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Beyond bungee jumping: Designing bungee cord to teach hooke's law in problem-solving lab

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Abstract: Physics instruction is critical for helping students develop thinking skills and practical skills through the engineering design process, however, they often find it difficult to apply the concepts of physics to solving real-world problems. Bungee jumping is one of the favorite real-world applications in Hooke's law as it requires a physics calculation to design the bungee cord required to meet the specified safety criteria. The purpose of this study, therefore, was to investigate 35 high school student's mastery of concepts on the behavior of the spring through the implementation of an engineering design process activity in the problem-solving laboratory instruction. A pre-experimental study with one group post-test design only was used to outline a problem-solving laboratory instruction and to assess students' mastery of concepts after the instruction. We found that only 48% of students or fewer were able to make effective use of Hooke's law to propose a solution and design a model related to the bungee cord problem. Although most students seemed to acquire a reasonable grasp of the energy concepts to solve the quantitative problems, it was found that there was a widespread tendency to improperly apply the conservation of energy concept to the context of jumping from a height in a qualitative problem. However, the physics behind designing bungee cords can be used to engage students in learning Hooke's law. Such a hands-on pass-fail test of the student solutions provides them with more meaningful real experiences in applying physics calculation to a real solution.
Keywords: bungee jumping; hooke's law; problem-solving lab; engineering design process

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Introduction

The importance of laboratory experiments in physics instruction is generally agreed upon by physics teachers (Otero & Meltzer, 2017). Most physics teachers would argue that physics instruction should be predominantly emphasized in laboratory experiments. Laboratory experiments in physics instruction can be used for observational experiments, testing theoretical experiments, and application experiments (Etkina et al., 2002). Much previous research reports that laboratory experiments, either virtual or real laboratory, could improve students' conceptual understanding of physics content (Volkwyn et al., 2008; Miller et al., 2013; Gunawan et al.2018). However, previous research also reports that laboratory activities are more effective to teach experimental practices rather than to reinforce classroom instruction (Holmes & Wieman, 2018; Holmes et al., 2017: Wieman & Holmes, 2015). Hence, labs that use a context, such as real-world problems, should be used in physics learning today.

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Meanwhile, the performance of Indonesian students in the PISA assessment which uses various contexts is still below the average OECD score from 2003 to 2018. There has been no significant change since Indonesia's first participation in the PISA program in 2001. Some 40% of students in Indonesia attained Level 2 or higher (OECD average: 78%). The results mean that students in Indonesia can only recognize the correct explanation for familiar scientific phenomena and can use such knowledge to identify, in simple cases, whether a conclusion is valid based on the data provided, but they find it difficult to apply their knowledge of and about science to various situations, including unfamiliar ones (OECD, 2019).

In relation to this situation, classroom instructions and laboratory activities that apply various contexts in constructing knowledge and applying concepts to real-world problems certainly play an important role. Students need to carry out laboratory instruction that not only verifies concepts but also how to apply them directly to solve problems. Students must also experience how the data and equations they calculate in physics classrooms can be used as solutions to practical problems in the real world. Such learning experiences are most likely to help students construct strong mental models because students' mental models might be context dependent (Wittmann et al., 2003; Bao & Redish, 2006). Those activities can also be found in a problem-solving laboratory that promotes the Engineering Design Process (EDP). Problem-solving laboratory activities incorporate commonplace devices and have immediate applications in the real world. It gives authentic experiences and opportunities for students to identify a problem, design procedures, collect information, organize data, and report findings (Chiapetta & Koballa, 2010). All of these skills are in line with the skills needed in the engineering design process.

The engineering design process has become a promising new trend in science learning nowadays. It introduces the ways that engineers might apply science and mathematics concepts by designing, building, and testing a model of real-world application. There have been many studies that apply the engineering design process approach (Sriyansyah et al., 2023, Teevasuthonsakul et al., 2017), but there are still few in number EDP activities that directly involve a hands-on pass-fail test of the student calculation, such as the activity carried out by Trout & Gaston (2001). Therefore, this paper presents an EDP activity in the problem-solving laboratory with the use of bungee jumping as context. Apart from the physics behind bungee jumping being interesting to review, it is one of the real-world challenging applications to give to students to practice ranging from low to high difficulty levels (Heck & Uylings, 2020; Tretter, 2012; Heck et al., 2010; Fitzgerald & Brand, 2004; Kagan & Kott, 1996; Menz, 1993).

Previous research has indeed been reported about a similar activity to design bungee jumping in the classroom (Tretter, 2012; Teevasuthonsakul et al., 2017; Haryadi & Pujiastuti, 2020), but these reports have not provided a comprehensive explanation of students' performance on the post-exam questions that related to the material covered in laboratory activity. The existing report like the report of Hariyadi & Pujiastuti (2020) only discusses a different focus, that is student's science process skills. The report of Teevasuthonsakul et al. (2017) is limited in that it only provides the design steps of bungee jumping activity without providing a detailed and comprehensive explanation of students' critical thinking skills. This deficiency led us to conduct an investigation, which aims to examine the effectiveness of problem-solving lab on bungee jumping toward students' mastery of concepts. As well as providing more evidence of the pedagogical benefit of bungee jumping activities in the classroom.

Other than that, Hooke's law was used as the topic in this study for the following two reasons. First, a few studies have been conducted to specifically investigate topics that require engineering design process activity and mathematical calculation of the student solution for a hands-on pass-fail test. Second, the dynamic model of spring arrangements, such as series, parallel, and combination, supports a variety of student ideas when they model any possible bungee cord construction for any criteria determined.

The information presented in this paper is expected to be an evaluation of applying engineering design process activity in problem-solving laboratory instruction and simultaneously as a reference to develop more appropriate instructional methods and curricular materials in learning Hooke’s law at the high school level.

Method

A pre-experimental study with one group post-test design only was used to engage 35 eleventh-year students at BINUS School Bekasi as the target population. The sampling was done using the convenience sampling technique because only two classes using the same course syllabus were available to the researcher. The participants were taught by the author SPS and were accustomed to using inductive learning methods on previous topics. Data was collected during the first term of the academic year 2023-2024.

Data was documented by using two sets of instruments which consisted of five items each, those are written quantitative questions and written free-response (qualitative) questions. The written quantitative questions were administered to 33 students on the summative assessment, while the written qualitative questions were administered to 35 students as a pop quiz a month after they took the summative assessment. The quantitative test is the items that must be answered using equations contained in Hooke's law and the qualitative test is conceptual questions. Students were administered the quantitative questions after their instruction, as a part of the summative assessment. However, there is a one-month delay for the written qualitative questions with two rationales. First, the qualitative questions are the post-exam questions that relate to the EDP and the material covered in the laboratory activity. Second, with the test so closely following the instruction, the possibility that students are relying on rote memorization cannot be ignored. Francis *et al*. (1998) reported that meaningful instruction produces real and long-lasting conceptual change. Therefore, we would like to know whether the conceptual change and laboratory experiences persist even a month after instruction.

Data analysis to determine student’s mastery of concepts was based on the average score of both (qualitative and quantitative) tests and the percentage of students who passed the test. Either qualitative or quantitative tests were scored by using the validated marking scheme. The total mark obtained was then converted into a scale of 100. The instruction is said to be effective if the average score is greater than or equal to 50 (the criterion was assigned by the Cambridge schools) and the percentage of students who pass the test is greater than or equal to 75%. Students’ conceptual difficulties were then carried out through descriptive analysis of trends in student answer patterns. The pattern of students' answers was reflected by the proportion of students giving responses for each response.

Context of the Investigation

Hooke’s law is studied at BINUS School Bekasi during the first semester of high school grade eleven. Two science classes were involved in this investigation. Both have six periods of physics instruction each week with each period lasting for 40 minutes. Hooke’s law includes several subtopics such as spring constant, spring in series and parallel, and elastic potential energy.

In this investigation, we used six periods in total to teach the topic of Hooke’s law. The first two meetings were used for lab sessions and the third meeting was for revision sessions. We integrated the steps of the engineering design process in every lab session. We adapted the Engineering Design Process proposed by Anne Jolly (2017) so that can be integrated into the problem-solving lab. The adapted EDP steps that were used in this investigation include (a) defining the problem, (b) research and planning, (c) creating, (d) testing and evaluating, (e) redesigning, and (f) communicating, as shown in Figure 1.

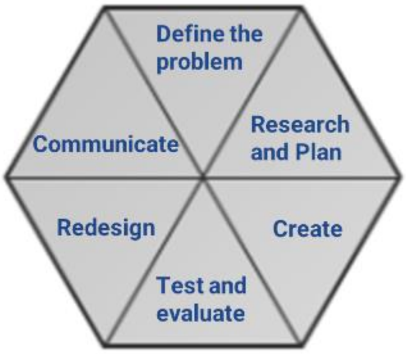


Figure 1. EDP in a nutshell adapted from (Jolly, 2017)

The first 80-minute lab session was used to discover Hooke's law using a typical spring. Students defined a problem and did research about how to design bungee cords to build up bungee jumping. The second 80-minute lab session was used for the bungee jumping problem-solving lab in which students must plan, create, test, evaluate, and redesign their bungee cord model. The last revision sessions were used to communicate the result and reinforce the concept of spring combinations before having the summative assessment.

Bungee Cord Challenge

The goals of the challenge are (a) to find out the characteristic (spring constant) of the rubber band chain by measuring, graphing, and calculating the gradient of the graph, and (b) to bungee jump the 500-g load as close to the egg as possible by applying their calculation. This activity introduces high school students to apply the calculations of Hooke's law, spring in series and in parallel, and conservation law of energy to design a bungee cord. Students must design and build a bungee jump apparatus that can drop a 500-g mass and stamp a raw egg without breaking it. Students will use rubber bands, string, and red ink as a stamp, a rubber balloon, measuring tape, a 500-g load, an egg tray, and a boiled egg. They should apply problem-solving skills, Hooke's law, springs in combination, and mathematics to solve the challenge in two steps. First, they must find out the spring constant of the rubber band chain. Second, they predict the perfect length of the string that connects the rubber band chain and the load. This prediction was obtained from the calculation by considering the conservation law of energy.

Results and Discussion

This section will discuss a description of the problem-solving laboratory instruction, students' mastery of concepts, predominant themes of students' reasoning, and the pedagogical benefits of bungee jumping laboratory activity.

Problem-solving lab with EDP activity

Students were divided into two classes; moreover, our lessons were structured into three instructional meetings, each lasting eighty minutes. The concept of Hooke's law includes several sub-concepts, such as (a) Hooke's law – explaining the spring constant, (b) elastic potential energy – some possible energy transformation, and (c) the arrangement of the springs and their characteristics. These concepts were delivered by using problem-solving laboratory instruction with the engineering design process approach. The steps of the problem-solving laboratory that were adapted from Supriyatman et. al. (2017) includes (a) orienting students to learn, (b) defining a problem, (c) guiding students to do pre-experiment, (d) guiding problem-solving based experiment, (e) evaluating a solution, (f) following up and enrichment. The adapted EDP steps that were used in this investigation include (a) defining the problem, (b) research and planning, (c) creating, (d) testing and evaluating, (e) redesigning, and (f) communicating (Anne Jolly, 2017). In the following sections, we describe the lessons we conducted in more detail.

The first practical activity in the first meeting was focused on defining the problem and researching the information. Students were oriented to the problem of constructing a bungee cord. They were guided to determine the goals of the challenge and what physics concepts they needed to know to solve the challenge. It is essential to make sure that students feel competent and engaged in solving the posed problems by providing an adequate problem definition (Wellhöfer and Lühken, 2022). Students were directed to find the characteristics of materials that are suitable for use as bungee cords and whether the arrangement of the bungee cords affects the characteristics of the material used. Therefore, this session aimed to introduce the concept of the spring constant and the arrangement of the springs, either in series or in parallel.

Students investigated the spring constant of two different springs by recording data and drawing a graph of mass against the extension. After they found the value of spring constants, students then looked for the effective spring constant when the springs are connected in series and parallel. They were asked to compare the value of the effective spring constant before they were shown the mathematical equation to obtain the effective spring constant through calculations. The final part of the lesson was that the students constructed the concept of spring constant; the steeper the gradient of the mass against the extension graph, the greater the spring constant, the stiffer the spring; the greater the number of springs in series the smaller the effective spring constant, and springs in parallel have a higher effective spring constant than if the springs are connected in series.

The second lesson was aimed at planning, creating, testing, evaluating, and redesigning a bungee cord model. Students are challenged to build a bungee cord which consists of a rubber band chain and non-elastic string to bungee jump the 500-g load as close to the egg as possible. The design solution was based on the calculation that uses Hooke's law and the conservation law of energy. Students were also introduced to the concept of elastic potential energy. During the lesson, the teacher prepared some rubber bands as bungee cord material to replace the springs, guided the students to do a correct calculation, and stimulated students' critical and creative thinking by asking questions. Students are required to test the spring constant of the rubber band with the initial length decided. They must know that different initial lengths of the rubber bands have different values of the spring constant. In the end, the initial length of the rubber chain also determined their creative solution of predicting the perfect length of the string. When they fail to meet the criteria in which their design could still crack the egg, they should evaluate their design and decide to redesign their model. In this stage, they may consider the arrangement of the rubber chain, either in series or in parallel.

Similarly to what was done by McNair and Hayward (2023), the EDP activity in this study fostered student engagement with STEM and demonstrated the true problem-solving nature of engineering and practical skills that can be applied to everyday life. The beauty of designing bungee cords using Hooke's law was that students might directly predict the perfect length of the cord required by using real calculation, and then apply their calculated value to their design.

The last lesson was focused on how the students communicated their results. The teacher then gave feedback and emphasized some essential concepts that were used in the EDP activity. The teacher showed qualitative and quantitative examples of how to apply the equation in another context. Thus, the main objective of this lesson was to summarize the concepts that have been learned during the activity and to follow up their learning by giving them structured questions.

Students' mastery of concepts

Students' mastery of concepts on the topic of Hooke's law is measured using written quantitative and qualitative tests. The written qualitative test was constructed in the form of conceptual questions that relate to the engineering design process and the material covered in the problem-solving laboratory activity students have done. The average student achievement for these two types of tests is shown in Figure 2.

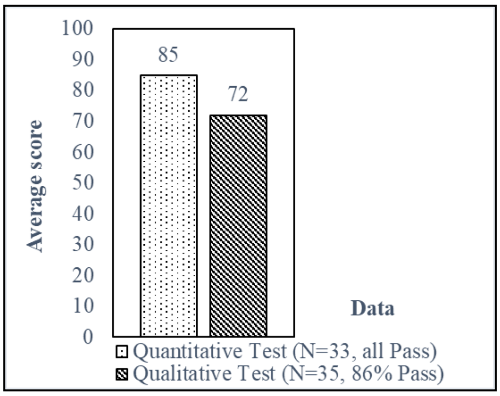
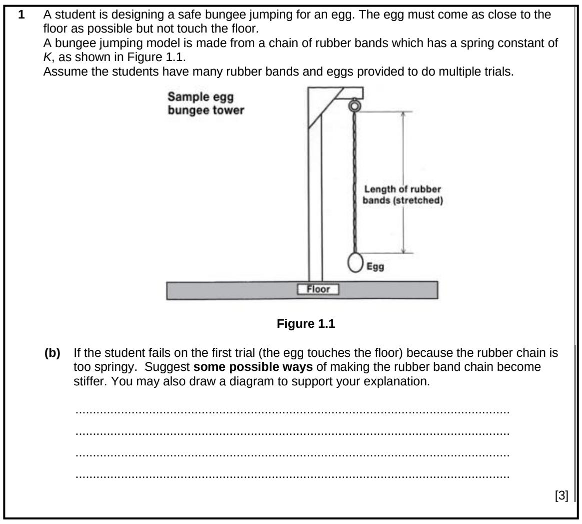


Figure 2. The average post-test score of quantitative and qualitative tests

The quantitative test scored higher than the qualitative test by 13 score points. It indicates that students outperformed in doing calculations compared to expressing reasonings. Despite the results of qualitative tests are lower than quantitative tests, both still exceed the minimum criteria set to be categorized as effective. In addition, these findings also show that students did not demonstrate understanding that comes from memorization when they took the qualitative test as a pop quiz that was administered a month delay from the last time the learning was obtained. It means that their understanding is long-lasting since they experienced a meaningful problem-solving laboratory. In other words, students' achievements showed that the EDP activity of designing bungee cords in the problem-solving lab is effective for teaching Hooke's law. These findings support previous research (Holmes & Wieman, 2018; Holmes *et al*., 2017: Wieman & Holmes, 2015) that laboratory activities are more effective in teaching experimental practices rather than reinforcing the classroom. As well as aligns with the report of Supriyatman *et al*.(2017) that a problem-solving laboratory supports students in constructing a scientific and strong mental model.

Predominant themes of students' reasoning

In the following, we will examine in detail the reasoning patterns in student's thinking of the conceptual questions given. It was chosen because the qualitative test was associated directly with the EDP and the materials covered in the problem-solving laboratory activity. The students' responses to items #1b, #1c, and #2 of the qualitative questions are shown in Tables 1, 2, and 3, respectively. The items #1b, #1c, and #2 of the written pop quiz are shown in Fig. 3, 4, and 5, respectively.



1 A student is designing a safe bungee jumping for an egg. The egg must come as close to the floor as possible but not touch the floor.
A bungee jumping model is made from a chain of rubber bands which has a spring constant of *K*, as shown in Figure 1.1.
Assume the students have many rubber bands and eggs provided to do multiple trials.

Figure 1.1

(b) If the student fails on the first trial (the egg touches the floor) because the rubber chain is too springy. Suggest **some possible ways** of making the rubber band chain become stiffer. You may also draw a diagram to support your explanation.

....
....
....
....

[3]

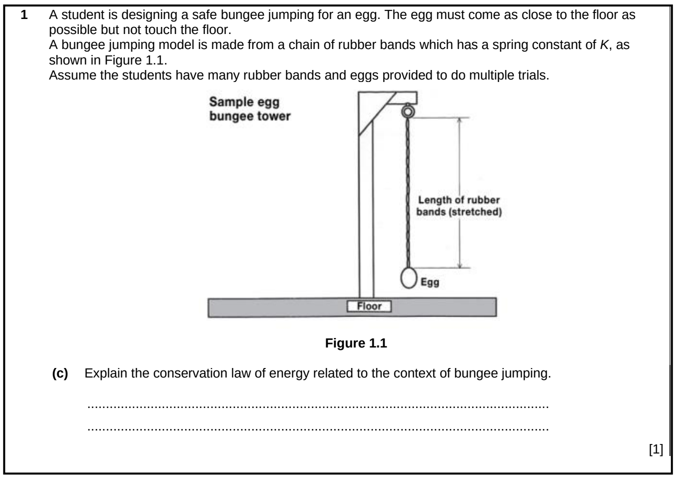
Figure 3. Question #1b of the written pop quiz used in the investigation

Question #1b examines students' creative thinking to find out all possible ways that can be done to modify the characteristics of the rubber band chain. Three possible ways are as follows: (1) double the knots, (2) shorten the chain, and (3) use parallel arrangement.

Table 1. Responses to pop quiz Question #1b

Student's response	Proportion giving response, N=35 (%)
All three correct possible ways	17
Two correct possible ways	57
One correct possible way	23
Other incorrect answers	3

More than half of the students gave two possible ways. They were able to propose a way to make the rubber into parallel chains and shorten the rubber chain, but they failed to find a way to increase the spring constant by increasing the amount of rubber to make knots. Overall, students have been able to understand that changing the initial length of the rubber chain they make produces different values of the spring constant. In addition, the first stage of solving the challenge made them understand that the larger the spring constant value, the stiffer the spring, and the steeper the gradient of the line in the force against the extension graph.



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Assume the students have many rubber bands and eggs provided to do multiple trials.

Figure 1.1

(c) Explain the conservation law of energy related to the context of bungee jumping.

....
....

[1]

Figure 4. Question #1c of the written pop quiz used in the investigation

Question #1c examines students' understanding of the conservation law of energy that is involved in the context of Bungee Jumping. The tendency of students' answers shows that students observed the phenomena partially. They cannot look at the relationship between the changes in gravitational potential energy (equal to mechanical energy) when the jumper is at the initial position and the elastic potential energy of the spring.

Table 2. Responses to pop quiz Question #1c

Response	Proportion giving response, N=35 (%)
GPE becomes EPE	26
GPE becomes KE	6
KE becomes EPE	17
EPE transformed into KE	14
GPE turns to EPE turns to KE	6
GPE turns to KE turns to EPE	6
Other incorrect answers	26

Only a quarter of students were able to answer correctly the energy transformation that occurs when the egg starts to fall until it almost touches the floor. Some of the difficulties shown by students include: (a) not being able to determine the direction of energy changes that occur, (b) not being able to identify all types of energy involved such as gravitational potential energy (GPE), kinetic energy (KE), and elastic potential energy (EPE), and (c) does not realize the existence of conservation of mechanical energy whose magnitude remains constant at every point when the egg moves downwards.

2 A bungee jumping engineer is designing a model of bungee jumping using a spring which has the spring constant of 20 Nm^{-1} and supports the maximum extension of 9 m. He has four 20 Nm^{1} springs available in which each spring can support a maximum extension of 6 m.

Draw a diagram to show how the four springs could be used for this purpose.

[3]

Figure 5. Question #2 of the written pop quiz used in the investigation

Question #2 examines students’ understanding of how to construct an arrangement of springs to meet two criteria, those are the required spring constant and the maximum extension targeted. This question is very interesting to further explore students' understanding of the characteristics of spring series in series and springs in parallel.

Of the 35 students, 38% of students cannot find the equivalent spring constant, and the way to make their arrangement meets the criteria of maximum extension targeted. 51% of students still do not understand the characteristics of spring combination in series and in parallel, in which $\Delta X1 = \Delta X2$ for two springs in parallel and $\Delta X1 + \Delta X2$ for two springs in series.

Regardless of students who answered the question with the correct explanation, some 14% of students indicated that they understood how to find the equivalent spring constant but still did not understand the characteristics of spring combinations in series and in parallel.

Table 3. Responses to pop quiz Question #2

Response	Proportion giving response, N=35 (%)
Correct diagram	77
with correct explanation	48
with a partially correct explanation	14
with incorrect explanation	6
without explanation	9
Other incorrect answers	23

Pedagogical benefits

Direct student involvement in EDP activities can address several skills such as science process skills, data collection skills, and practical skills (laboratory techniques). When students complete each stage of the challenge in designing bungee cords, they indirectly interact with each other as group members. This certainly increases their skills in working together to complete group tasks well. This is confirmed by the results of previous research where bungee jumping EDP activities can also improve students' critical thinking skills (Teevasuthonsakul *et al*., 2017) and students' science process skills (Haryadi & Pujiastuti, 2020).

Other benefits are obtained, for example, when students realize that the different thicknesses of each piece of rubber will certainly affect the results obtained. They are required to be able to find solutions to these technical problems using practical techniques. Students must be able to find the limitations of the tools and procedures they use and propose improvements to get better results. Apart from problem-solving skills and understanding concepts, all skills such as science process skills, data collection skills, practical skills (practicum techniques), and communication skills, can be addressed with this bungee jumping design activity.

Conclusion

This study examines the effectiveness of designing a bungee cord to teach Hooke's law in a problem-solving lab. The engineering design process was described in this activity. Results from two different sets of instruments that were administered at different time intervals consistently showed that the average scores for students' performances passed the minimum criteria specified. All students (N=33) passed the quantitative question test, but only 86% of students (N=35) passed the qualitative question test. Nevertheless, it can still be said that the EDP activity of designing bungee cords in the problem-solving lab gave a meaningful experience to students in the learning of Hooke's law.

Besides that, this hands-on pass-fail test of the student solutions also provides them with more meaningful real experiences in applying physics calculation to a real solution. This activity can be used to not only teach conceptual understanding and mastery of concepts but also science process skills, communication skills, practical skills (lab technique), and teamwork. However, it still needs continuous efforts to further investigate and overcome students' conceptual difficulties shown in the findings. Information obtained from this study is useful for designing an appropriate instructional method and curricular materials in the future in learning Hooke's law.

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References

Bao, L. & Redish, E. F. (2006). Model analysis: representing and assessing the dynamics of student learning. *Phys. Rev. Phys. Educ. Res.* 2(1), 010103-1 – 010103-16. doi: https://doi.org/10.1103/PhysRevSTPER.2.010103

Chiapetta, E. L. & Koballa, T. R. (2010). *Science instruction in the middle and secondary schools: developing fundamental knowledge and skills - 7th ed.* New York: Allyn & Bacon.

Etkina, E., Heuvalen, V., Brookes, D. T., & Mills, D. (2002). Role of experiments in physics instruction – A process approach. *Phys. Teach.* 40(6), 351 – 355. doi: https://doi.org/10.1119/1.1511592

Fitzgerald, M. & Brand, L. (2004). Egg bungee jump! A pre-engineering activity based on calculation, risk, failure, success, and serendipity! *Applied Science* Jan. 15 – 17. Retrieved from https://eric.ed.gov/?q=LAWS+AND+OF+AND+NEWTON&pg=7&id=EJ956774

Francis, G. E., Adams J. P., & Noonan, E. J. (1998). Do they stay fixed? *Phys. Teach.* 36 (6), 488 – 490. doi: https://doi.org/10.1119/1.879933

Gunawan, G., Nisrina, N. Suranti, N. M. Y., Herayanti, L., & Rahmatiah, R. (2018). Virtual laboratory to improve students' conceptual understanding in physics learning. *MISEIC 2018 Journal of Physics: Conf. Series* 1108, 012049-1 – 012049-6. Doi: 10.1088/1742-6596/1108/1/012049

Haryadi, R. & Pujiastuti, H. (2020). Use of bungee jumping with STEM approach to improve science process skills. *National Conference on Mathematics Education (NaCoME)*, *Journal of Physics: Conf. Series* 1480, 1 – 7. Doi: 10.1088/1742-6596/1480/1/012073

Heck, A. & Uylings, P. (2020). A Lagrangian approach to bungee jumping. *Phys. Educ.* 55, pp. 1 – 11. Doi: 10.1088/1361-6552/ab5cdc

Heck, A., Uylings, P., & Kedzierska, E. (2010). Understanding the physics of bungee jumping. *Phys. Educ.* 45(1), 63 – 72. Doi: 10.1088/0031-9120/45/1/007

Holmes, N. G. & Wieman, C. (2018). Introductory physics labs: we can do better. *Physics Today* 71(1), 38 – 45. Doi: https://doi.org/10.1063/PT.3.3816

Holmes, N. G., Olsen, J., Thomas, J. L., & Wieman, C. E. (2017). Value added or misattributed? A multi-institution study on the educational benefit of labs for reinforcing physics content. *Phys. Rev. Phys. Educ. Res.* 13(1), 020103-1 – 020103-12. Doi: 10.1103/PhysRevPhysEducRes.13.010129

Jolly, A. (2017). *STEM by design: strategies and activities for grades 4 – 8*. New York: Routledge.

Kagan, D. & Kott, A. (1996).The greater-than-*g* acceleration of a bungee jumper. *Phys. Teach.* 34 (8). 368 – 373. Retrieved from https://eric.ed.gov/?id=EJ531419

McNair, S. A. M. & Hayward, S. J. (2023). How do engineers do that?—An interactive introduction to the engineering design process for secondary age school pupils. *Phys. Educ.* 58 045002. doi 10.1088/1361-6552/accef3

Menz, P. G. (1993). The physics of bungee jumping. *Phys. Teach.* 31(8). 483 – 487. Retrieved from https://iopscience.iop.org/article/10.1088/0031-9120/29/4/012/pdf

Miller, K., Lasry, N., Chu, K. & Mazur, E. (2013). Role of physics lecture demonstrations in conceptual learning. *Phys. Rev. Phys. Educ. Res.* 9(2), 020113-1 – 020113-5. Doi: 10.1103/PhysRevSTPER.9.020113

OECD. (2019a). *PISA 2018 Results (Volume I): What Students Know and Can Do.* PISA. OECD Publishing, Paris. Doi: https://doi.org/10.1787/5f07c754-en.

Otero, V. K. & Meltzer, D. E. (2017). The past and future of physics education reform. *Physics Today* 70(5), 50 – 56. Doi: https://doi.org/10.1063/PT.3.3555

Sriyansyah, S. P., Sihole, T., & Nurhasanah, F. (2023). Gender differences in students' numerical literacy in the STEAM classroom. *The 1st International Conference on Science Education and Sciences. AIP Conf. Proc.* 2619, 110003-1–110003-6. Doi: https://doi.org/10.1063/5.0122549

Supriyatman, Suhandi, A., Rusdiana, D., Samsudin, A., Wibowo, F.C. (2017). Problem-solving laboratory-based course development to improve mental model and mental modeling ability. *Proceedings of the First Indonesian Communication Forum of Teacher Training and Education Faculty Leaders International Conference on Education 2017, Advances in Social Science, Education and Humanities Research,* 174, 4 – 7. Doi: 10.2991/ice-17.2018.2

Teevasuthonsakul, C., Yuvanatheeme, V., Sriput, V., & Suwandecha, S. (2017). Design steps for physic STEM education learning in secondary school. *Siam Physics Congress 2017 (SPC2017)*, *Journal of Physics: Conf. Series* 901, 1 – 4. Doi: 10.1088/1742-6596/901/1/012118

Tretter, T. (2012). Taking the leap: A classroom bungee jump activity helps students understand physics concepts. *The science teacher*, April/May, 53 – 57.

Trout, K. P. & Gaston, C. A. (2001). Active-learning physics experiments using the Tarzan Swing. *Phys. Teach.* 39 (3), 160 – 163. Doi: https://doi.org/10.1119/1.1364061

Volkwyn, T. S., Allie, S., Buffler, A., & Lubben, F. (2008). Impact of a conventional introductory laboratory course on the understanding of measurement. *Phys. Rev. Phys. Educ. Res.* 4(1), 010108-1 – 010108-10. Doi: https://doi.org/10.1103/PhysRevSTPER.4.010108

Wellhöfer, L. & Lühken, A. (2022). Problem-Based Learning in an Introductory Inorganic Laboratory:

Identifying Connections between Learner Motivation and Implementation. *J. Chem. Educ.* 99, 864−873. https://doi.org/10.1021/acs.jchemed.1c00808

Wieman, C. & Holmes, N. G. (2015). Measuring the impact of an instructional laboratory on the learning of introductory physics. *Am. J. Phys.* 83(11), 972 – 978. Doi: https://doi.org/10.1119/1.4931717

Wittmann, M. C., Steinberg, R. N., & Redish, E. F. (2003). Understanding and affecting student reasoning about sound. *Int. J. Sci. Edu.* 25 (8) ,991 – 1013. Retrieved from https://arxiv.org/ftp/physics/papers/0207/0207031.pdf