26TH CONFERENCE OF SLOVAK PHYSICISTS

05.-08. SEPTEMBER 2022

Faculty of Science
UPJŠ KOŠICE

PROCEEDINGS

Slovak Physical Society

EDITORS

Andrea Džubinská
Marián Reiffers

26th CONFERENCE OF SLOVAK PHYSICISTS
PROCEEDINGS

Editors: Ing. RNDr. Andrea Džubinská, PhD., prof. RNDr. Marián Reiffers, DrSc.

All papers were anonymously reviewed

Published: Slovak Physical Society
Printed: EQUILIBRIA, s.r.o., Košice
Košice 2022

ISBN 978-80-89855-19-3
EAN 9788089855193

CONTENT

APPLICATION OF OPEN SAGEMATH SOFTWARE IN PHYSICS EDUCATION AND RESEARCH

D. Borovsky, dominik.borovsky@student.upjs.sk, J. Hanc, jozef.hanc@upjs.sk, Institute of Physics, Pavol Jozef Safarik University in Košice, Park Angelinum 9, 040 01 Košice, Slovakia

INTRODUCTION

The development of physics, and generally in science, is nowadays closely associated with the digital technology of scientific computing. The exponentially fast progress in science and technology also poses a huge challenge to science education where traditional teaching methods based on building a purely theoretical, idealized picture of the world are becoming unsustainable in the 21st century.

Society, industry and stakeholders demand that young graduates should have a wide range of knowledge and skills that can be effectively applied in practice. In response to this, STEM education (an interdisciplinary approach in teaching science, technology, engineering, and mathematics) was established emphasizing interdisciplinarity and connections of theoretical knowledge with real-world phenomena [1, 2, 3].

In our contribution, we present SageMath (or Sage for short), a free open-source mathematics software [4, 5, 6]. Sage combines the power of several hundred open-source packages (e.g., SciPy, Numpy, SymPy, R, or Maxima). Sage notebooks are Jupyter notebooks (https://jupyter.org/) belonging to well-known open data science and computing tools [7, 8]. As interactive docs, they can also be lab reports, worksheets, tutorials, lessons, or textbooks.

SAGE IN PHYSICS EDUCATION

From our several-year experience viewpoint, Sage appears as a universal, interactive and easy-to-use digital environment based on Python [9] which can be reciprocally applicable in physics education and research. Developing modeling skills of students in physics education (or generally STEM education) is now an important part of education [10, 11]. Sage opens the gates to advanced modeling as a new aspect of education.

For example, solving a problem from the well-known international physics competition called *The Young Physics Tournament*, students can describe a model of the Wilberforce pendulum, a spring-mass system consisting of a mass m with an adjustable moment of inertia I suspended from a helical spring [12]. Using Sage as a CAS system, students can find and explore an analytic solution of the Lagrange equations (Fig. 1, *upper part*) much more quickly and with no typos.

In the frame of inquiry-based science approach [3] and the flipped learning [13], students can also discover a trajectory of the Apollo 8 spaceship [14] (Fig. 1, *middle part*). Here Sage serves as a very precise and fast numerical tool correcting typical wrong students' impressions from lectures and textbooks on mechanics that Hamilton's variational approach must always be more difficult than Newton's equations of motion.

As a final illustration, we mention SageMath as an interactive visualization tool. In the case of the Van der Pol oscillator described by the differential equation $\ddot{x} - \mu\,(1 - x^2)\,\dot{x} + x = F\cos(\omega t)$, students can explore chaotic behavior (Fig. 1, *lower part*) and get fundamentals of the modern theory of dynamical systems [15, 16]. There is also an opportunity for interdisciplinary connections to biology, where the same model describes the activity of the human heart or neurons.

SAGE IN PHYSICS RESEARCH

Regarding research, SageMath can be also a powerful open alternative to the well-known commercial scientific environments Mathematica [17], Maple [18] or MATLAB [19]. As a particular example, we applied SageMath [20] in exponentially fast, highly accurate, and very reliable calculations of gamma difference distribution $\mathcal{GDD}$ — the difference $X \equiv X_1 - X_2$ of two independent random variables X_1, X_2 having a gamma distribution [21]. At the double 53-bit precision, our computational algorithm developed and implemented in SageMath outperformed the speed of commercial Mathematica by two orders and MATLAB 5 - 10 times.

Our results are very promising since $\mathcal{GDD}$ provides a wide range of applications not only in physics and metrology (e.g., controlling the measurement accuracy of optical detectors) but also in engineering (setting optimal performance of WiFi networks), medicine (chemotherapy cancer treatment), biology (modeling forests), or economics (modeling of Bitcoin market).

CONCLUSIONS

Using SageMath as an open digital environment for scientific computing, teachers and students get not a special education "toy" but a real research tool for interactive visualization, modeling, programming, and solving authentic, complex interdisciplinary problems. It naturally improves motivation to study science following the main STEM education mission.

Moreover, students armed with digital skills developed in SageMath can immediately engage in actual scientific tasks as student research assistants (as one of the authors – DB) or later as Ph.D. students. From the research viewpoint, such an essential interconnection leads to much broader opportunities to test and inspect the benefits and pitfalls of Sage computational tools and algorithms during research.

ACKNOWLEDGMENTS: This work is supported by the Slovak Research and Development Agency under the Contract no. APVV-21-0216.

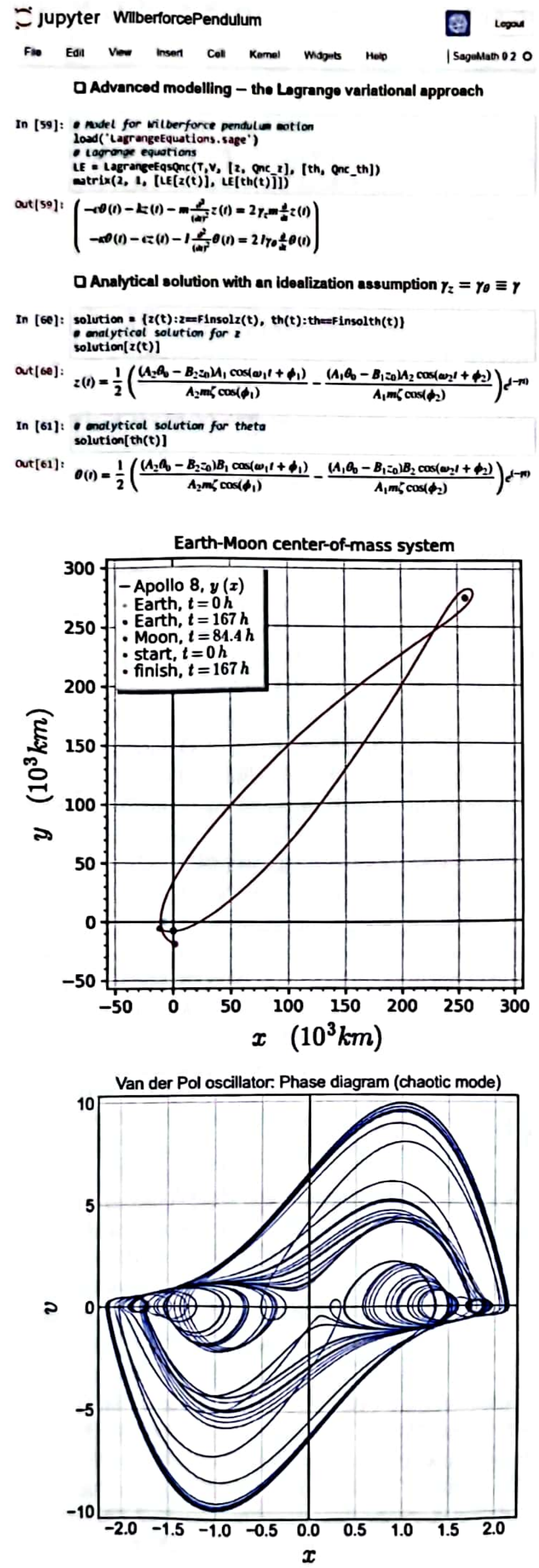

Fig. 1. Examples of advanced computing and modeling in education using SageMath

REFERENCES

1. L.D. English, Int. J. STEM Educ. **3**(1), 3 (2016).
2. T.R. Kelley, J.G. Knowles, Int. J. STEM Educ. **3**(1), 11 (2016).
3. C.P. Constantinou, O.E. Tsivitanidou, E. Rybska, in Professional Development for Inquiry-Based Science, Teaching and Learning, ed. by O.E. Tsivitanidou, et al. (Springer, Cham - 2018) pp. 1 - 23.
4. W.A. Stein, et al.: Sage Mathematics Software - SageMath (2022). http://www.sagemath.org
5. P. Zimmermann, et al., Computational Mathematics with SageMath (SIAM, Philadelphia - 2018).
6. OpenDreamKit: Open Digital Research Environment Toolkit for the Advancement of Mathematics. https://opendreamkit.org/index.html
7. T. Kluyver, et al., in Proceedings of the 20th International Conference on Electronic Publishing., ed. by F. Loizides, et al. (Ios Press, Amsterdam - 2016) pp. 87 - 90.
8. J.S.S. Lowndes, et al., Nat. Ecol. Evol. **1**, 1 (2017).
9. G. Van Rossum, F.L. Drake: Python 3 Reference Manual (CreateSpace, Scotts Valley, CA - 2009).
10. J. Weber, T. Wilhelm, Eur. J. Phys. **41**, 034003 (2020).
11. R.H. Landau, M.J. Páez: Computational Problems for Physics: With Guided Solutions Using Python, 1st edn. (CRC Press, Boca Raton, FL - 2018).
12. R.F. Uy, C. Yuan, Z. Chai, J. Khor, Eur. J. Phys. **43**, 015011 (2021).
13. R. Talbert, J. Bergmann: Flipped Learning: A Guide for Higher Education Faculty (Stylus Publishing, Sterling, Virginia - 2017).
14. E.W. Schmid, G. Spitz, W. Lösch: Theoretical Physics on the Personal Computer, 2nd edn. (Springer, New York - 2012).
15. T. Tél, M. Gruiz: Chaotic Dynamics: An Introduction Based on Classical Mechanics, 1st edn. (Cambridge University Press, Cambridge - 2006).
16. S.H. Strogatz: Nonlinear Dynamics & Chaos: With Applications to Physics, Biology, Chemistry & Engineering, 2nd edn. (CRC Press, New York - 2018).
17. Wolfram Research, Inc.: Mathematica (2021). https://www.wolfram.com/mathematica
18. Maplesoft, a division of Waterloo Maple Inc., (Maple - 2019). https://www.maplesoft.com/
19. The Mathworks, Inc. MATLAB (2021). https://www.mathworks.com/
20. M. Hančová, A. Gajdoš, J. Hanč, J. Stat. Comput. Simul. **92**, 2205 (2022).
21. B. Klar, J. Stat. Comput. Simul. **85**, 3708 (2015).