Using Self-Evaluation Assignments to Teach 3D Coordinate Transformations in Robotics

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Abstract: Teaching robotics courses online is challenging due to the complexity of the interdisciplinary topics involved. One of the most challenging topics is 3D coordinate transformations. Students often struggle to grasp the concept of 3D coordinate transformations and their relevance to real-world robotic applications. This paper applies the Scholarship of Teaching and Learning methodology to address this challenge and shares the self-evaluation assignments given to students to gradually enhance their ability to solve a real-world robotic navigation problem – a crucial skill required in almost all robotic applications. Each assignment includes an informative description that explains the purpose of the task and its connection to the next assignment. Manageable MATLAB resources are provided in each assignment, allowing students to study fundamental Matlab scripts and use MATLAB Grader for self-evaluation before submission. The instructor provides feedback on incorrect answers through MATLAB Grader. The assignments focus on problem-solving and can be automatically graded, building upon prior work done by the instructor. The paper will also detail strategies for motivating students to engage with these challenging assignments and how the instructor assists distracted students in catching up with any missing assignments.

Keywords: Robotics, MATLAB, Scholarship of Teaching and Learning (SoTL)

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Introduction

Driven by the increasing demand for automation in industries and continued innovative technical improvements in industrial robots, job opportunities in the field of robotics have been on the rise in recent years. Introduction to Robotics is one of the most popular technical elective courses for undergraduate students in the Mechanical Engineering Department of Prairie View A&M University since 2016. The course used to be delivered in the classroom through lectures and simulations. However, due to the Covid pandemic, the course had to be transitioned to an online format and has remained online since then. This is because students appreciate the flexibility provided by the online class, enabling them to take it at their convenience from anywhere. Technical elective courses are typically chosen by senior students whose schedules are not often tied to the campus.

3D coordinate transformation is one of the most challenging topics in Robotics. It involves calculating the position of a point relative to different references, matrix computations, and implementation. Being able to implement the 3D coordinate transformation concept in a real-life robotic application will significantly increase students' confidence and competence in the job market. This motivation drives me to explore alternative ways of teaching the subject, enabling students to learn transformation in robotics and apply their knowledge to practical problems in an online environment. A workshop focusing on teaching computation online organized by MathWorks inspired me. The MATLAB Grader platform developed by MathWorks is a tool that assists educators in designing computational and coding assignments, automatically grading them, and providing online feedback. This work aims to investigate the impact of using MATLAB Grader on students' learning outcomes in an online Robotics course. Feedback from the students and observations from the instructor will be collected, allowing improvements to be made in the teaching and learning process for future course offerings. This recursive approach aligns with the model of Scholarship of Teaching and Learning (SoTL) (Bernstein, 2010), which has been gaining more attention in recent years. According to Google Scholar, the number of hits on items including "scholarship of teaching" doubled between 2011 – 2020 (Healey, 2023 & Manarin 2021).

SoTL is a methodology used in higher education to reflect on and transform teaching and learning practices (Fanghanel, 2016). It begins with identifying a teaching problem that is linked to students' learning or misunderstanding issues, followed by adjustments to the teaching strategy, and reflections from both students and faculty. A rigorous process of SoTL is introduced in the next section.

Method

Scholarship of Teaching and Learning (SoTL)

While various forms of SoTL exist across the globe, principles of good practice for SoTL in the United States are defined in Table 1 (Felten, P, 2013). The following part of this section will present these principles in accordance with the table.

Table 1. Principles of Good Practice in SoTL

Principles of Good Practice in SoTL
1. Inquiry focused on student learning
2. Grounded in context
3. Methodologically sound
4. Conducted in partnership with students
5. Appropriately public

Robotics is a subject that requires hands-on projects to reinforce the concepts taught in the classroom. I first learned Robotics as a graduate student with access to resources, allowing me to purchase equipment such as robots, cameras, and grippers. After learning the 3D coordinate transformation topic, I could use the equipment to practice and verify if the robot could reach the desired location through camera navigation.

Five or six years ago, I began teaching Introduction to Robotics as an undergraduate technical elective with 70 students divided into two lecture sections. Unfortunately, assigning hands-on projects was not feasible due to limited funding and space constraints. The challenges increased during the Covid pandemic when the class had to be moved online, making teaching and learning more challenging.

In 1996, ABET adopted a set of engineering program accreditation standards to access students' learning outcomes (Huber, 2002 & Wankat, 2002). One of the learning outcomes emphasized by these standards is the ability to identify and solve complex engineering problems. As one of the most important domains in the era of Artificial Intelligent, Robotics courses should be designed to meet the accreditation standard.

3D coordinate transformation is one of the most important topics in Robotics. It involves the coordinates of the robot, camera, and object. The ability to transform these coordinates from one to another is fundamental knowledge for real-life applications. However, I have observed that many students have not encountered the material covered at this level, and they are struggling to understand the concept.

How can I design online assignments that allow students to apply their knowledge of 3D coordinate transformation to real-life robotic problems? Additionally, how can I ensure that students can work on the assignments at their own pace while receiving instant feedback from the instructor? The MATLAB workshop, which focuses on teaching computation online, introduced me to a new platform MATLAB Grader, which technically solves my question.

The assignments will be given to the students in the Department of Mechanical Engineering at Prairie View A&M University (PVAMU). PVAMU is one of the public historically black colleges and universities (HBCUs) located in Prairie View, approximately forty miles northwest of Houston, Texas. It is the second oldest public institution of higher learning in Texas, founded in 1876. Based on the statistics conducted in the Fall of 2020, 94% of PVAMU undergraduates are from underrepresented minority groups, with 86% being African-American.

To study the impact of using MATLAB Grader in an online Robotics course, this work adopts an end-of-course survey, students' actions, and the instructor's reflections (Wankat, 1999). The details will be presented in the latter section.

Self-evaluation Assignments

Three assignments are designed to gradually build students' ability to apply the 3D coordinate transformation concept to a real-life robotic navigation problem. Students can work on the assignment online at their own pace. Instant feedback will be given to students, and their work can be automatically graded, building upon the instructor's prior work.

The assignments are designed using MATLAB Grader, a browser-based environment for creating interactive course assignments, automatically grading student work, and providing feedback. The assignments can be run in any learning environment, such as Canvas. The three assignments are designed following the flow presented in Figure 1. The underlying logic of the assignments focuses on self-enhancement. Students' skills are gradually improved as they complete each assignment. According to a psychology study (Sedikides,1993), self-enhancement motivation is one of the most powerful determinants of the self-evaluation process.

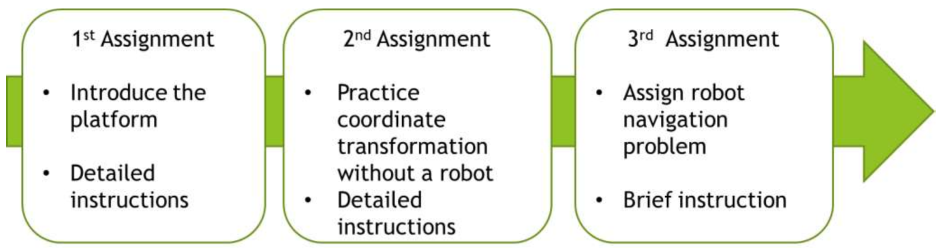


Figure 1. The three assignments are progressively designed.

The first assignment introduces the MATLAB Grader environment with a Degree of Freedom problem. The description of the first assignment is shown in Figure 2.

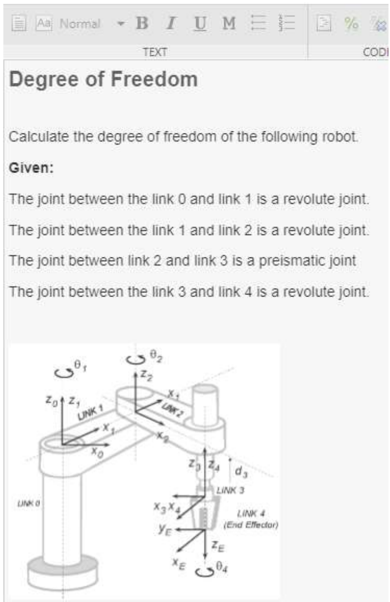
1. Create a MathWorks Account at www.mathworks.com.
2. Go to https://matlabacademy.mathworks.com/, and choose the **MATLAB Onramp** course.
   a. Complete the "Course overview" module (5 min)
   b. Complete the "Commands" module (20 min)

   If you completed this course 3 months ago, please still go over these modules one more time. It helps you to complete this and future homework.

3. You should have received an email notification from the instructor for a course created in Mathworks Last Friday on Oct. 21. Click the **Introduction to Robotics** course link in the email notification to view the course.
4. You can also find the course by going to Matlab Grader through this link: *grader.mathworks.com*
5. After signing into Matlab Grader and selecting the Introduction to Robotics course, you can find the assignments for the course in the menu on the left.
6. Complete the "Assignment about DOF/Degree of Freedom" Problem.
   a. Input the value of *r* and *p* in the Script;
   b. Input the calculation for *n* in the Script;
   c. Before you submit your solution, you have the option of running the code to check your output by click "Run Script";
   d. Before you submit your solution, you can also click "Run Pretest" to get feedback on your answer. Your work will not be graded by clicking the "Run Pretest" button;
   e. Click the "Submit" button, and your work will be graded.

Figure 2. The description of the first assignment.

Screenshots of the first assignment in MATLAB Grader environment are shown in Figures 3 (a) to (c).



(a) DOF problem.

(b) The script in MATLAB Grader.

(c)Feedback for common errors can be designed in the assessment window.

Figure 3. Screenshots of the first assignment in MATLAB Grader.

The second assignment requires students to demonstrate their understanding of coordinate transformation without a robot. The description of the second assignment is shown in Figure 4.

Finally, the third assignment requires the students to apply the 3D coordinate transformation knowledge to a real-life robotic navigation problem. A detailed description is not necessary for the students this time. Based on the previous assignments, they can directly access the MATLAB Grader environment to start working on the assignment. The screenshot of the third assignment is shown in Figure 5. It is modified from an existing Transformation problem in the MATLAB Grader library.

1. Login to MathWorks Account at www.mathworks.com.

2. Go to https://matlabacademy.mathworks.com/, and choose the **MATLAB Onramp** course.
   a. Complete the "Matlab Desktop and Editor" module (15 mins)
   b. Complete the "Vectors and Matrices" module (15 mins)
   c. Complete the "Indexing into and Modifying Arrays" module (15 mins)
   d. Complete the "Array Calculations" Module (5 mins)

3. Go to *grader.mathworks.com* and select the Introduction to Robotics course.

4. Complete Homework 4, and take note of the following:
   a. There are Two problems with this homework. (Rotation matrix and Coordinate transformation)
   b. Read the problem instructions carefully;
   c. Before you submit your solution, you have the option of running the code to check your output by clicking "Run Script";
   d. Before you submit your solution, you can also click "Run Pretest" to check the syntax error. Your work will not be graded by clicking the "Run Pretest" button;
   e. For this homework, the "Run Pretest" option will only check syntax errors. It will not check all the computation errors. In other words, passing the pretest does not guarantee you get 100 points. Because the computation results will be checked after clicking the submit button.
   f. Your work will be graded after clicking the "Submit" button.

Figure 4. The description of the second assignment

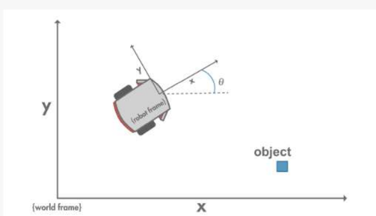
Problem Description and Instructions*

Aa Heading B I U M TEXT CODE INSERT

Transformations

Transforming from one frame (coordinate system) to another arises in many applications. Consider the situation shown in the figure below.

- A fixed camera is used to determine the position and orientation of the robot and objects in one frame, labeled the world frame. In other words, the camera is located at the origin of the world frame, which can be considered as the fixed frame.
- A robot navigating the environment uses various sensors to determine the location of objects in its own coordinate frame, labeled the robot frame, which can be considered as the moving frame. In order to successfully navigate to a desired location, we must transform coordinates in the world frame to the robot frame. So the robot knows the relative position between the object and the robot frame itself.



Three variables are defined in the script below.

- The position of the robot in the world frame, `pRobotWorld`
- The rotation of the robot with respect to the world frame, `theta`, and
- The object coordinates in the world frame, `pObjectWorld`

Your task is to complete the script by:

1. Create a homogenous transformation matrix, `T` that represents the translation and rotation of the robot with respect to the world frame.

(Hint: Consider robot frame is the moving frame and world frame is the fixed frame. Think about how to use the given **`pRobotWorld`** value to find **T**)

2. Use `T` to find the object postion in robot frame. Store this value in the variable **`pObjectRobot`**

3. Take the first three elements of **pObjectRobot** as the position of the object in the robot frame and store the value in **pObjectRobot_xyz**

Figure 5. Screenshot of the third assignment in MATLAB Grader

Results

The idea for this work was developed during a MATLAB Teaching Workshop organized in the middle of the semester when the class had already started. Therefore, a control group was not formed. An anonymous end-of-course survey was given to the students, with the questions shown in Table 2.

Table 2 Questions of the end-of-course survey

Questions
My Matlab skill improves by using Matlab Grader.
Is it difficult to learn Matlab and Matlab Grader?
Matlab and Matlab Grader help me understand the course material better.
Taking it all together, how satisfied are you with the Introduction to Robotic course?

Out of 30 students, 21 took the survey. 76% of students agree that their MATLAB skills have improved, while 24% somewhat agree. Regarding the difficulty levels, 57% of students find MATLAB somewhat difficult, while 43% find it very easy. Additionally, 71% of students agree MATLAB helps them understand the course material better, while 29% somewhat agree. Overall, 76% of students are very satisfied with the course, 19% are fairly satisfied, and 5% are not very satisfied. To yield statistically significant results, more data should be collected in the future.

The biggest achievement of this work is providing students with an opportunity to apply their learning to the most common real-life robotic problem. I also noticed that the first assignment has many late submissions. This might be because MATLAB is a relatively new platform for some students, and stepping out of their comfort zone may have been challenging. Upon discovering the issue of late submissions, I had to persuade them both as a group and as individuals by discussing three points (Macdonald,2004): (1) The connection between the first assignment and the next two assignments. (2) The connection between these assignments and the final exam. (3) The benefits to their careers in the field of AI Robotics. As a result, the submission for the second and third assignments became more timely and complete.

Discussion

Evaluation of the assignments could be more rigorous if there were a secure exam proctor function in MATLAB Grader. Integrating MATLAB Grader with Canvas could potentially solve this problem, as Canvas offers a secure exam proctor function. However, I encountered difficulties in successfully integrating my Canvas account with MATLAB Grader. According to the feedback from the Canvas administrator on my campus, the issue is likely because I have both a student and an instructor account in Canvas. The student account was created when I took a faculty development course with the university. This could be fixed in the future release of MATLAB Grader.

Apart from using surveys, I am considering using end-of-course interviews to delve more deeply into students' perspectives (Mohajan, 2018). By conducting interviews after the final grades are posted, students with different performance levels can participate, leading to more objective insights (Hutchings, 2000).

Conclusion

This paper applies the Scholarship of Teaching and Learning methodology to study the impact of using a new platform aimed at improving the teaching and learning experience in an online robotics course. Details of the assignments developed on the new platform are shared. An end-of-course survey and observations of the instructor are discussed in this paper.

Acknowledgments

This work is inspired by the MATLAB Workshop focusing on teaching computation online, which was organized in 2022. The free workshop brought educators in physics, engineering, and mathematics to share teaching strategies, tools, and materials with a particular focus on transitioning courses to partially or fully online formats.

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