A Not-So-Ordinary Approach to Ordinary Differential Equations: Evaluating the Effectiveness of "CLEAR" in Enhancing Learning

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Abstract

Teaching ordinary differential equations (ODEs), while essential, is often challenging due to the abstract nature of the topic and students' difficulty in relating it to real-world applications. To address this, the Contextualized Learning via Enquiring, Answering, and Reflecting (CLEAR) approach was implemented to help students connect ODEs with authentic, real-life contexts. CLEAR was introduced during the Spring Semester of AY2025 in the graduate-level course "Applied Mathematics for Engineering" at the Singapore University of Technology and Design. As part of the assignment, students successfully developed nine unique real-world contexts, each leading to the formulation of questions and corresponding solutions involving the application of ODEs. The impact of CLEAR was explored through two guiding questions: (1) Does the CLEAR approach help students relate ODEs to observed phenomena beyond the classroom?; (2) How do students perceive the CLEAR approach? Overall, students demonstrated an enhanced ability to contextualize ODEs and reported a positive learning experience with the CLEAR assignment. Many expressed appreciations for how the approach extended their understanding beyond classroom theory and found the process engaging and enjoyable. These findings offer valuable anecdotal evidence that may inform and enhance future approaches to teaching ODEs. Furthermore, given that the CLEAR approach requires no additional hardware or software, it presents a scalable and cost-effective strategy that can potentially be adopted across a wide range of courses and disciplines.

Keywords: student-centered learning, assessment, active learning, higher-order thinking, engagement

Introduction

In the teaching and learning of mathematics, ordinary differential equations (ODEs) constitute a foundational topic that provides the mathematical basis for modelling and explaining a wide range of real-world phenomena in engineering, the natural sciences, and applied research. Despite their importance, students often perceive ODEs as abstract, procedurally demanding, and disconnected from their lived experiences, which can impede both conceptual understanding and motivation (Santos et al., 2020). Although inquiry-based approaches have been proposed to address these challenges, prior work indicates that such methods still fall short in helping students build meaningful links between differential equations and their personal or observed contexts outside the classroom (Hyland et al., 2023).

To address this gap, scenario-based student-generated questions (sb-SGQA) have been developed as a pedagogical strategy that positions students as co-creators of learning materials, thereby increasing authenticity and engagement (Tay, 2024). By constructing their own scenarios and assessment questions, students take on a more active role in the learning process, which promotes autonomy and fosters the development of higher-order thinking skills such as synthesis, evaluation, and creative problem-solving (Yu & Wu, 2020). This shift from passive recipients to active agents enables learners to deepen their metacognitive awareness, strengthen conceptual understanding, and assume greater ownership of their learning trajectories. Building on this foundation, the integration of reflective practices within the sb-SGQA framework led to the development of the Contextualized Learning via Enquiring, Answering, and Reflecting (CLEAR) approach. CLEAR seeks not only to engage students in authentic mathematical inquiry but also to support iterative reflection as a means of consolidating understanding and enhancing personal relevance. Hence, this study seeks to explore the impact of the CLEAR in the context of teaching ODEs through the following research questions (RQ):

- RQ1: Does the CLEAR approach help students relate ODEs to observed phenomena beyond the classroom?
- RQ2: How do students perceive the CLEAR approach?

Methodology

The CLEAR approach was implemented during the Spring Semester of AY2025 in the graduate-level course "Applied Mathematics for Engineering" at the Singapore University of Technology and Design. Students, in groups of 2, were tasked to develop CLEAR assignments which are considered as their student-initialed assessment (SIA) that utilize ODEs concepts and principles to a context they could draw upon from life experience. To help with scaffolding, a sample contextualized CLEAR assignment was provided (Figure 1). A total of 10 graduate students were enrolled in the class. As the course was taught for the first time, a control was not available for comparison. Consequently, data for discussion would rely on analysis of students' work (RQ1) and feedback from students (RQ2).

The implementation schedule of SIA outlines a structured sequence of activities across the entire semester. In Week 1, students are introduced to the SIA and informed that they will design their own examination questions as part of their mid-term assessment. By Week 4, they receive individualized formative feedback to support the development of their work. In Week 6, students submit the first draft of their SIA questions, which they subsequently present for class-wide peer review in Week 7. Following this feedback cycle, students refine and submit the final version of their SIA in Week 9. In Week 11, a perception survey is administered to gather students' reflections on their experiences with the SIA process.

Figure 1
Sample CLEAR Assignment

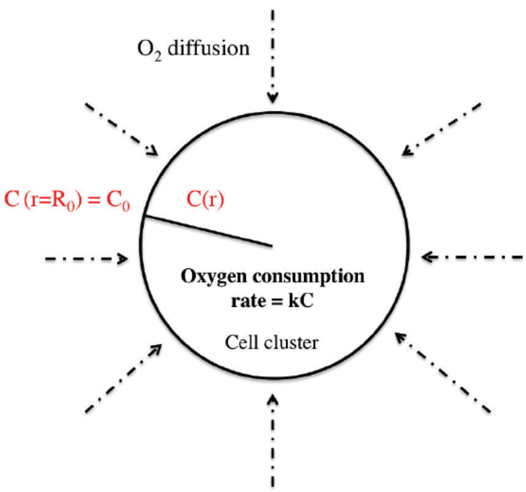
Question 1: Cellular respiration in cells

The cells in human body require a source of energy to function and they are able to obtain it by breaking down food molecules to release the stored energy inside. This process is called "cellular respiration". Oxygen is consumed to break down food (e.g. glucose) in this process.

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$$

Assume a constant concentration of glucose inside the cells and its concentration is much more than the oxygen concentration. Therefore, the reaction rate can be approximated to be a 1st order reaction with respect to oxygen concentration. In this question, we will be looking at the transport and consumption of oxygen inside a cluster of cells.

We consider a steady-state O_2 diffusion in a sphere of radius R_0, with a irreversible reaction of O_2 consumption. Assume that the oxygen concentration at the outer surface of the cell cluster is maintained at C_0 where the value of rate constant k is $10^{-2}/s$, the spherical radius is $0.02\,m$, the diffusivity D is $10^{-5}\,m^2/s$ and C_0 is taken to be $5\,mol/m^3$.



(a) By using shell balance technique, derive the governing equation and the boundary conditions for oxygen concentration profile, C(r). State any assumptions you have made.

Note. The assignment showed 1) the context and 2) questions. Answers to the questions were also provided but not shown in the image above.

The assessment rubric for SIA comprises three major components designed to evaluate both the technical and higher-order learning outcomes of the project. The first component, Technical Strength (55%), assesses the depth and breadth of students' understanding of relevant concepts, the accuracy with which they apply appropriate methods, theories, and calculations, and the proportionality of the workload required to produce their solution, with a small penalty applied when the scope is excessively heavy or insufficiently rigorous. The second component, Presentation (30%), evaluates the clarity and coherence of both the oral and written presentations, with particular emphasis on the articulation of the problem statement and the rationale behind the proposed solution. The final component, Advanced Learning (15%), measures students' higher-order cognitive engagement, including creative thinking, critical thinking, and the novelty and significance of their contributions. Collectively, the rubric provides a structured and balanced framework for assessing analytical rigour, communication quality, and innovative thinking.

Results and Discussion

An analysis of the contexts developed by the students revealed that students were able to meaningfully relate ODEs to real-world phenomena beyond the classroom (Table 1). Deep diving into one such assignment, heat transfer for nuclear fuel was used as a relevant and authentic context for the application of ODEs (Figure 2), along with reasonable answers to the questions developed (not shown in abstract). This finding addresses RQ1 and responds to the concerns raised in a previous study (Santos et al., 2020).

Table 1
List of Contexts Students Developed Questions and Answers for Through CLEAR

Context No.	Topic
1	Yeast modelling for beer fermentation.
2	Linearly-doped Schottky barrier diode.
3	Heat transfer in 3D printing.
4	Vibrations of circular membrane.
5	Movement of electrical signals transmitted in neurons.
6	Heat transfer in nuclear fuel.
7	Transverse diffusion of population inversion in a fiber laser.
8	Spring-mass system.
9	Geodesic distance.

Note. 9 contexts were shown as the 4th context was duplicated by another group.

Subsequently, student feedback was analyzed to gain insight into their perception of the CLEAR approach. Table 2 presents the semester's feedback, reproduced as provided. In general, graduate students appreciated the concepts taught to beyond the classroom (Feedback No. 1, 4, 5 and 6). One appreciated how approximations are commonly used (Feedback No. 3), and another enjoyed the learning process (Feedback No. 2). These results help to answer the second research question, indicating that students were generally positive.

Figure 2
Example of CLEAR Assignment by One Group for Context Number 6

Question 1: Heat Transfer in a Cylindrical Nuclear Fuel

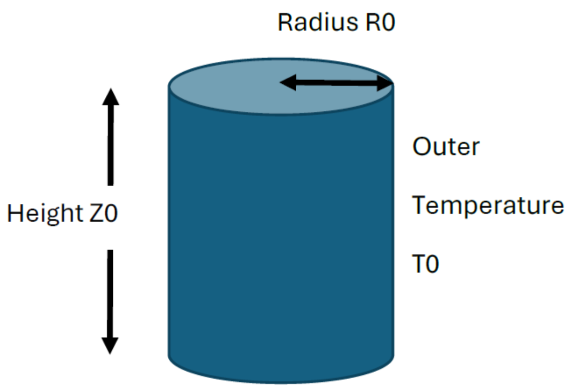
Nuclear materials generate heat due to some neutron interactions. To collect thermal energy, nuclear fuel is immersed in a coolant (e.g., water), which absorbs the heat and drives a turbine to produce electricity.

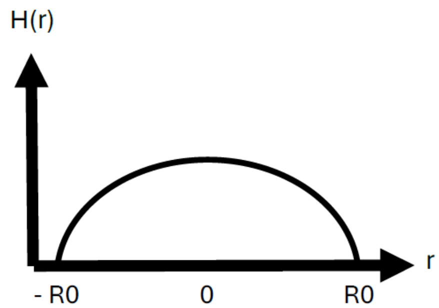
However, too much heat in the fuel creates thermal stress, risk of melting or structural failure. To prevent these problems, the temperature distribution must be analyzed within the nuclear fuel.

In this case, please consider a cylindrical nuclear fuel rod of constant thermal conductivity k, height Z_0 and radius R_0, where heat conduction occurs only in the radial direction. The outer cylindrical surface maintains a fixed temperature T_0. The heat generation rate, in W/cm^3, inside the fuel is given by

$$H(r) = H_0(R_0^2 - r^2)$$

where H_0 is a constant.





Assume that you are a nuclear engineer. Please:

a) Derive this ODE equation using shell-balance techniques.

$$\frac{1}{r}\frac{d}{dr}\left(r\frac{dT}{dr}\right) + \frac{H(r)}{k} = 0$$

b) Write boundary conditions for solving the ODE
c) Find the temperature profile T(r) over the cylindrical fuel by solving the given ODE.

Note. The first page of the assignment is shown for illustrative purposes.

Table 2
Student Feedback on the Use of CLEAR

Feedback No.	Feedback
1	Cool to be able to model real life scenarios
2	Applied math is fun to solve and useful in various problems
3	A lot of approximation is used in real life
4	He (the lecturer) can help with our research math relevant problems and bring Math to real–word applications
5	Very relatable to different scenarios
6	How to use maths knowledge in real engineering conditions

Conclusion

This study implemented the SIA as an instructional framework for teaching ordinary differential equations (ODEs) to graduate students. Although ODEs are traditionally regarded as challenging and often perceived as abstract or disconnected from students' lived experiences, the findings of this study indicate that the CLEAR approach in SIA can meaningfully bridge this gap. Students were able to construct a diverse range of authentic and personally relevant contexts for applying ODE concepts, demonstrating a notable shift from procedural engagement toward conceptual and contextual understanding. Furthermore, students' perceptions of CLEAR were generally positive, with feedback indicating that the learning process was not only accessible but also enjoyable. These outcomes provide preliminary yet valuable evidence that CLEAR has the potential to enhance students' engagement, agency, and relevance-making when learning ODEs. Importantly, because CLEAR relies solely on pedagogical design rather than specialized hardware, software, or costly infrastructure, the approach is inherently scalable. This positions CLEAR as a feasible and adaptable instructional model that can be implemented across different classes, course levels, and even disciplines beyond mathematics and engineering.

Limitations and Future Work

Despite the encouraging results, several limitations warrant consideration. First, the study involved a relatively small cohort of ten students, which restricts the extent to which quantitative findings can be meaningfully interpreted or generalized. Second, the participants were drawn from five different academic departments, each with varying degrees of prior mathematical preparation and disciplinary orientations. While this diversity offers rich qualitative insight, it also introduces heterogeneity that can obscure systematic patterns in students' responses or performance. To strengthen the validity and reliability of future analyses, subsequent studies would benefit from aggregating data across multiple cohorts to achieve a larger and more comparable sample size. Longer-term investigations could also examine the sustainability of the benefits observed, such as whether CLEAR supports deeper retention of ODE concepts or improved transfer to advanced coursework. Furthermore, future work may explore how CLEAR can be adapted or expanded—for example, through integration with digital tools, collaborative learning structures, or discipline-specific scenarios—to further enhance its impact on students' conceptual understanding and engagement.

Declaration of Generative AI and AI-Assisted Technologies in the Writing Process

The author declares that Grammarly, an AI-assisted writing software, was used in proofreading and refining the language used in the manuscript. The usage was limited to correcting grammatical and spelling errors and rephrasing statements for accuracy and clarity. The author further declares that, apart from Grammarly, no other AI or AI-assisted technologies have been used to generate content in writing the manuscript. The ideas, design, procedures, findings, analyses, and discussion are originally written and derived from careful and systematic conduct of the research.

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