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Utilizing AI Chatbots to Enhance Students' Critical Thinking and Problem-Solving Skills in Numerical Methods to Promote Reproducibility

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ABSTRACT

Practically every scientific field is impacted by the reproducibility dilemma. It has long been known that a significant amount of the science being generated cannot be reproducible and that findings from science that are not reproducible are at best doubtful and at least effectively insignificant. The principles of creative thinking are presented in this study article, which also emphasizes the need for computational thinking for problem-solving and enhancing mathematical proficiency. It emphasizes how mathematization helps develop problem-solving skills through numerical methods and goes into additional information about the process. In addition, the article addresses teaching with an artificial intelligent AI Chatbot, to achieve reproducibility. The AI Chatbot fosters students' creativity and curiosity while assisting them in comprehending and applying mathematics to practical situations. The study offers scientific insights into how AI technology might enhance student learning and foster mathematical thinking in mathematical classrooms. The current work presents ChatGPT, a conversational paradigm that can execute code on demand in response to computational problems. As part of the interaction, ChatGPT converts each query into the appropriate code, executes the code, and publishes the computed result. Among ChatGPT's noteworthy attributes is its well-known precision in solving numerical problems; as a subject, it does well in calculus, physics, linear algebra, and other courses. We combine this approach with interpretations in MATLAB, and PYTHON. Additionally, a user interface secure environment is needed for the code to run and reproduce the solutions to the mathematical problems presented by this scientific research.

استخدام روبوتات الذكاء الأصطناعي لتعزيز مهارات التفكير النقدي وحل المسائل الرياضية للطلاب بطرق التحليل العدديّة لتعزيز إعادة الإنتاجية

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الملخص

عمليا تؤثر معضلة قابلية اعادة توليدنتائج الأبحاث علي كل مجال علمي تقريبًا. لطالما كان من المعروف أن جزءًا كبيرًا من العلم الذي يتم إنتاجه لا يمكن إعادة إنتاجه وأن النتائج العلمية التي لا يمكن إعادة إنتاجها تكون في أحسن الأحوال مشكوك فيها وعلى الأقل غير مهمة بشكل فعال. يتم تقديم مبادئ التفكير الإبداعي في مقالة الدراسة هذه، والتي تؤكد أيضًا على الحاجة إلى التفكير الحسابي لحل المشكلات وتحسين الكفاءة الرياضية. يركز البحث على كيفية تساعد الرياضيات في تطوير مهارات حل المشكلات من خلال الطرق العددية ويتعمق في

الكلمات المفتاحية:
روبوت الذكاء الاصطناعي
حل المسائل الرياضية
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الطرق العددية
قابلية انتاج الحل للمسائل

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معلومات إضافية حول العملية. بالإضافة إلى ذلك، تتناول المقالة التدريس باستخدام روبوت دردشة ذكي اصطناعي لتحقيق قابلية الإنتاج. يعزز روبوت الدردشة الذكي الإصطناعي إبداع الطلاب وفضولهم بينما يساعدهم على فهم وتطبيق الرياضيات في الظروف العملية. تقدم الدراسة رؤى علمية حول كيفية استخدام تكنولوجيا الذكاء الاصطناعي لتحسين تعلم الطلاب وتعزيز التفكير الرياضي في الفصول الدراسية للرياضيات. يقدم العمل الحالي ChatGPT، وهو نموذج حوار يمكنه تنفيذ الكود عند الطلب استجابة للمشكلات الحسابية. كجزء من التفاعل، يحول ChatGPT كل استعلام إلى الكود المناسب، وينفذ الكود لاحقا، وتنشر النتيجة المحسوبة. من بين السمات الجديرة بالاهتمام لـ ChatGPT دقته المعروفة في حل المسائل العددية؛ كموضوع، يعمل بشكل جيد في حساب التفاضل والتكامل والفيزياء والجبر الخطي وغيرها من العلوم الرياضية. نقوم بدمج هذه الطريقة مع التفسيرات وتنفيذها على بيئة MATLAB وPYTHON. بالإضافة إلى ذلك، هناك حاجة إلى بيئة واجهة مستخدم لكي يعمل الكود ويعيد إنتاج حلول للمشاكل الرياضية التي يقدمها هذا البحث العلمي.

1. Introduction

In STEM education, recent research show that AI chatbots like ChatGPT enhance students' critical thinking, problem-solving, and concept comprehension; however, their use in numerical techniques is not thoroughly covered. STEM education is an interdisciplinary method that integrates science, technology, engineering, and mathematics. Its goal is to educate students for future careers in these sectors by giving them practical problem-solving abilities, rather than making them proficient in trigonometry when they would never utilize it outside of a math classroom. Numerical methods help engineers obtain numerical solutions when mathematical problems cannot be solved analytically by breaking down complex computations into simpler ones; this puts them in a position not just to find out what value an answer should have but also why it is so. These tools also allow engineers to take into account non-linearity dynamic behavior, and uncertainty are known as the three musketeers, who always walk hand in hand; not because they're equally important in every situation but due to being crucial regardless of when used which makes them essential in real-life engineering scenarios. However, traditional analytical techniques rely on precise mathematical formulas, which might not exist or be extremely difficult to answer. Limitation to probabilistic next word, despite ChatGPT along with other language models, operating via probabilistically predicting the next word given the context, they are not limited to text generation. They can comprehend the context and generate appropriate solutions, including deciphering and addressing numerical challenges. Executing code on demand while ChatGPT doesn't run code, it can answer questions including ones involving numbers with suggestions, clarifications, or brief passages of code. Usually, an external environment such as an integrated development environment (IDE), online compiler, or local development environment is where code is executed. ChatGPT's query translation function does not convert questions into executable code directly. Rather, it can comprehend the question's intent and produce text-based answers, which can contain suggestions or snippets of code that are pertinent to the question. The user is responsible for interpreting and running the code per their needs and comprehension.

Combination with interpretations in PYTHON and MATLAB ChatGPT does not run code or understand numerical expressions, although it is possible to integrate it with programs such as MATLAB or PYTHON for numerical computations. Based on the advice or code samples that ChatGPT offers, users can decide to include code execution in their workflow. The front end and a secure setting in which to run code ensure a secure environment for code execution is essential, particularly for code that is executed from outside sources. However, rather than ChatGPT itself, this accountability usually rests with the user or the platform that hosts the execution environment. All things considered, even though ChatGPT can help with producing answers such as code snippets for mathematical problems it's critical to fully comprehend both its strengths and weaknesses. It's a tool for producing text-based suggestions and responses depending on input, not a direct code execution environment.

While ChatGPT is a web application, does not require users to download or install anything to be accessed freely on the platforms where it is deployed, such as websites or messaging apps. While ChatGPT possesses a calculator feature and can assist in mathematical computations along with problem solving tasks; it is not designed for standalone use like typical calculator applications or programs. It functions more like a conversational interface for information retrieval and a variety of tasks, including mathematical calculations. Scholars can indeed communicate with ChatGPT and pose questions from a variety of academic fields, as an interdisciplinary query suggested. It's not only researchers who can leverage ChatGPT for asking questions on any topic; virtually anyone with internet connectivity can exploit the same resource without limitations. Regarding accuracy and applicability, ChatGPT can, to the extent of its capabilities, deliver accurate answers to numerical problems; nevertheless, it is crucial to remember that its responses are derived from patterns discovered in massive datasets, not from a clear comprehension of mathematical ideas. Although it can be useful for topics like linear algebra, mathematics, and physics, its answers cannot always be as thorough or rigorous as those given by qualified software or human specialists. In terms of privacy and accessibility; using ChatGPT comes at no cost whatsoever; users are not required to reveal any personal information during interactions with the AI.

Using a constructionist theoretical framework, the authors [1] examined the potential of ChatGPT and Bing Chat, sophisticated conversational AIs, as objects to think with, resources that promote creativity, problem-solving abilities, reflective and critical thinking, and concept comprehension in enhancing STEM education. Using user experience as a guide, the article [2] examined the possible effects of ChatGPT and other related AI technologies on education. It concluded that new assessment forms are needed to emphasize creativity and critical thinking, which AI cannot replace.

Plagiarism concerns, minimizing students' ability to think independently, and including biased or erroneous material are potential obstacles to using AI chatbots to promote reproducibility in the classroom instruction of numerical methods [3], [4]. The effective application of AI chatbots, such as ChatGPT, in education is restricted by limits in the quality of output, which include a deficiency in critical thinking and in-depth comprehension [5]. There have been concerns raised about how AI technologies might impact students' development of important skills such as problem-solving or collaborative work [6]. Notably other challenges would be gaining popularity among educators and learners. These obstacles show how carefully AI Chatbots must be integrated into educational environments in order to properly support learning objectives and handle any potential ethical and pedagogical issues.

AI Chatbots have demonstrated potential in accommodating varying learning styles and preferences to improve students' proficiency with numerical procedures. Incorporating AI technologies such as machine learning and natural language processing, Chatbots can adapt to various learning styles as identified by the Felder-Silverman Learning Styles Model [7]. These Chatbots include students in real-world learning scenarios, such as exposing misconceptions about fractions to improve critical thinking and encourage mathematical reasoning [8]. Advanced Chatbots have been shown through experimental studies to significantly enhance pupils' literacy and numeracy abilities when learning science [9]. Additionally, in higher education, an integrated Chatbot system may test student responses, personalize learning experiences, and develop critical thinking skills, all of which improve learning [10]

2. The reproducibility challenge influences scientific disciplines

The issue of reproducibility significantly affects many scientific areas; robotics, artificial intelligence, machine learning, and scientific computing. Research shows that reproducing results can be difficult because of things like unpublished data, training condition sensitivity, and a lack of thorough experimental descriptions. Developing techniques and instruments to improve reproducibility is one way that this dilemma is being addressed [11 - 14]. To increase repeatability in domains such as relativistic astrophysical simulations and surgical robots, researchers stress the significance of methodical methods, precise documentation, and community initiatives. Reproducibility as a service is one of the solutions designed to close the gap between the current tools for reproducibility and the necessity to replicate experiments if the original computational infrastructure is vanished [15]. Enhancing reproducibility is crucial for upholding the integrity of science itself; which directly impacts the validity of research findings across different fields. The reproducibility dilemma severely limits advances in science and weakens confidence in published outcomes [16], [17]. Reproducibility is essential for scientific study because it enables the validation and further investigation of prior findings [18]. Many disciplines, including engineering, life sciences, sociological theory, medical practice, and economy, are affected by the worry of irreproducible conclusions [19], [20]. Techniques for research need to be extensively revised to guarantee the validity and dependability of scientific claims. To address irreproducibility, efforts to improve the effectiveness and return on investment of research support should focus on determining the issue's prevalence, comprehending the root causes thereof, and putting corrective measures in place. To continue to strengthen the scientific foundation and open the door for discoveries, researchers should prioritize reproducibility and transparency in their studies.

3. AI Chatbots combined with MATLAB and PHYTON, in engineering sciences using numerical methods to improve the reproducibility of scientific research

AI Chatbots coupled with MATLAB and PYTHON can serve as a valuable tool for engineering research through numerical methods that foster reproducibility. Although Chatbots are not directly integrated into software libraries like MATLAB or PYTHON, they can still act as intelligent aides working hand in hand with these languages. Guiding researchers with recommended practices and established numerical techniques through the engineering workflow in MATLAB and PYTHON environments, even without explicit inclusion into libraries AI Chatbots can still play an assisting role. Consistency is key when it comes to Chatbots; they can help achieve this through various means including using pre-built templates plus code snippets that ensure uniformity among projects, thus reducing errors introduced through human coding inconsistency. Researchers can refer back to specific versions of codes with ease recognitions to changes signaled by Chatbots based on previous findings; this makes replication simpler. Before even delving into simulations in MATLAB or PYTHON, researchers can catch potential issues early by training Chatbots on engineering specific faults an effective strategy only if quality data is used since these systems are still under development. By doing this, a researcher avoid wasting time or effort on mistakes. When combined, MATLAB and PYTHON offer the essential features needed for numerical calculations. Together with these languages, Chatbots help to make research more replicable by automating processes, streamlining workflows, and highlighting risks that could arise. In areas where human skill remains irreplaceable; like intricate engineering tasks, Chatbots can be considered as a sidekick assisting a researcher where possible while acknowledging limitations for optimal performance.

3.1 Reproducibility Demonstration Case Study No. 1

An interesting example that can demonstrate reproducibility issues through numerical methods using ChatGPT and PYTHON would be to use it for solving a system of linear equations. Let's consider the Gauss elimination or LU decomposition or iterative techniques like Jacobi or Gauss-Seidel as examples from a textbook such as Chapra's "Numerical Methods for Engineers" [21]. The problem statement considers a system of linear equations of the type Ax = b, where x is the vector of unknowns, b is the right-hand side vector, and *A* is a coefficient matrix. This case study is centered on solving a system of linear equations using Gauss elimination as illustrated in Fig. 1. The aim is to apply the Gauss elimination method in PYTHON to solve the system of equations Ax=b. We will then compare the solution with the known answer if one is available. The first task involves using AI ChatGPT to assist in developing the Gauss elimination method in PYTHON programming code so that we can effectively solve the system of linear equations. Then, verify the accuracy of the procedure by comparing the obtained answer with the known solution, if one is available. It is imperative to incorporate remarks and clarifications in the source documentation to ensure reproducibility. A sensitivity study could be needed to evaluate the performance and robustness of the approach by changing factors, such as matrix size and coefficients.

To tackle reproducibility challenges, it needs to ensure the PYTHON code is given along with input data including coefficient matrix A and vector b, plus an expected output if possible solution is known; this would help guarantee readability and maintainability of the code. Starting with supplying instructions or a README document that details how to run the code and achieve the same results. Then including information about the PYTHON environment, such as its version and specific libraries utilized can this facilitates reproducibility. In order to validate reproducibility, others should be urged to run the code and cross verify their findings with the expected output. Evaluation of the solution's accuracy and deviations from a known solution is followed by an analysis on outcomes of Gauss elimination procedure that should be undertaken as a first step towards assessing computational efficiency in this manner. Providing feedback on potential implications if any or how such an approach can be adopted for real engineering challenges is essential; making it more elaborate without explaining so much detail. This case study could demonstrate two things; the ease of reproducing numerical techniques in PYTHON for solving linear equations and how that demonstration can provide insight into both the efficiency and accuracy of Gauss Elimination. Moreover, if a student or a professional seeking knowledge on numerical methods and computational techniques in engineering, this practical case study example can be an excellent aid for their educational purposes.

The inputs utilized by the Gauss-Seidel function in this implementation include the coefficient matrix A, the vector b containing the constants on the right-hand side of the equations, and optionally an initial guess x0. The convergence tolerance tol and the maximum number of iterations (max-iter) are specified parameters. The algorithm iterates until convergence is reached or the maximum number of iterations is met. The function yields the number of iterations completed as well as the solution vector, x. The application can be tested by employing the Gauss-Seidel numerical technique to solve example 11.3 from page 304, Chapra's "Numerical Methods for Engineers" [21].

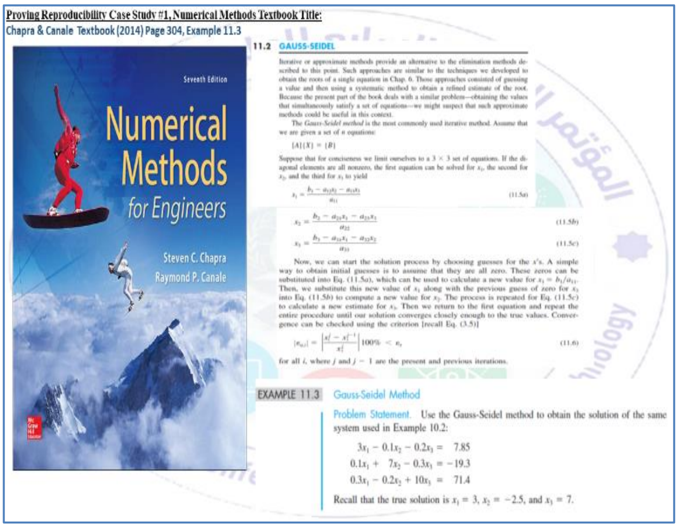

Fig. 1: First case study solving a system of linear equations using Gauss elimination, Exp. 11.3, from Chapra and Canale textbook

The program can be coded to the PYTHON solution platform with its coefficient matrix A and right-side vector b. The true solution of example 11.3 shown in Fig. 1 from Chapra's book [21] is x1= 3, x2= 2.5, and x3 =7. The resulting values are the same when the PYTHON worked on general code was suggested by ChatGPT as shown in Fig. 2. The PYTHON code was rearranged on the SPYDER software as shown in Fig. 3 and the Gauss-Seidel function in this configuration uses the inputs from example 11.3 as a first case study to ensure the reducibility of the results, the coefficient matrix A, the right-hand vector b, tolerance, tol for convergence, an optional initial guess x0, and a maximum number of iterations, max-iter. The solution of the x values was reproduced accurately as in Fig. 3 and the PYTHON code successfully solved the case study problem.

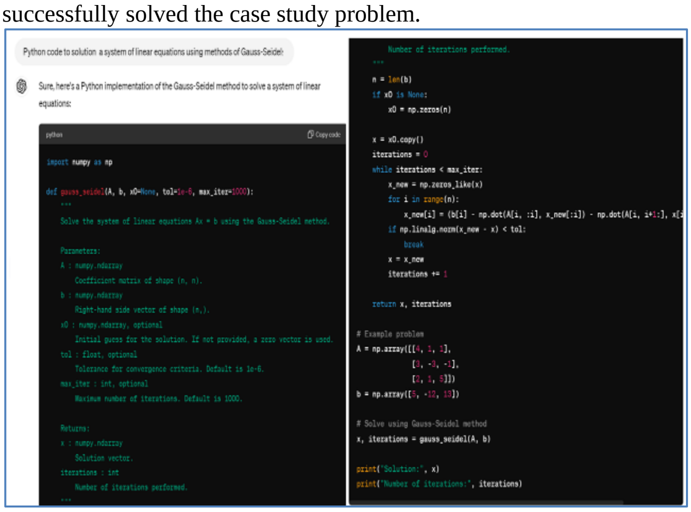

Fig. 2: General code suggested by ChatGPT to use the Gauss-Seidel function in PYTHON to solve a system of equations using the inputs from example 11.3 as a first case study to ensure the reducibility

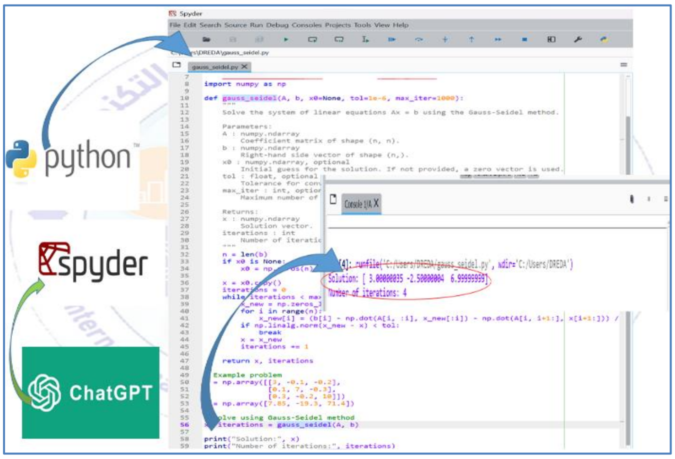

Fig. 3: The first case study problem was precisely reproducing the solution of the x values using the PYTHON code

3.2 Reproducibility Demonstration Case Study No. 2

The following procedures were followed in a second case study to guarantee reproducibility by implementing Simpson's rule in MATLAB and PYTHON, the solution to Example 6.3 from Nayef Ghasem's book 'Numerical Methods in Chemical Engineering Using PYTHON and Simulink' [22] was solved. Fig. 4 illustrates how the problem of the example was stated in the book by including all pertinent equations, parameters, and boundary conditions. The definite integral of x to the power 0.5 over the interval 0 to 8 is approximated using Simpson's formula with four subdivisions in example 6.3 of the textbook Ghasem (2024), cited in [22]. In the given case, the definite integral is to be evaluated manually, and the human calculations are to be verified using MATLAB programming of Simpson's rule with n subintervals. Then to create a general PYTHON program with n subdivisions to apply Simpson's rule to the evaluation of a definite integral by consulting ChatGPT as shown in Fig. 5.

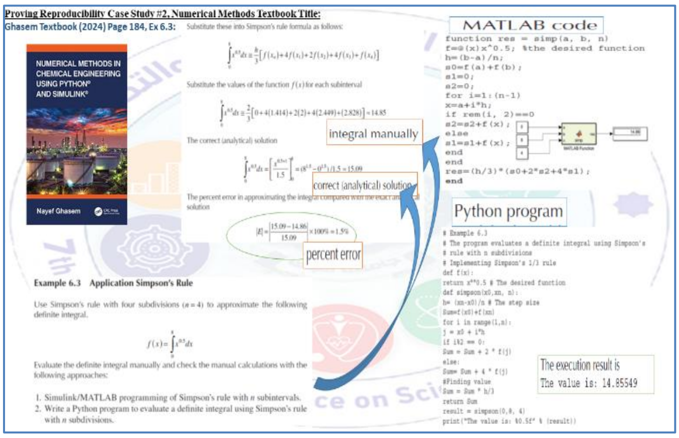

Fig. 4: Second case study solving of the definite integral of x approximated using Simpson's formula of example 6.3 in Ghasem (2024) textbook

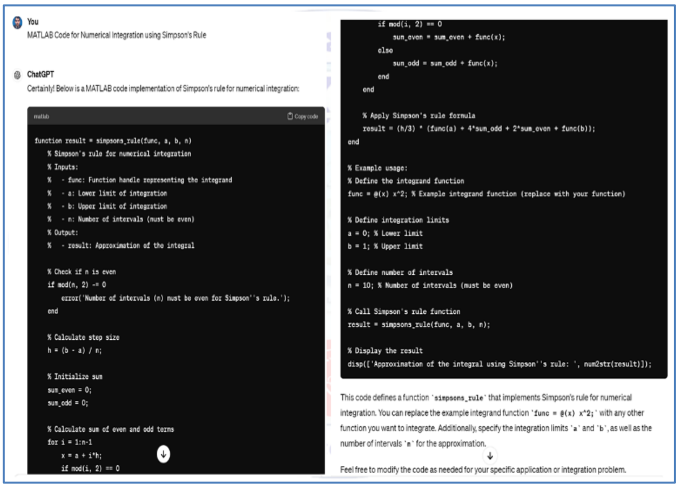

Fig. 5: General MATLAB code suggested by ChatGPT to use to apply Simpson's rule to the evaluation of a definite integral

It is an important step to making sure that the MATLAB code applied in Fig. 6 is well-commented and adhered to best practices for readability and maintainability. Verification of the outcome will be studied by solving Example 6.3 with the information from the book [22] after applying Simpson's rule and checking the answer against any analytical or benchmark solution that has been supplied. Proper documentation is crucial for MATLAB and PYTHON programs. It should include comments that explain the process and any assumptions taken at each step. For others to reproduce what was accomplished, it is also important to properly credit the book or any other outside sources that were used. It is crucial to share information about the example's input data, including function values and its incorporation constraints. The solution of the area value 14.855 was reproduced accurately as in Fig. 6 and the MATLAB code successfully solved the case study problem Example 6.3 in the textbook [22].
Validation of both codes was done by cross-referencing results obtained through additional techniques or software tools this approach would help verify the precision of this reproducing research work. A sensitivity study to assess the implementation's robustness involved tweaking input parameters within reasonable limits and duly documenting the outcome report.

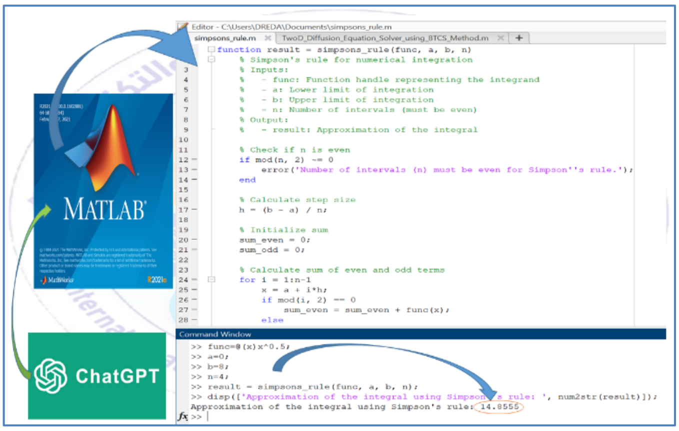

Fig. 6: The second case study problem of Ex 6.3 in the textbook was successfully solved by reproducing the area value solution of 14.855 employing the MATLAB code recommended by ChatGPT

The report, presented with any related graphs or tables along with an explanation of challenges faced and their resolution, should include reproducibility statements. These indicate others can reproduce the results using provided code and instructions, and an easy way to ensure verifiability by collaborators working on Example 6.3 in MATLAB and PYTHON is through such procedures as illustrated using Simpson's rule solution. The work's reputation and reliability can reach new heights with comprehensive validation and proper documentation in place. We sought ChatGPT's help once more this time to craft a PYTHON code that endorses Simpson's rule for numerical integration. Taking a look at the PYTHON code depicted in Fig. 7 can showcase how to verify coding programs can be utilized. The ultimate aim of this research is to ensure reproducibility through alternative coding methodologies using different tools.

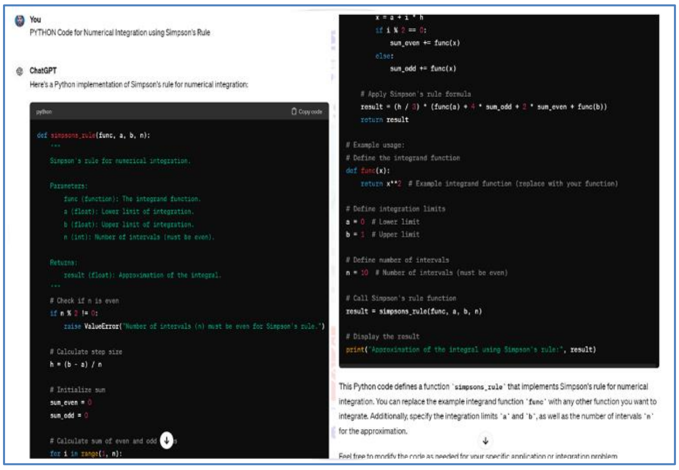

Fig. 7: General PYTHON code suggested by ChatGPT to use to apply Simpson's rule to the evaluation of a definite integral

Following this, the general code suggested by ChatGPT is set on the platform of SPYDER to run the PYTHON script as illustrated in Fig. 8. The area value solution of 14.855 was accurately duplicated, and illustrated in Fig. 8, and the PYTHON code successfully addressed the reproducibility of the case study problem Example 6.3 in the textbook [22].

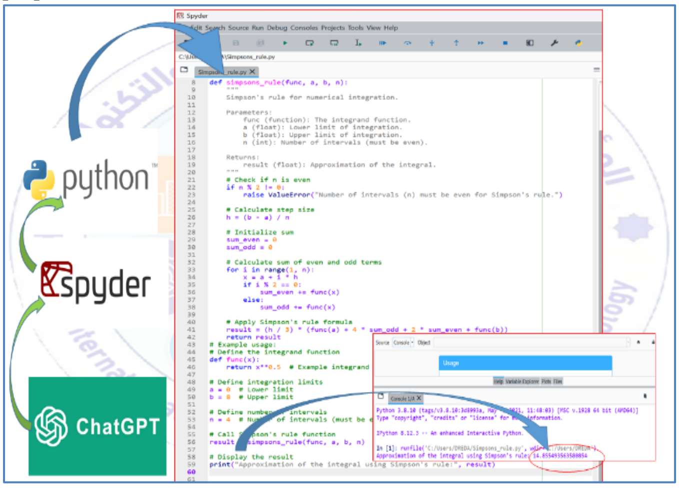

Fig. 8: The second case study problem of Ex 6.3 in the textbook was successfully solved by reproducing the area value solution of 14.855 employing the PYTHON code recommended by ChatGPT

3.3 Reproducibility Demonstration Case Study No. 3

This paper aims to demonstrate the potential of the AI Chatbot in reproducing some of the research project's findings in other research works from open literature. To ensure the reproducibility of literature research work outcomes published in the literature, this study examined the usage of AI Chatbots in the previous two case studies on two well-known numerical textbooks. For a third case study, let's delve into the research published by Edali et al. [23]. It serves as a valuable compass and resource for implementing a systematic approach to teaching simulation to postgraduate students. When should this journey begin is at an early stage in the master's program, and it continues through subsequent courses. They consider simulation tools to be an essential resource for aspiring chemical engineers. In their research, the new curricula that were implemented into a simulation-based design in four consecutive graduate courses are detailed. The focus is particularly on the advanced computational numerical methods course they put in focus to present the curriculum development with simulation components, where students gain technical competency by strengthening their modelling and simulation skills. The recommendations and resources from the study listed at the end of the paper present a practical approach to delivering simulation-based teaching early in postgraduate programs, followed by continuity in subsequent courses. Simulation packages are identified as an indispensable future tool for chemical engineers by the authors [23]. Conspicuously, the research adopts numerical methods different from those used by another study referenced as literate [23] which can be inferred from their approach towards addressing a heat transfer numerical problem using FTCS explicit App 2 as shown in Fig. 2 of their article [23]. During the session, the participants were taken through constructing models using PDEs in Excel worksheets along with the background of Visual Basic coding where they experimented with a variety of finite difference approaches and also evaluated the stability of the solution. The reason behind their utilization of Excel worksheets in the Visual Basic environment was to ensure that they understood how to come up with differential equations based on specific physical situations. The problem details as given in the publication [23] must be comprehended to prove the reproducibility of the findings of a heat transfer numerical problem addressed by the FTCS (Forward-Time Central-Space) explicit approach. Analyzing the problem details as given in the paper [23] is essential to showing the reproducibility of the problem solution in the research by Edali et al. 2021 [23] of the outcomes of a heat transfer numerical issue addressed using the FTCS explicit technique. This research paper addresses the topic of demonstrating the reproducibility of the research problem discussed and presented in Edali et al. 2021 [23] as a case study #3 of this research work. The system's geometry, boundary conditions, initial conditions, material qualities, and any other crucial parameters are all detailed in Fig. 9 of this work. Once these details are known, the FTCS explicit technique for solving the heat transport problem can be implemented with a PYTHON code. The results of the code as consulted and recommended by the AI ChatGPT, will then be compared to those reported in the publication [23].

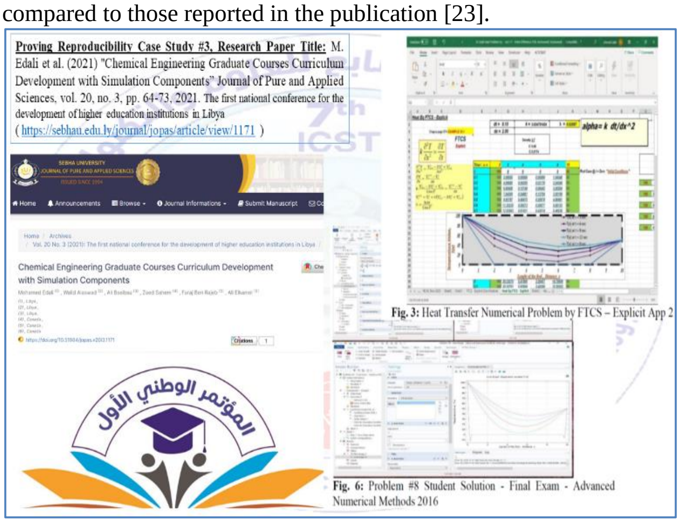

Fig. 9: Third case study solving of the heat transfer numerical problem addressed using the FTCS explicit technique using Excel worksheets and VBA from Edali et al. 2021 research work [23]

A general framework for applying the FTCS explicit technique to a 1-D heat transfer problem has been made available via ChatGPT. It has the ability to modify this framework according to the details of the issue as stated in the publication [23]. A simple layout of the code recommended by ChatGPT is shown in Fig. 10.

The temperature array T is initialized and the boundary conditions are set in this PYTHON code. The temperature array is then updated by iteration over time steps using the FTCS explicit approach. Plotting the temperature profile is the last step. Getting the precise specifications of the issue parameters, boundary conditions, and beginning conditions from the publication [23] is necessary to demonstrate reproducibility.

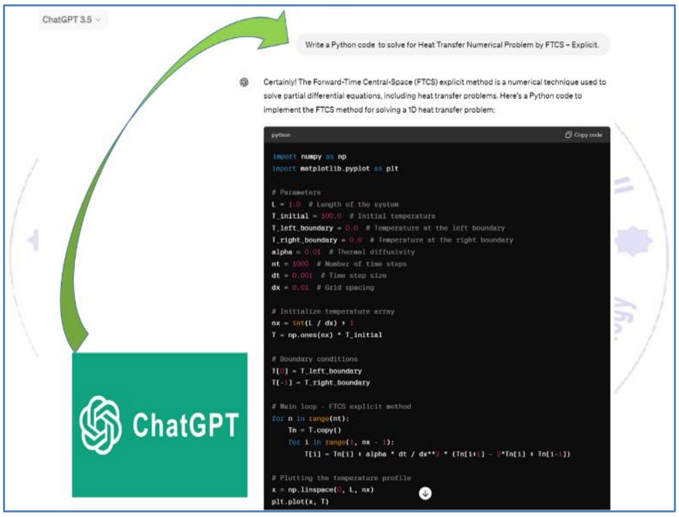

Fig. 10: General PYTHON code suggested by ChatGPT to use applying the FTCS explicit technique to a 1-D heat transfer problem

Using the SPYDER console to implement the PYTHON code with the given details as shown in Fig. 11, then executing the code, and comparing the temperature profile that is achieved with the findings published in the publication [23]. When comparing the temperature distribution of rod profiles in Fig. 11 to those reported in Fig. 3 of the publication [23], observe that Fig. 11 PYTHON code indicates the setting for estimating the rod temperature profile at 12 seconds.

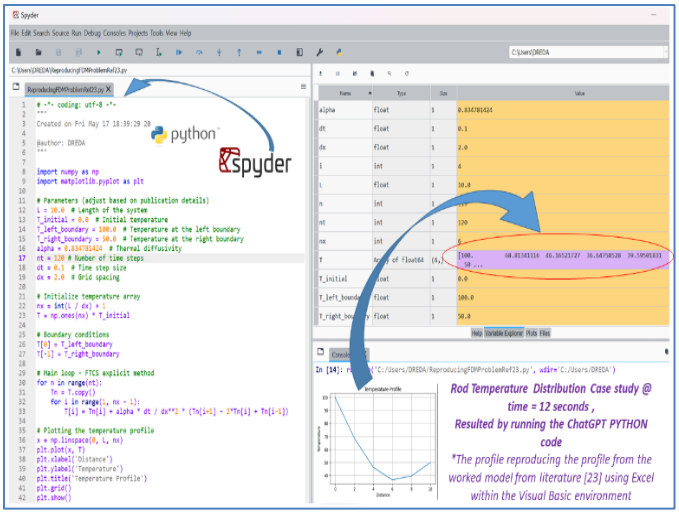

Fig. 11: The parameter for predicting the rod temperature profile at 12 seconds is shown by the PYTHON code

Temperature profile data at 0 and 6 seconds is used by changing the number of time steps in the PYTHON code to ensure consistency as detailed in Fig. 12. The rod temperature distribution results show reproducibility demonstrated in Fig. 12 by consistent matching temperature profiles within tolerable tolerance limits of Fig. 3 in the published paper [23].

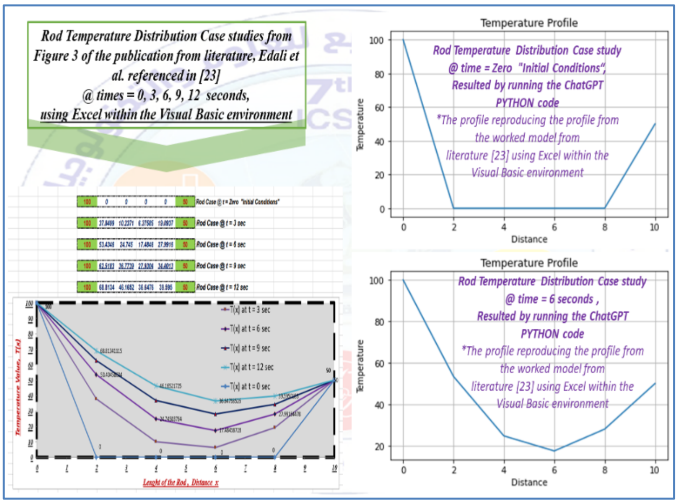

Fig. 12: Altering the number of time steps in the PYTHON code results into temperature profile data at 0 and 6 seconds matching temperature profiles within acceptable tolerance bounds of Fig. 3 in the published study [23]

4. Conclusion

The paper examines reproducibility and its implication for scientific reliability, addressing this dilemma across various scientific scopes. It underscores that problem-solving effectiveness and mathematical enhancement stem from both computational and creative perception. The deployment of an AI Chatbot in classroom pedagogy is detailed; it fosters student creativity, ensures reproducibility, and sharpens mathematical thinking. The conversational model called ChatGPT which is introduced as a tool that can create computer codes most especially in mathematical numerical methods solving techniques where physics and calculus issues prevail to solve computational problems. The implementation of ChatGPT with MATLAB / PYTHON interpretations creates a safe space for reproducing code solutions; this later ensures mathematical reproducibility which in science upholds integrity and reliability of research findings through validation and referencing previous discoveries of published research work in literature. Reproducibility should be considered valid across all disciplines where investigations are carried out, therefore it plays an essential role ensuring that study findings are confirmed independently which means that the work can be duplicated. In turn, reproducibility helps to sustain trust towards scientific results by other researchers who would take these outcomes into consideration when making decisions or further scientific work development on the same topic. Progressing Research in Science needs to ensure its reproducibility as it is crucially important to the development of science as it enables validation of research findings; these procedures can be a base on which future breakthroughs and advancements be made.

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