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Review of the dissertation
***Researching innovative strategies for enhancement of understanding
and motivation in science***
submitted by Daniel DZIOMB for the degree: Doctor of Philosophy in Biophysics

Dissertation presented by Daniel Dziob is written in English and consists of the *Thesis overview* and the copies of six research papers co-authored by mgr Dziob and published in renowned peer-reviewed journals (labels [A1] through [A6] are used in the Dissertation and are used in the present review):

- [A1] D. Dziob, D. Sokołowska, M. Młynarczyk, and J. K. Mościcki, *A Simplified experimental method to study conductivity percolation*, Review of Scientific Instruments 90, 076105 (2019).
- [A2] D. Dziob and D. Sokołowska, *Experiment on percolation for Introductory Physics Laboratories - A case study*, American Journal of Physics, 88(6), 456 (2020).
- [A3] D. Dziob and D. Sokołowska, *Water network percolation on yeast as an experiment proposal for advanced physics laboratories for bio-science students*, European Journal of Physics 41(2), 025801 (2020).
- [A4] D. Dziob and M. Čepič, *Simple method for measuring thermal conductivity*, Physics Education 55(4), 045004 (2020), published online 28 April 2020.
- [A5] D. Dziob, Ł. Kwiatkowski, and D. Sokołowska, *Class Tournament as an Assessment Method in Physics Courses: A pilot Study*, EURASIA Journal of Mathematics, Science and Technology Education 14(4), 1111 (2018).
- [A6] D. Dziob, *Board game in physics classes - a proposal for a new method of student assessment*, Research in Science Education 50(3), 845 (2020).

In declarations that accompany the Dissertation, all co-authors of papers A1 to A5 described the character and the extent of their contributions to the reported work. One may conclude that Mr Dziob played a decisive role in initiating and completing most of the research presented in papers A1 to A5. He is the sole author of the paper A6. According to the *Web of Science* (14 September, 2020) beside the papers A1 through A6, Mr Dziob published also 7 other research papers in peer-reviewed journals. Altogether his 13 papers listed in the *Web of Science* were cited 30 times and 15 times without self citations (25 September, 2020).

The six papers included in the Dissertation represent Mr Dziob's work on developing new methods in teaching physics and biophysics. The general plan, main ideas and motivation of his Dissertation he describes in the part *Thesis overview*. There, referring to well chosen, relevant literature, Mr Dziob shortly reviews recent research on teaching science and enumerates the most often recommended methods: inquiry-based learning, problem-based and collaborative learning. He observes that the quoted research devotes much place to the question "how to teach?" but omits the far more important problem "what to teach?" in order to make physics more interesting for students. According to his diagnosis, physics as it is now taught at schools, is seen by students as very remote from real-life phenomena and recent research and therefore often found boring. In his Dissertation he indicates three directions that we may follow to inspire students' interest in physics. First, he suggests to incorporate examples of recently investigated topics into physics curricula, second, to do more experimental work and third, to introduce assessment methods that stimulate both: cooperation and competition between students. These directions are followed in the research work presented in the Dissertation.

As a contemporary physics topic Mr Dziob chooses the phenomenon of conductivity percolation and describes how to include this topic into the program of Introductory Physics Laboratory. The simplified method of impedance measurements developed by Mr Dziob and coauthors and discussed in paper [A1] considerably reduces the measurements' costs and make the whole experimental procedure, as well as the accompanying data analysis understandable for the first year physics students. In [A1] investigation of conductivity of (quasi two-dimensional) water network formed in a nonconducting granular material (sand) is used to exemplify the feasibility of this method. Observation of conductivity changes with time during dehydration of the system allows to determine the critical exponent above the percolation threshold. The value obtained is compatible with the one obtained with the standard, more elaborate method.

The method described in [A1] is used to prepare another new module for the Introductory Physics Laboratory thoroughly described in paper [A2]. Since the majority of first year students probably never met percolation phenomena, they start the task with reading some text on the phenomenon itself, its quantitative characteristics and the definitions of quantities they are supposed to measure. The text, shortly summarized in [A2] under the title "Theoretical background" is clearly written and should be easy accessible for students. The term "theoretical" is a gross exaggeration since the text explains only the phenomenon itself and quotes formulae used for its description. In the next step students build the experimental setup according to the instructions given and adjust the relevant experimental parameters. The next, experimental part consists in measuring the dielectric loss factor as a function of time close to the percolation threshold in a system similar to that described in [A1]. The last part of the task is to analyze the data and estimate the critical exponent of conductivity. The tasks given to students was organized according to the suggestions prepared by the American Association of Physics Teachers for Introductory Physics Laboratories. The most interesting part of [A2] contains experience gathered by the Authors while testing the module with the group of 5 students. Students found the module interesting and inspiring to their own individual investigations of the phenomenon which they all understood well and were able to analyze the data they got. Two students, due to improper adjustment of the experimental setup and the scarcity of time could not reach the percolation threshold but correctly analyzed data obtained by other students. Despite the smallness of the testing group one may conclude that the module proposed fulfills much of the scope of Introductory Physics Laboratory and certainly deserves to be introduced into the physics curricula.

There is however one point I would like Author to explain: I do not understand a comment, which comes as a foot-note to Table IV, that "Experimental values for 2D percolation are usually lower than those resulting from theoretical models". What assumptions of the theoretical model referred to are not fulfilled in the reported experiments?

As mentioned in *Thesis overview* the concept of percolation can be applied to describe and analyze many very different natural phenomena and processes. In particular it may be applied

to analyze the processes related to water permeating aggregates of living cells. The next experimental module discussed by Mr Dziob is intended for master students of biophysics. The thorough description of the corresponding experimental design is given in paper [A3]. It is proposed there to apply the same simplified measuring technique as in [A1] and [A2] but for a three dimensional sample of living yeast cells initially containing as much as 70% of water and placed between horizontal plates of a large capacitor. Holes in the upper plate allow for free evaporation of water (i. e. dehydration of the sample) into the air. The time evolution of systems conductivity measured between capacitor plates are then interpreted by the Authors as a consequence of two subsequent percolation phenomena. First of which accompanies the destruction of 3D network of (conducting) water connections and below the 3D percolation threshold as percolation accompanying the destruction of the remaining 2D network "on the surfaces of the cells". This laboratory module has been tested with four master students of biophysics. In performing the experiment students were trained in dealing with AC circuits and learned to appreciate the power of physical methods in investigating and interpreting systems interesting in biology. The quoted results they obtained compared very well with those from the literature obtained with more sophisticated methods. Therefore, I find the experiment itself as very well suited for the laboratory for biophysics students. However, it was not clear for me how the 2D network hypothesized in the text forms in the system. What are the arguments for such interpretation except the observed two linear regimes in the log-log plot of conductivity versus time?

To summarize my review of the first part of the dissertation: I find the idea to confront students of physics and biophysics with experiments on percolation very good, and the form of its realization proposed in the Dissertation as very well suited for students laboratories.

The second part of Mr Dziob's thesis presents his research on teaching physics at secondary school level. To broaden the list of measurements feasible in school laboratories. Mr Dziob designs a simple method to measure thermal conductivities of common materials of which household containers for liquids are made. In [A4] the actual implementation of the method is described, and the values obtained are discussed. It rightly is pointed out in [A4] that the method fails for containers made of materials whose conductivity exceeds the one of water. The method is certainly well suited to be used in secondary school laboratories. The reasoning leading to the crucial formula is very simple and will easily be understood by pupils but it applies only to the limiting case of containers with negligibly thin walls. This condition should be mentioned in [A4] even if all measurements discussed there were made for containers for which the thin-walls approximation is reasonably well fulfilled. I cannot understand why Authors use linear approximations to analyze their experimental data. This introduces additional, errors to the estimated values of thermal conductivities. Secondary school students know the logarithmic function, therefore there is no point to refrain from using it in the analysis of experimental data.

As a next topic of his Dissertation Mr Dziob addresses assessment methods at school. In papers [A5] and [A6] he proposes to methods that he sees as an alternative to the summative grades usually awarded for students' achievements. In [A5] he designs a tournament in which groups of students compete. Such a tournament allows to assess different elements of students' knowledge and skills including his social competences to collaborate with other members of his group. Additionally each student can compare his self-assessment with the marks given for his contribution by others in the group. Post-tournament tests indicate that such a tournament augmented knowledge and skills of students although, as Mr Dziob cautiously warns, the number of students tested was rather small: 28 taking part in the tournament and 22 in the control group. There is one more factor that is not mentioned in [A5] – students that took part in the tournament spent more time with the material it addresses and it certainly gives them some advantage over the control group.

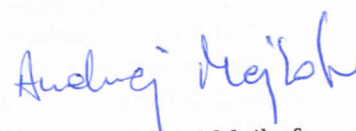
As far as physics is concerned only very scant examples of tournament's questions and problems are given. The tournament's problem copied in Figure 5 cannot be solved without

additional information about the ammeter's resistivity – probably it is given elsewhere in the text of the problem.

In [A6] Mr Dziob designs and tests a board game as an assessment tool. During this game students, proceeding from field to field, encounter different questions and problems from physics. There are questions concerning history of physics, definitions of physical quantities, laws of physics, measuring instruments etc. After reaching some of the fields students are asked to make simple experiments. Again examples of questions and problems given are rather scant. The effectiveness of the proposed game as a teaching tool was tested on a group of 131 pupils from two high schools. In each of these schools one experimental and one control group was formed. Similarly as in [A6] statistical methods used as research tools in social sciences were applied. Results obtained endorse the hypothesis that participation in the game in question augmented the knowledge and skills of pupils. The statistics are larger than in [A5] but still rather small. Nevertheless, I find the results reported in papers [A5] and [A6] as very promising. Experimental methods presented there inspire collaboration in a group to profit from the known effectiveness of learning from peers.

Conclusion

In his Dissertation Mr Daniel Dziob addresses nearly all important aspects of physics teaching: from introducing new topics to physics curricula to keep abreast of the progress in research, developing new experimental techniques feasible in introductory physics courses or school laboratories as well as new methods of assessment of students' progress. In all these points he obtained original and valuable results. Therefore, despite some critical points raised in my review, I find the Dissertation of Mr Dziob fulfills the requirements of the "Ustawa o stopniach i tytule naukowym" and suggest that Mr Dziob be allowed to proceed to further stages of the doctoral procedure.



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