Introduction of Deterministic Chaotic Systems in Physics Teaching in High Schools

Robert Repnik[1], Damjan Osrajnik[1], Vladimir Grubelnik[2]

[1]Faculty of Natural Sciences and Mathematics, University of Maribor, Slovenia
[2]Faculty of Electrical Engineering and Computer Science, University of Maribor, Slovenia

Abstract. Nowadays, mathematical modeling is indispensable in scientific research, specifically in studies of oscillating systems, which are present in a variety of everyday phenomena [1-5]. Studying complex oscillating systems includes the area of deterministic chaos [1], which has received wide attention since its discovery [6]. Therefore, it is reasonable to introduce dynamic systems with elements of deterministic chaos in education at the high school level. Based on the curricula analysis [7,8] and the test results, which show how students understand topics related to dynamic systems, we develop the didactic model to implement complex oscillating systems in schools practice. The didactic model is based on understanding the systems dimensions, feedbacks, open and closed systems, stability analysis of two-dimensional dynamic systems, and criteria for transition to the chaotic regime [1]. Usually, the simulations' results of mathematical modeling are clear and instructive. However, for correlating them with the real-life, the practical experimental approach is of great importance. One of the possibilities is to study acoustic systems, where we can form time series of oscillating pressure changes, based on sound recordings of different instruments. By using nonlinear analysis, we focus on possible appearance of deterministic chaos [9,10].

[1] S. H. Strogatz, *Nonlinear Dynamics and Chaos*, Addison-Wesley Publishing Company, 1994.
[2] H. P. Schecker, Physik-Modellieren, Grafikorientierte Modellbildungssysteme im Physikunterricht, Ernst Klett Verlag, Stuttgart, 1998.
[3] W.A. Robinson. *Modeling Dynamic Climate Systems*, Springer, New York, 2001.
[4] B. Hannon, and M. Ruth (2001). *Dynamic Modeling*, Springer, New York, 1-388.
[5] M. Ruth, and J. Lindholm (2002). *Dynamic Modeling for Marine Conservation*, Springer, New York, 1-449.
[6] E. N. Lorenz (1963), Deterministic nonperiodic flow, J. Atmos. Sci. 20 130–141.
[7] G. Planinšič, R. Belina, I. Kukman in M. Cvahte, Učni načrt, splošna gimnazija, Fizika, Ministrstvo za izobraževanje, znanost in šport, 2015. http://eportal.mss.edus.si/msswww/programi2018/programi/media/pdf/un_gimnazija/2015/UN-FIZIKA-gimn-12.pdf
[8] A. Žakelj et al. Učni načrt. Matematika : gimnazija : splošna, klasična in strokovna gimnazija: obvezni predmet in matura (560 ur) Ljubljana : Ministrstvo za šolstvo in šport : Zavod RS za šolstvo, 2008 http://eportal.mss.edus.si/msswww/programi2018/programi/media/pdf/un_gimnazija/un_matematika_gimn.pdf
[9] D. Osrajnik, V. Grubelnik, and R. Repnik. (2021) Multirhythmicity but no deterministic chaos in vibrating strings. *Chaos, solitons and fractals*. [Print ed.]. Sep. 2021, vol. 150, str. 1-5. DOI: 10.1016/j.chaos.2021.111206.
[10] S. Bešlagić, and M. Perc (2010). Cautionary example of nonlinear time series analysis : from tones to sounds. *Nonlinear phenomena in complex systems : an interdisciplinary journal*. 2010, vol. 13, no. 1, str. 70-78. ISSN 1561-4085.

ACKNOWLEDGMENT: This article is partly a result of research supported by the Republic of Slovenia and the European Union under the European Social Fund within the project "Scientific and mathematical literacy: the development of critical thinking and problem-solving (NA-MA POTI)".