Collection of Solved Problems in Physics – online learning source encourages students' active learning

Zdeňka Koupilová, Dana Mandíková, Marie Snětinová
Faculty of Mathematics and Physics, Charles University in Prague
Krzysztof Rochowicz, Grzegorz Karwasz
Institute of Physics, Nicolaus Copernicus University in Torun, Poland

Solving quantitative problems is one of the favorite exercises in teaching physics. It requires two, or even three *key* competences: mathematical fluency, knowing physics and understanding the written text [1]. Nowadays, European educational indications clearly separate these competences, so there is no need any more that physics plays the role of "all-doing but bad boy" [2]. Teaching should develop in students the ability to solve problems. Students should acquire the skills that will enable them a systematic and continuous search of knowledge, as well as developing a logical, critical and creative way of thinking. One of the goals of science (and physics) education is teaching students to solve problems [3].

For not-so-skilled students the common collections of unsolved or briefly solved problems are not very suitable for self-study. Moreover, reading solved problems is a very ineffective way of learning. There is also usually a lack of time to solve enough problems in the class.

The collection of solved problems preparation at Charles University [4] goes beyond the traditional role of numerical exercises in Physics. The form of the electronic database of problems with structured solution is designed specially to substitute tutor's help and to encourage students to solve the problems independently, or at least to solve some parts. It uses various hints, notes with laws and formulas and plots.
The difficulty of understanding the written text is eased by step-by-step hints and explanations, written in a simple language. The numerical insecurity of a student is overcome by several, alternative and complementary problems, forming a sequence with a rising difficulty *(Passing of a Train I* and *II*, tasks no. 386 and 387). Finally, essentials of physics are underlined by coming back, on different levels, to the same problem: a simple mathematical pendulum (tasks no. 937 and 481), ballistic pendulum (*I* and *II*, tasks no. 146 and 147), and a mathematical pendulum with big amplitude.

Typical structure of a task contains compulsory sections (title, assignment, at least one section of solution and the answer) and recommended sections (hints, analysis, comments, links to similar tasks, see Fig. 1).

In analysis section a strategy of solution and physical principle used within the solution of the problem are highlighted; no formulas are used here to persuade students to think more about the physical context of the problem than about the mathematics involved. The main difficulties that students face in solving problems relate to a low degree of development of certain skills that are essential in any process of problem solving, for example, linking their prior knowledge to the new problem situation, conducting a qualitative analysis of the situation, developing a solution strategy or carrying out appropriate calculations [5]. Thus, in solution section a special attention is paid to a step by step description, including every logical operation and formulas' operation, list of known and sought-after data, unit conversions and numerical calculations.

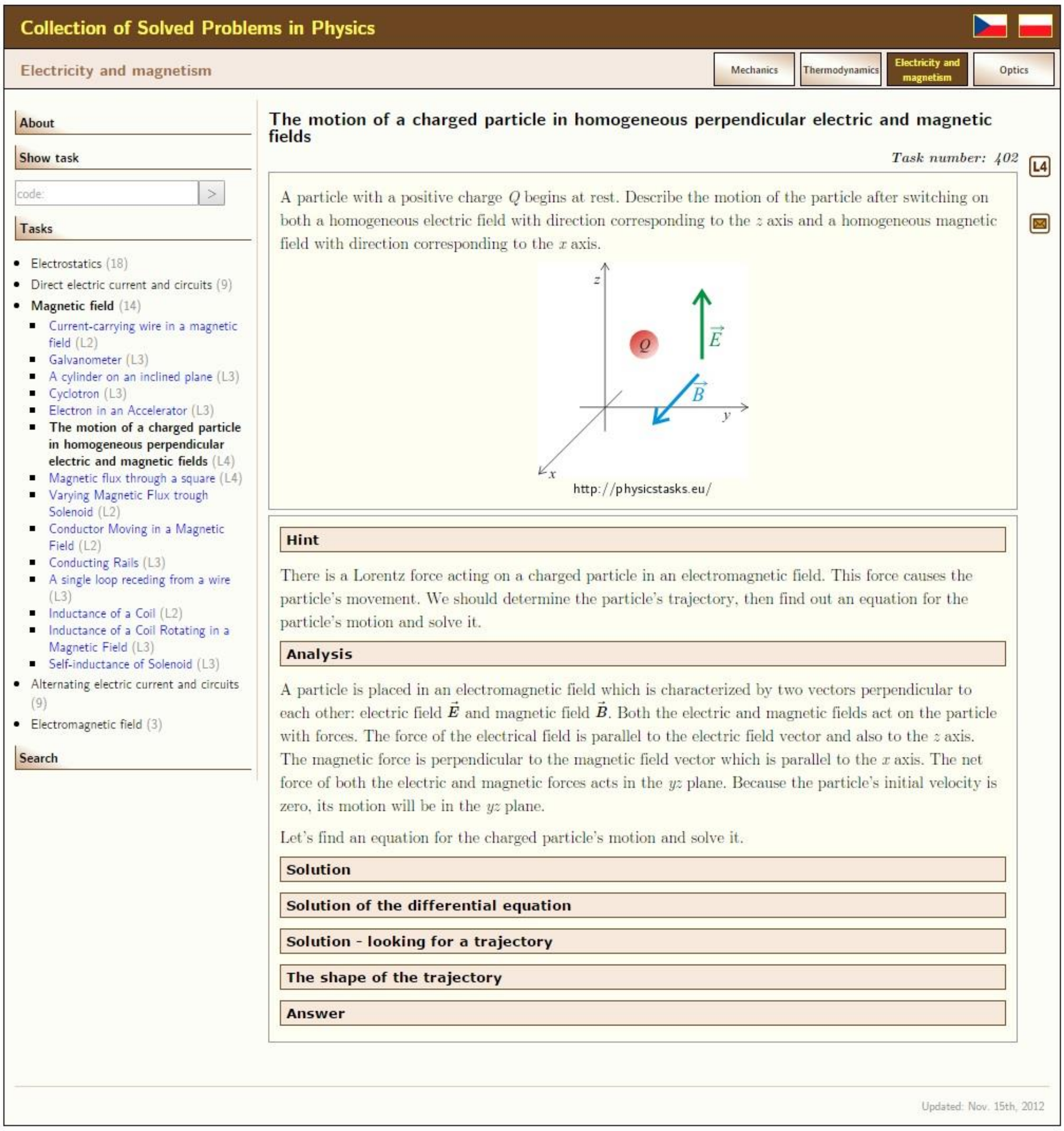
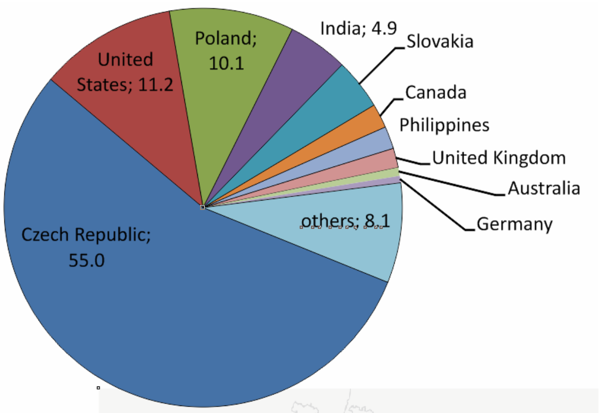


Fig. 1: The screenshot of a typical task.

In the period January 2014 – June 2015 we have had usually over 1000 visitors per day. The number of visitors precisely distinguishes school days, weekends and holidays. The geographical distribution of the visitors is figured on Graph 1.



Graph 1: Geographical distribution of visitors

Current content of the web database includes nearly a thousand physics and about 400 math problems in Czech. Besides them there are available translations of over than 100 physical tasks in Polish and 120 in English (see Table 1).

<table>
<tr><th colspan="3">Topics</th><th>Tasks</th></tr>
<tr><td rowspan="10">Czech</td><td rowspan="7">Physics</td><td>Mechanics</td><td>220</td></tr>
<tr><td>Electricity and Magnetim</td><td>260</td></tr>
<tr><td>Thermodynamics</td><td>140</td></tr>
<tr><td>Optics</td><td>50</td></tr>
<tr><td>Physics of microworld</td><td>90</td></tr>
<tr><td>Theoretical mechanics</td><td>50</td></tr>
<tr><td>Mathematical methods</td><td>80</td></tr>
<tr><td rowspan="3">Math</td><td>Mathematical analysis</td><td>190</td></tr>
<tr><td>Linear algebra</td><td>160</td></tr>
<tr><td>Algebra</td><td>15</td></tr>
<tr><td colspan="2" rowspan="3">English</td><td>Mechanics</td><td>50</td></tr>
<tr><td>Thermodynamics</td><td>20</td></tr>
<tr><td>Electricity and Magnetim</td><td>50</td></tr>
<tr><td colspan="2" rowspan="4">Polish</td><td>Mechanics</td><td>30</td></tr>
<tr><td>Thermodynamics</td><td>36</td></tr>
<tr><td>Electricity and Magnetim</td><td>20</td></tr>
<tr><td>Physics of microworld</td><td>12</td></tr>
</table>

Table 1: Rough numbers of published problems in individual subjects

The Department of the Education of Physics (ZDF) of Nicolaus Copernicus University in Torun published online the Polish translation of more than one hundred tasks (see Table 1). Apart from this, a booklet with selected task in Mechanics has been prepared as the educational material for Polish students and teachers distributed during ZDF seminars. First edition was printed in 300 copies in 2013. It was assessed as an excellent tool for students' self-study, that's why we decided to extend its content (some problems for more advanced learners were added) and it was printed in 2014 at the NCU publishing house [6].

An example of work linking tasks with experiments is a problem of a spinning reel with a tape wound on it. Such an experiment used to be shown during lectures on mechanics by one of our colleagues (Hieronim). While unrolling the tape, the direction of the movement of the reel depends on the angle that the tape forms with the horizontal direction – see the movie on our webpage [7].

In accord with calculations, see [6], the effect is based on the interaction between two forces – the one pulling the reel (to the right on Fig 2) and the static friction force (acting in this case to the left). These two forces (actually moments of these forces) can be added in a such way that sometimes the spool accelerates to the right, sometimes to the left, depending on the angle of application of the force to pull (see the movie [7]).

Although the theoretical description of a similar problem is one of textbook "classics" [8], a real experiment attracts much more web visitors than the solved problem itself. Further, precise measurements using computer-controlled force sensors illustrate several other aspects, like slipping, errors in digital approximations, simplifications in calculations, see Fig. 2c.

Fig. 2: From simplified picture of the situation in the Problem Collection (left panel) to a real demonstration (middle) and computer-aided experiment (right). The direction of movement of a rolling bobbin depends on the angle of the pulling force; the friction force is opposite to the pulling force, and is always in a constant ratio to it, depending on the angle. Adopted from ref. [7].

We have also analyzed both theoretically and experimentally the problem of static and kinetic friction (see also the example with an inclined plane on the same webpage [7] and links given there), which is crucial for explaining a similar case of "a cat pulling a ball of wool". Depending on the point of application of the pulling force, the static friction force changes its value. Moreover, if the thread is hooked above the axis (at least at the level of $R/2$, where R is the radius of the ball), the friction force changes direction (see [5, 8]). The friction during rolling is a static friction and it acts always *against* a possible direction of the slip (and not always contrary to the pulling force!).

Conclusion

Solved problems in physics are therefore only a starting point into illustrating different aspects of the real world. We plan to add new tasks and new topics to on-line database and to continue in translation tasks into English and Polish. We have also established a new branch – collection of physics experiments [9] and we will be working on links between problems and experiments.

References and links:

[1] The Organisation for Economic Co-operation and Development (OECD): *Testing student and university performance globally: OECD's AHELO*, http://www.oecd.org/edu/skills-beyond-school/testingstudentanduniversityperformancegloballyoecdsahelo.htm

[2] Karwasz G., *Hyper-constructivism in teaching Physics: defining social competences*, GIREP 2015 *Proceedings* (2015).

[3] Harskamp, E., Ding, N. (2006): *Structured collaboration versus individual learning in solving physics problems*. International Journal of Science Education, 28(14), 1669–1688.

[4] Koupilova Z., Mandikova D. *Collection of Solved Problems in Physics*, Univerzita Karlova, Prague, http://physicstasks.eu/

[5] Becerra-Labra C., Gras-Marti A., Torregrosa J.M. (2012): *Effects of a Problem-based Structure of Physics Contents on Conceptual Learning and the Ability to Solve Problems*, International Journal of Science Education, 34(8), 1235-1253.

[6] Koupilova Z., Mandikova D., Rochowicz K., Karwasz G., *Sbirka zadań z fizyki*, Wydawnictwo UMK (2014).

[7] Służewski K., Karwasz, G., *Hieronim's roll*, http://dydaktyka.fizyka.umk.pl/nowa_strona/?q=node/472

[8] Mazzoldi P., Saggion A., Voci C.: *Problemi di fisica generale*, Padova, 1998.

[9] http://fyzikalnipokusy.cz