTRACT

This project implements scaffolds for transfer of learning from mathematics to engineering in an upper-division undergraduate technical elective Sensors and Systems course to assist students' adaptation of theoretical mathematical concepts into applied engineering topics. Students find it challenging to transfer knowledge learned in mathematics courses to applied engineering topics.

New mathematics assignments were created to emphasize the mathematical concepts the students would utilize in this engineering course. The incremental learning through scaffolding assignments identified gaps in learning or recollection and used skills, and assisted the students' re-learning and re-applying these mathematical skills in the engineering courses.

Students were able to connect math symbology with engineering symbology, and successfully applied mathematical concepts to engineering problems related to sensors. Student performance improved once the students were guided with scaffolds to achieve transfer of learning from mathematics. This project impacted students from mechanical engineering, electrical engineering, civil engineering, and engineering technology disciplines.



INTRODUCTION

The work is part of "Engaged Student Learning through IoT" project for which Sensors and Systems course represents the teaching of physical layer of IoT systems that capture sensor data from physical environmental stimuli and integrates this data into an embedded system. The IoT involves infrastructure in which a wide variety of physical devices interact with one another and share information. When designing, working with or combining these devices, engineering and computer science students must consider many aspects of their disciplines, such as sensors, signals, device integration and interfaces, system functions, control, testing and measurement, which are covered in the Sensors and Systems course.

RESEARCH QUESTION

This part of the research aims to answer the guiding question: Can transfer of learning from mathematics to engineering be achieved in a technical elective Sensors and Systems course through scaffolding assignments to assist students in connecting their math knowledge with applied engineering concepts?

METHODS

Three scaffolding exercises were created over the 3 years of the project that covered

1. Linearization
2. Units
3. Calibration and error calculations

SAMPLE PROBLEMS

1. LINEARIZATION

In your math classes you have met two types of linearization:

1) In Calculus: Linearization using tangent line to a graph.
2) In Linear Algebra: Fitting a finite number of points with a least squares line.

Assume our function is exponential decay, let's say

$$f(x)=⟦2\ e⟧^{(-10x)}.$$

- Use calculus methods to find the equation of the tangent line to the graph at the point $(1,2/e^{10})$. How can you tell without a calculator whether the tangent line is above or below the graph of the function (except at the point x=1)?
- Use the tangent line to get an estimates for f(0.98) and for f(1.01) and f(10). Which of those estimates is the least trustworthy? What is the reason for that?
- Calculate errors, and graph your results.

2. UNITS

- Assume $f(x)$ is a function, where x is measured in units of v (as in variable) and the function values are measured in units of o (as in outputs). Write down the definition of the derivative of $f(x)$ as a limit of the difference quotient.
- What are the units of the numerator and denominator of this difference quotient? What does that make the units of $f'(x)$?
- The second derivative $f''(x)$. is the derivative of $f'(x)$. What does that make its units?
- The integral is defined as a limit of Riemann sums. Write down the limit form and then decide on the units off $\int_{b,a} f(x)dx$.

3. CALIBRATION AND ERROR CALCULATIONS

Polynomial fit

Assume that the transfer function is described by a more complex function. $y = a_0 + a_1x + a_2x_2 + a_3x_3$, where the constants a_0, a_1, a_2 and a_3 need to be determined.

To establish the transfer function for the sensor we must specify the constants a_0, a_1, a_2 and a_3 .

- Find a_0, a_1, a_2 and a_3 using four points (x_1,y_1), (x_4,y_4), (x_7,y_7) and (x_{11},y_{11}) from the Table and calculate the error of approximation and graph your results.
- Find a_0, a_1, a_2 and a_3 by solution of the least squares problem and calculate the error of approximation.
- Which of these methods is better? What is the reason for this?

STUDENT REFLECTIONS

1. Linearization: Math Check

a) Did you remember what linearization was?

"*Yes, I did remember what linearization was. I had to refresh my memory on how to do both calculus and linear algebra. The calculus seemed to come back easier.*" May 2024
"Not at all." May 2024.
"I had only a vague recollection of linearization and pretty much had to relearn it for this assignment." May 2023.
"I do not remember how to do the rest of this homework." May 2022.

b) Did this exercise refresh your understanding of linearization and help with applying it in engineering?

"Yes, this exercise refreshed my understanding of linearization by forcing me to use calculus in problems 1-4 and engineering analysis in problems 5-6." May 2024.
"The tangent line was something I almost forgot about but it came back easily. Liner algebra is new to me since I just took the class, but the least squares was only briefly touched on so I had to look back at the book." May 2024
"I certainly feel better about it having done the assignment, I rarely remember mathematical concepts that I take unless I'm utilizing them regularly ad didn't really recognize least squares fit at all despite taking Linear Algebra last year." May 2023
"I know that the process dealt with linear algebra and calculus but it was just a difficult exercise." May 2023
"I just finished taking Linear Algebra, and we briefly went over $A^TAx = A^Tb$, but I am not sure what to do with it." May 2022.
"I remember linearization for the most part but definitely needed this refresher. ☺ " May 2022.

2. Units: Math Check

a) Did you remember how to obtain units on derivatives and integrals?

"It took some practice." May 2024.
"*I had to refresh my memory." May 2023.*
"I have no recollection of extracting units from variables when solving derivatives and integrals." May 2022.
"At first glance, the assignment seemed hard but after today's lesson with some hints, things just clicked." May 2022.

b) Does this exercise refresh your understanding of calculating units from your math classes?

"Yes, it most definitely does help. … It will definitely help with other [engineering] courses as well." May 2024.
"Yes. Also, units were very important in dynamics." May 2023
"Yes, doing exercises like this are very helpful for remembering what I feel like my brain discarded from Calc/Physics/Intro to Engineering, etc." May 2023.
"[In math classes] units are often left out." May 2022.

STUDENT REFLECTIONS (cont.)

3. Linear/Polynomial Fit (Calibration) and Error Analysis

a) Did you remember how to do linear fit and polynomial fit using least squares approximation and mean squares error?

"I did remember linear fit using least squares approximation, but [did] not cover polynomial fit using least squares approximation and mean squares error." May 2024
"I did not remember how to do linear fit and polynomial fit." May 2024.
"Did not remember at all. Had to learn it over again." May 2024.

b) Were you able to apply these concepts to the input/output temperature sensor data provided in the table? Please elaborate.

"Yes, using a regression for the table was straightforward and manageable. The assignment clearly laid out what I needed to do and how I was to do it; this also gave me great practice for the midterm exam." May 2024
"No, I was not able to apply these concepts to the sensor data." May 2024.
"Yes, I do believe I was able to get most of the concepts." May 2024.

FINDINGS

Some students:

1) forgot some of the mathematics background they covered in previous math courses that is necessary to be successful in engineering courses, due to elapsed time between the math and engineering courses
2) could not make direct connections between symbology used in mathematics courses and those used in engineering courses when they differed significantly
3) did not demonstrate clear understanding of the purpose of some of the mathematical techniques learned and how they applied to engineering
4) did not cover some of the topics in their math classes.

Transfer learning exercises assisted students with **"4 Rs"**: **remembering**, **reviewing**, **relearning** and **relating** some of the relevant math concepts as they applied to engineering topics. The scaffolding exercises helped students with incremental learning and making the necessary connections with engineering concepts in the Sensors and Systems course. incremental learning.

Acknowledgment

The work presented here is funded in part by
National Science Foundation under grant no: 2044255.

The authors thank Dr. Beate Zimmer who created the original Linearization and Units math exercises for the Sensors and Systems course.

References

[1] M. Mehrubeoglu, L. McLauchlan, D. Hicks, A. Yeaman, M. Vasilyeva, "Transfer Learning from Math to Engineering and Using Scaffolds through Hands-on Learning to Build New Engineering Skills in Sensors and Systems Course," *submitted to 2024 ASEE Annual Conference and Exposition, Portland, OR, 23-26 June 2024.*
[2] M. Mehrubeoglu, L. McLauchlan, D. Hicks, B. Zimmer, "Work in Progress: Developing an IoT-based Engaged Student Learning Environment and Tools for Engineering and Computer Science Programs," *2022 ASEE Annual Conference and Exposition, Minneapolis, MN, 26-29 June 2022.*
[3] C. Ekici, M. Mehrubeoglu, D. Palaniappan, C. Alagoz, "Coherence and Transfer of Complex Learning with Fourier Analysis Learning Trajectories for Engineering Mathematics Education," *2020 IEEE Frontiers in Education Conference (FIE), Uppsala, Sweden, 2020, pp. 1-9, doi: 10.1109/FIE44824.2020.9274075.*