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Proceedings of ICPRSE 2025

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Preface

The Proceedings of ICPRSE 2025 contains papers presented at the 3rd International Conference on Physics and Related Science Education. This conference was held in Divčibare from October 30 to November 1, 2025.

The conference brought together researchers, didacticians and practitioners from across the region with the aim of networking and exchanging knowledge about education, pedagogical technologies, and educational innovations. The presented papers cover several topics from innovative approaches in the implementation of school and laboratory experiments, application of new technologies and technological innovations in the teaching of physics and related sciences, to the student-centered learning and teacher (mentor) training.

The breadth of issues in physics education and related sciences indicates the need for greater networking and greater interdisciplinarity, therefore, special thanks to the authors and conference participants for their valuable contributions, as well as to committees and local hosts for their dedication in making this event possible.

The ICPRSE2025 International Scientific Committee consists of lecturers and researchers from the region. All papers were reviewed to ensure the quality of the final publication. During this process, the following criteria were evaluated: relevance of content, clear structure, clarity, and originality. Authors are responsible for the reliability of the statements, respect for copyright and ethical norms of scientific and professional writing.

Употреба " pametnog " мобилног телефона у настави физике – РНУРНОХ апликација

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Апстракт. Циљ овог рада је да покаже како се мобилни телефон, који се често сматра фактором ометања у настави, може претворити у користан дидактички алат у настави физике. Савремени телефони садрже бројне сензоре (акцелерометар, жироскоп, магнетометар, луксметар и др.), што их чини погодним за експериментална мјерења. У раду је представљена бесплатна апликација „Phurphox“, која pametni телефон претвара у преносиви мултифункционални мјерни уређај. Она омогућава прикупљање и анализу података директно на телефону или у реалном времену на другом уређају, а доступна је и за Android и за iOS. Приказани су и примјери једноставних експеримената које наставници могу користити како би физику учинили занимљивијом и привлачнијом ученицима.

Кључне речи: мобилни телефон, настава физике, „Phurphox“ апликација.

УВОД

Развој мобилне телефоније донио је значајне промјене у савременом друштву и отворио нове могућности у области образовања. Данас више милијарди људи користи мобилне уређаје и интернет, а ова масовност употребе отвара питања на који начин се може омогућити укључивање ових уређаја у наставни процес и како их учинити ефикасним средством учења. Савремени телефони својим функционалностима, капацитетом меморије и брзином процесора парирају рачунарима, а по неким карактеристикама их и премашују, јер омогућавају приступ информацијама у сваком тренутку и на било којем мјесту. Иако постоји извјесна доза отпора у друштву према њиховој примјени у настави, они представљају приступачну и већ широко доступну технологију која може значајно унаприједити образовни систем без додатних трошкова (Gábor & Péter, 2015).

Истраживања показују да примјена мобилних уређаја у настави повећава мотивацију ученика и подстиче нове облике интеракције између ученика, наставника и технологије. Ипак, коришћење мобилних телефона у образовању мора имати јасно дефинисану сврху – оно треба да допринесе учењу на нов, занимљив и дјелотворан начин. Наставници притом морају пажљиво процијенити могућности својих ученика, као и услове за примјену, јер само уз добро осмишљено планирање могу се постићи жељени резултати (Кojičić, 2012).

Поједина истраживања показују да мобилни телефони у учионици могу бити и средство учења и извор ометања. Иако већина наставника има јасна правила везана за коришћење мобилних уређаја како би смањила ометања, само око половине их сматра да те мјере заиста функционишу. Аутори истраживања истичу да би мобилни уређаји могли бити успјешно интегрисани у наставу како би повећали мотивацију ученика и подстакли активно учење, али за то је неопходно јасно одређивање циљева, добро планирање и процјена спремности ученика (Morris & Sarapin, 2020).

У неким истраживањима показано је да студенти генерално имају либералнији став према коришћењу мобилних телефона у учионици. Они сматрају да уређаји могу бити корисни за учење, али и за приступ информацијама и комуникацију током наставе, те често користе телефоне више него што је дозвољено (Stachowski, Kathryn L. Hamilton, & Bertram, 2020).

Резултати су показали да су ученици који су више користили паметне телефоне остваривали боље академске резултате у поређењу са ученицима са нижим нивоом употребе. Ови резултати указују на то да употреба паметних телефона може представљати потенцијалну неједнакост у образовним приликама међу ученицима основних школа. Такође, понашање у вези са паметним телефонима показало се као посреднички фактор који утиче на академске перформансе. Мање прилика за приступ паметним телефонима може негативно утицати на ефикасност у учењу и академске резултате. Аутори сугеришу да наставници основних школа треба да буду свјесни овог питања и да користе ове налазе као смјернице за обликовање образовних политика и пракси које укључују употребу паметних телефона у образовним активностима (Wang, Hsieh, & Kung, 2023).

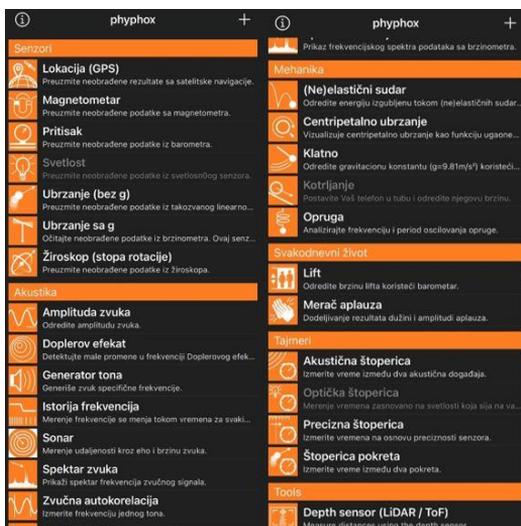
Једна од данас многобројних доступних апликација која може послужити у настави физике је апликација „Phyphox“, која претвара паметни телефон у лабораторијски уређај за физичке експерименте, користећи уграђене сензоре као што су акцелометар, микрофон, магнетометар и барометар. Она омогућава извођење експеримената из области механике, звука, оптике и магнетизма, прикупљање података у реалном времену и њихову анализу, као и даљинско управљање експериментом. „Phyphox“ подржава и креирање прилагођених експеримената, чиме подстиче активно и вођено истраживачко учење, побољшава креативно размишљање и академске резултате ученика (Imtinan & Kuswanto, 2023).

Апликација „Phyphox“ лако је доступна и потпуно бесплатна на оба оперативна система (Android и iOS). Име апликације је сложеница од енглеских ријечи “physical phone experiments” (физички експерименти са телефоном), а настала је у Њемачком универзитету у Ахену (RWTH Aachen University).

У наставку ћемо представити два једностана експеримента који се помоћу апликације „Phyphox“ и паметног телефона (уз интеграцију са рачунаром) могу извршити мјерења, како у школским условима, тако и кућним условима – када се експерименти дају у форми домаћих задатака.

Треба нагласити да су могућности употребе „Phyphox“ апликације у извођењу физичких експеримената огромне, а детаљна упутства за њихово извођење су лако доступна на интернету. Основни ограничавајући фактор заправо представља сам уређај мобилног телефона, јер неки сензори нису физички присутни код јефтинијих уређаја. Осим тога приступ сензора свјетла на Apple уређајима није могућ, јер ова компанија то не дозвољава. Такође, нису сви сензори на свим уређајима једнако прецизни, што отвара питања тачности добијених резултата. Ипак, у школским и

кућним условима, који се свакако не сматрају научним, едукативни ефекат може бити одличан.



Слика 1. Приказ дисплеја апликације

Експеримент 1: Мјерење зависности центрипеталног убрзања од угаоне брзине

Најједноставнији облик криволинијског кретања материјалне тачке је кружно кретање. У свакој тачки путање правац тренутне брзине се поклапа са тангентом на путању. Вектор брзине и радијус вектор су међусобно нормални.

Врсте кружног кретања:

- Равномијерно кружно кретање - интензитет брзине се не мијења и остаје константан;
- Промјенљиво кружно кретање - интензитет брзине се мијења.

Уколико се материјална тачка креће по кружници сталним интензитетом брзине, говоримо о равномјерном кружном кретању. Пошто је у том случају бројна вриједност (интензитет) брзине константна, тангенцијално убрзање је једнако нули. Ипак, како се правац брзине непрекидно мијења, јавља се нормално, односно центрипетално убрзање (a_n). Правац овог убрзања поклапа се са полупречником кружнице, док је смјер увијек усмјерен ка њеном центру.

Круто тијело дефинише се као тијело које задржава сталан облик и запремину. Дјелићи крутог тијела при ротацији описују кружне путање, а све те кружнице леже у међусобно паралелним равнима. При ротационом кретању различите тачке тијела за исто вријеме прелазе различите путеве. Најдужи пут прелазе оне тачке које се налазе најудаљеније од осе ротације. Исто важи и за њихове помјераје. Сходно томе, како су пријеђени путеви различити, различите су и брзине појединих тачака. У случају промјенљивог кретања, промјене брзина у истом временском интервалу такође се разликују, што условљава различита убрзања.

Због наведених особености ротационог кретања, неопходно је увести нове физичке величине ради његовог адекватног описа. Једна од основних је угаона брзина (ω), која представља величину којом се описује брзина ротације крутог тијела. Веза угаоне брзине и нормалног убрзања:

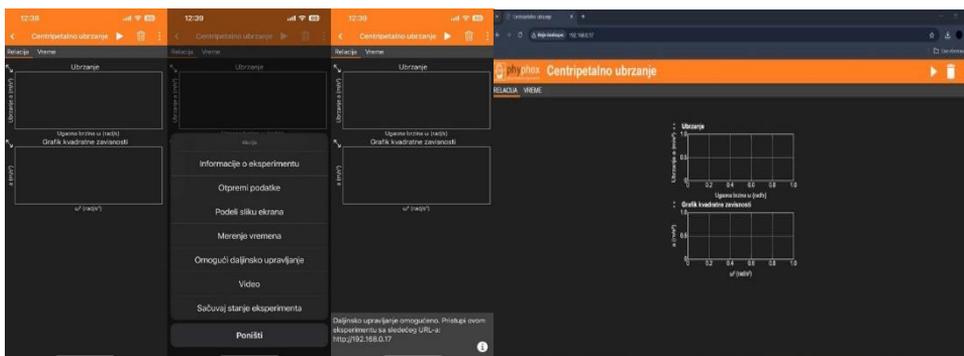
$$a_n = \omega^2 r$$

Дакле, центрипетално убрзање расте са квадратом угаоне брзине и ову зависност ћемо да потврдимо помоћу мобилног телефона и „Phurphox“ апликације.

Поступак

У апликацији „Phurphox“ потребно је изабрати опцију „Centripetal acceleration“. Након тога активира се функција „Enable remote access“, чиме се омогућава контролisaње процеса мјерења путем рачунара. У интернет претраживач на рачунару уноси се генерисана URL адреса, чиме се успоставља веза са мобилним уређајем.

Мобилни телефон поставља се у поклопац лонца или шерпе, док се само мјерење врши преко рачунара. Током ротације поклопца, сензор жироскопа у мобилном телефону прикупља податке о угаоној брзини, а акцелерометар региструје вриједности линеарног убрзања. Нагиб добијеног графикана представља прецизну мјеру удаљености између центра ротације и положаја MEMS^{*} инерционог сензора покрета, који интегрише функције акцелерометра и жироскопа.



Слика 2. Поступак активирања апликације и управљање мјерењима помоћу рачунара

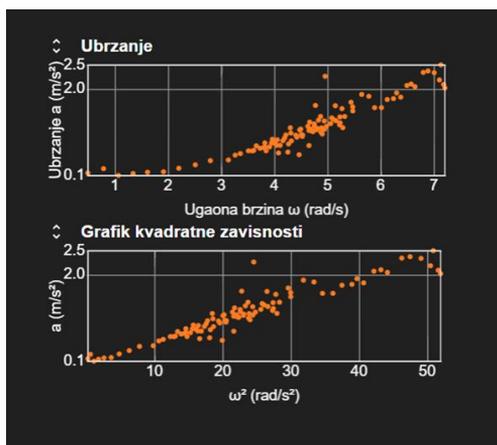
Заврtimo поклопац и заједно са њим телефон, а на рачунару покренемо мјерења. Наравно, при овом процесу водити рачуна о брзини ротације, облику поклопца и ручице на поклопцу и његовој (не)могућности ротирања. Овдје може да дође до изражаја и креативност и домишљатост ученика који могу да смисле и друге врсте „носача“ мобилног телефона при ротацији.

^{*} Micro Electro Mechanical Systems



Слика 3. Поставка експеримента

Резултати и закључак



Слика 4. Графици зависности a од ω (горњи график) и ω^2 (доњи график)

Добијени графикон има облик квадратне функције, што је било и очекивано на основу теоријских претпоставки. Одступања појединих тачака могу се приписати неравномјерној ротацији мобилног телефона током мјерења. Прецизност експеримента могла би бити значајно унапријеђена коришћењем уређаја који би се ротирао константном угаоном брзином током дужег временског интервала.

Експеримент 2: Истраживање убрзања помоћу акцелератора са 3 осе за детекцију вибрација повезаних са срчаним циклусом

Овај експеримент је одличан примјер интердисциплинарности научних области, у овом случају физике (и појма осцилације) са медицином (органа срца, тј. физиономијом и физиолошком функцијом тог органа). Срце је сложен мишићни орган који се састоји од четири шупљине: горње шупљине чине лијева и десна

преткомора, а доње лијева и десна комора. Мишићни зид – септум – раздваја лијеву од десне преткоморе, односно лијеву од десне коморе. Најчешће се примјењује подјела на лијево и десно срце: лијево срце чине лијева преткомора и лијева комора, а десно срце десна преткомора и десна комора. Оваква подјела одговара начину циркулације крви. У физиолошким условима, крв из лијевог и десног срца се не мијеша.

Лијева комора представља највећу и најснажнију шупљину срца. Њена основна функција је испумпавање крви у највећу артерију организма – аорту, која се преко својих грана разгранави и обезбјеђује снабдијевање читавог тијела крвљу, односно кисеоником и хранљивим материјама.

Проток крви кроз срце омогућен је и регулисан дјеловањем четири залиска (валвула):

- **Трикуспидални залистак** регулише проток крви између десне преткоморе и десне коморе.
- **Пулмонални залистак** контролише пролаз крви из десне коморе у плућну артерију, која је проводи ка плућима.
- **Митрални залистак** омогућава проток крви између лијеве преткоморе и лијеве коморе.
- **Аортни залистак** контролише пролаз крви из лијеве коморе у аорту.

Истовременим грчењем обје преткоморе долази до отварања залиска и преласка крви у коморе, које се шире како би примиле тај волумен. Након тога, контракцијом комора залисци између преткомора и комора се затварају, чиме се спречава повратни ток крви у преткоморе. Истовремено, отварају се залисци између комора и великих артерија, омогућавајући избацивање крви у артеријски систем. Паралелно с тим процесом, преткоморе се шире и примају крв из венског система. Иако лијева и десна страна срца избацују једнаку количину крви, лијева комора ствара знатно већи притисак.

Термин систола односи се на фазу контракције срчаних комора и преткомора, којом се крв потискује у крвне судове. Супротно томе, дијастола означава фазу опуштања срчаних шупљина након систоле, када се оне поново пуне крвљу.

Сеизмокардиограм (СКГ) представља метод који користи акцелерометар за мјерење вибрација тијела повезаних са срчаним циклусом. Ова метода омогућава регистровање механичких сигнала које срце генерише током контракција и пумпања крви. СКГ је графички приказ вибрација које се шире кроз тијело као посљедица контракција миокарда, отварања и затварања залиска, те кретања крви кроз срчане шупљине.

За потребе ових мјерења користе се троосни акцелерометри, високоосјетљиви сензори способни да детектују минималне промјене у убрзању. Они се најчешће постављају на површину коже у пределу грудног коша, гдје се срчане вибрације најлакше региструју.

СКГ има значајну примјену у праћењу срчаних функција код пацијената са хроничним кардиолошким обољењима. Могуће је открити неправилности у срчаним вибрацијама које указују на патолошка стања, као што су атријална фибрилација (AFib) или друге врсте аритмија.

Поступак

Потребно је лећи на леђа и поставити мобилни телефон као што је приказано на слици.



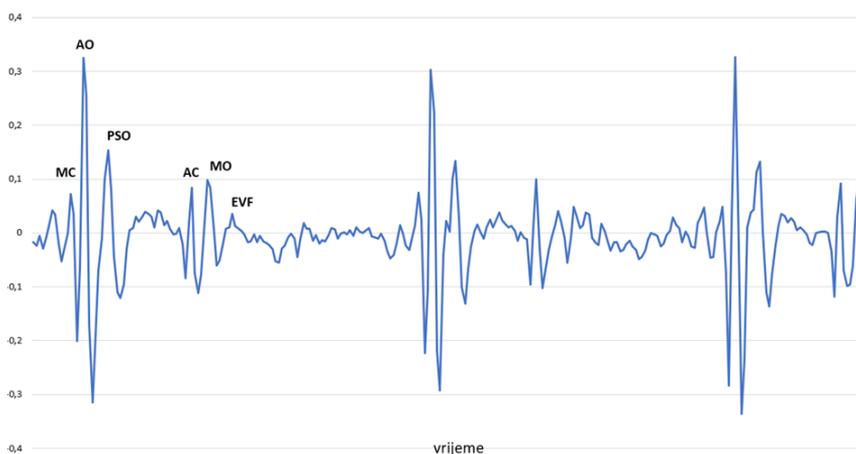
Слика 5. Начин постављања телефона на грудни кош при извођењу експеримента

Резултати и закључак

Фазе срчаног циклуса:

- **MC** (Mitral valve closure) – Затварање митралног залиска.
- **AO** (Aortic valve opening) – Отварање аортног залиска.
- **PSO** (Peak systolic outflow) – Врхунац систолног протока.
- **AC** (Aortic valve closing) – Затварање аортног залиска.
- **MO** (Mitral valve opening) – Отварање митралног залиска.
- **EVF** (Early ventricular filling) – Рана фаза пуњења срчане коморе.





Слика 6. Изглед сеизмокардиограма и карактеристичних фаза срчаног циклуса

Приједлози за још експеримената

У наставку ћемо, у краткој форми, дати још неколико приједлога за извођење физичких експеримената или демонстрационих огледа.

- Експеримент: **Клатно**

Шта треба: комад ужета и мали предмет (кључ, подлошка, каменчић).

Поступак: Повезати предмет на уже и направити клатно. Телефон држати на руци и заљуљати клатно. У „Phyphox“ покренути експеримент "Pendulum" (клатно). Апликација мјери период осцилације помоћу акцелерометра.

Циљ: Научити како период клатна зависи од дужине ужета.

- Експеримент: **Убрзање у вожњи**

Шта треба: телефон и возило (ауто, бицикл, аутобус).

Поступак: Покренути експеримент "Acceleration". Положити телефон хоризонтално у возило. Посматрати граф док возило убрзава, кочи или скреће.

Циљ: Видјети како акцелерометар биљежи промјене кретања у три смјера (x, y, z).

- Експеримент: **Доплеров ефект**

Шта треба: други телефон или уређај који пушта звук одређене фреквенције (нпр. 1000 Hz).

Поступак: Један уређај треба да пусти тон одређене фреквенције. На другом телефону (са „Phyphox“ апликацијом) се покрене експеримент "Doppler". Заједно са другим телефоном се прође поред извора звука брзим ходом или вожњом бицикла.

Циљ: Уочити промјену фреквенције звука када се приближава и када се удаљава од извора звука (тј. потврдити суштину Доплеровог ефекта).

- **Експеримент: Мјерење броја корака**

Шта треба: само мобилни телефон.

Поступак: Покренути експеримент "Step counter". Ходати нормалном брзином хода, у току неколико минута. Апликација броји кораке и биљежи убрзање при сваком кораку.

Циљ: Научити како акцелерометар може препознати образац кретања.

- **Експеримент: Промјена притиска (барометар)**

Шта треба: телефон који има сензор барометра + зграда са спратовима или брдо.

Поступак: Покренути у апликацији експеримент "Barometer". Кренути уз степенице или се попети на брдо. Посматрати како се мијења атмосферски притисак са висином.

Циљ: Показати везу између висине и притиска (барометарска формула).

ЗАКЉУЧАК

Резултати представљених експеримената показују да мобилни телефон, као свакодневни уређај у рукама ученика, може бити ефикасно средство за извођење физичких мјерења и подстицање активног учења. Иако се у образовном контексту често доживљава као фактор ометања, правилно усмјерена примјена мобилног телефона у контролисаним условима може значајно унаприједити наставни процес. Једна од бројних апликација је „Phyphox“, која пружа приступачан и једноставан начин да се ученицима приближе апстрактни физички појмови кроз практична искуства, што резултира већом мотивацијом, креативношћу и развијањем истраживачког духа. Тиме се потврђује да мобилни телефон, уз добро осмишљену педагошку интеграцију, може постати вриједан савезник наставника у реализацији савремене наставе физике.

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Energy for Students: The Hierarchy of Concepts

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Understanding and comprehension of concepts related to energy, its forms, work and heat cause constant problems for students. Surprisingly, even trained physicists have often problems with explanation of energy transformations and transfer, often mistakenly recognized as work, and problems related to dissipation of energy and various aspects of energies related to fields [1-3]. A long list of publications and heated discussions among scholars, published over decennia in European Journal of Physics, American Journal of Physics, journals focused on university level of physics education, as well as in Physics Education and The Physics Teacher, both focused on pre-university level of education, confirm the mentioned problems.

In years of lecturing Methodology of teaching mechanics and thermodynamics I interviewed many students, listened to their explanation of processes related to energy in various circumstances and how they understand them, I found very similar problems as reported in the huge pile of literature mentioned above. Let me quote a few

- Work is strongly associated of perception of physical effort, for example, work is present in walking up the stairs.
- The changes of mechanical energy of the body are necessary related to the work, for example, the skater pushes herself from the wall and starts to move.
- The work-kinetic energy theorem is applied to complex objects and is associated to changes of mechanical energy, for example, acceleration of the car is due to the work of static friction.
- The energy of the object increases/decreases if the mechanical energy of the object increases/decreases.
- Energy can be lost; especially mechanical energy is prone to be lost or destroyed.
- ... and many others.

After years of trying to train students in identification of the presence of work, of distinguishing, when the work-kinetic energy theorem is applicable and when the work-energy in general have to be applied and similar, I would like to share with you a teaching sequence I believe might work for students.

In this presentation we first discuss how to teach energy to students who meet physics concepts related to energy for the first time in compulsory school. The teaching is based on experience of students and the focus on energy as a property of well-defined objects, even more complex ones like a man or a car. At this level also the transfer of energy in form of work and heat is introduced and all criteria for their presence can also be introduced, accompanied with practical experimental work.

In the second part we extend the concept of energy to systems, define systems and consider the role of interactions among the various components of the system, like potential and conservative forces. In many publications authors discuss the proper choice of a system as having a crucial role in exercises [4,5]. In spite of formal position, a teacher has to be able to analyse any system students want to discuss, not only systems which allow easy and straightforward calculations of work, heat and energy transformations. A few examples are given and discussed. This extension is appropriate for the grammar school in preparation for university level.

Finally, in the third part, we extend the concepts introduced at the pre-university level to energy associated to fluids, waves and empty space in general, as considered at the university level. We all know that interactions to distance require fields, gravitational, electric and magnetic, fields of elastic deformation as it is not possible the energy is transferred faster than speed of traveling waves. But even in empty space, waves transfer energy, and energy is associated to the fields. Is there a link between the energy of the field and the energy of the object? As Art Hobson said, “There are no particles there are only fields” [6], how is the energy of the field around the charged particle associated to the changes of potential energy of two charged particles?

Finally, the hierarchy of concepts regarding the level of education and regarding the concepts themselves is discussed. For example, where in the hierarchy of concepts is the concepts called “Mechanical work”? Is it more important for the student to answer the qualitative question, “Was the mechanical work involved in the process”? Or has the student to be able to calculate the amount of work in Joules? Properly introduced hierarchy of concepts also helps avoiding many mistakes in energy considerations of different processes, such as mistaken declaration of integral of the 2nd Newton’s law as a work-energy theorem.

ACKNOWLEDGEMENTS

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From observation to abstraction: empirical strategies in physics education in Slovakia

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Abstract. This paper presents an overview of physics education in Slovak primary schools in the context of the current national curriculum reform. Physics is positioned within the educational area Man and Nature and aims primarily at developing students' scientific literacy, inquiry skills, and critical thinking. The revised curriculum emphasizes empirical strategies, beginning with observation, measurement, and graphical data processing, and gradually progressing toward abstraction and theoretical models. Constructivist approaches, including the use of puzzling situations and cognitive conflict, are central to teaching methods. The paper also discusses the progression of content, highlighting the postponement of particle models to higher grades in accordance with cognitive development. Special attention is given to textbooks and supplementary teaching materials developed within an educational project, including teacher and student worksheets that integrate experiments, methodological notes, and indicators of critical thinking. These resources support teachers in motivating students, addressing misconceptions, and fostering active and meaningful learning. The Slovak experience illustrates both the opportunities and challenges of implementing inquiry-based science education at the primary level.

Keywords: physics education, lower secondary education, scientific literacy, inquiry-based learning, critical thinking.

INTRODUCTION

In 2023, Slovakia entered a new phase of curriculum reform through the adoption of a revised State Educational Program (SEP) [1]. This reform reflects the need to modernize the educational system and prepare pupils for the challenges of the 21st century. Within the field of natural sciences, physics occupies a central role, as it provides pupils with tools to understand natural phenomena and at the same time cultivates scientific ways of thinking. The main aim of this paper is to present how physics is taught in Slovak primary schools, with an emphasis on educational goals, teaching strategies, methods, and the structure of content progression.

THE POSITION OF PHYSICS IN THE SLOVAK EDUCATION SYSTEM

Slovakia's education system is structured into primary education (Grades 1–9) and secondary education. Physics is taught as a separate subject beginning in Grade 6, when

pupils are approximately 11–12 years old. The subject is also present in the lower grades of eight-year grammar schools, which parallel the second stage of primary education. Physics belongs to the educational area Man and Nature, which also includes chemistry and biology. This integration emphasizes interdisciplinary connections and the broader development of scientific literacy [2].

The weekly time allocation for physics in primary schools typically ranges from one to two lessons, depending on the grade level. Despite the relatively modest time frame, physics is expected to contribute significantly to the development of core competencies, including problem solving, experimentation, and data interpretation. The curriculum emphasizes learning about everyday phenomena in a way that is meaningful and developmentally appropriate.

GOALS OF PHYSICS EDUCATION IN PRIMARY SCHOOLS

The overarching aim of physics education at the primary level is the development of scientific literacy [2]. This involves not only acquiring factual knowledge but also fostering the ability to ask questions, design and conduct simple investigations, interpret results, and apply knowledge to new situations.

At the same time, physics teaching supports the development of critical and abstract thinking. Pupils are guided to recognize patterns, relationships between quantities, and general scientific principles. Another important goal is to nurture curiosity and motivation to learn science, which can influence pupils' later decisions to continue studying science and technology.

Cognitive development theories, especially those of Piaget [3], play an important role in shaping the Slovak curriculum. For younger adolescents, it is considered appropriate to build knowledge through direct observation and hands-on activities before introducing abstract theoretical models. This ensures that learning is rooted in pupils' concrete experiences and avoids premature formalism.

TEACHING STRATEGIES AND METHODS

A distinctive feature of physics education in Slovakia is the emphasis on empirical inquiry (Figure 1). Teaching typically follows a sequence that begins with observation and measurement, continues with data processing (often through graphical methods), and culminates in the discovery of relationships between physical quantities and the generalization of conclusions.

Graphical methods are considered particularly valuable. They not only support empirical reasoning but also provide an intermediate step toward abstraction. Graphs serve as a bridge between raw measurements and analytical expressions (formulas), which require higher levels of abstract thinking.

Constructivist principles are central to the teaching approach. Lessons often begin with puzzling or counterintuitive situations that create cognitive conflict. For example, demonstrations with a Cartesian diver or with liquids of different densities challenge pupils' naïve conceptions and stimulate them to seek explanations. Through subsequent investigations, pupils reconcile their prior experiences with scientific explanations.

Returning to the initial demonstrations allows teachers to illustrate how pupils' thinking has evolved.

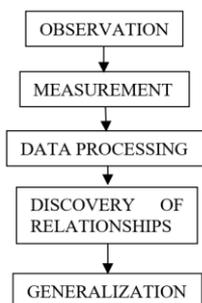


Figure 1. Empirical inquiry scheme

STRUCTURE AND CONTENT PROGRESSION

The revised Slovak curriculum differs significantly from the earlier model implemented before 2008. In the older approach, physics instruction began with atomic structure, which proved to be too abstract for 11- or 12-year-old learners. This led to rote memorization and formalism without true understanding.

The current concept instead begins with macroscopic phenomena that can be observed and measured directly. Pupils start by studying mechanics, properties of matter, sound, and heat through experiments and hands-on activities. The particle structure of matter is postponed until Grade 9, when pupils are cognitively more prepared to grasp abstract models. This progression respects developmental psychology and provides a logical pathway from concrete phenomena to abstract theoretical constructs.

ROLE OF TEXTBOOKS AND TEACHING MATERIALS

The physics textbooks for primary schools authored by Lapitková and colleagues were developed in connection with the previous curriculum reform (before 2023) [4]. However, the pedagogical principles applied in their design—emphasizing a practical-scientific character—remain highly relevant and consistent with the current curricular reform (Figure 2) [5-8]. Unlike earlier textbooks that relied heavily on descriptive explanations, the new materials place greater emphasis on tasks, experiments, and problem-solving activities.

Pupils are encouraged to perform simple measurements, record data, and process results in graphical form. Explanations are concise and often appear after pupils have already engaged with phenomena through experimentation. This approach fosters active learning and aligns with constructivist pedagogy, where knowledge is built rather than passively received.

In addition to textbooks, teachers are supported by methodological guides, workbooks, and digital resources. However, the availability and use of experimental kits and

laboratory equipment vary across schools, which can influence the extent to which empirical strategies are implemented in practice.

As part of a recent educational project, supplementary teaching materials were created to support both teachers and pupils. For each topic in the physics textbook, a teacher's worksheet and a pupil's worksheet were prepared. At the beginning of every topic, the list of teaching aids required for the experiments is provided, with the expectation that these materials are available in experimental kits distributed to schools within the project.



Figure 2. Physics textbooks for elementary school [5-8]

The teacher's worksheet (Figure 3) goes beyond expected pupil answers: it also contains experimental values that pupils should obtain during measurements, as well as their evaluation. Each experiment is accompanied by a clearly stated aim, helping teachers to understand its intended purpose. In some cases, alternative experiments are suggested, providing teachers with ideas for variations in implementation. The methodological guide also includes supplementary experimental and theoretical tasks, carefully selected to promote the development of critical and scientific thinking.

The teacher's worksheet is enriched with methodological notes on motivation, preparation, and the use of teaching aids, as well as on strategies for fostering critical thinking. Specific notes on critical thinking highlight how a given task can contribute to its development, what questions to ask pupils, and how to guide their reasoning. To support this, icons representing individual indicators of critical thinking were integrated into the guide, drawing attention to the cognitive skills targeted by each activity.

Motivational notes are designed to direct pupils' attention to the problem under investigation. They also anticipate common misconceptions and offer suggestions for addressing and overcoming them. Finally, the guide provides teachers with advice on simplified explanations of physical phenomena, which are acceptable at the primary school level, ensuring accessibility without compromising scientific integrity.

CHALLENGES AND PERSPECTIVES

The implementation of the new curriculum presents both opportunities and challenges. On the one hand, it provides a modern and pupil-centered framework that emphasizes

inquiry, problem solving, and critical thinking. On the other hand, its success depends on adequate teacher preparation, professional development, and the provision of teaching resources.

Some schools face difficulties with equipment or lack of laboratory facilities, which may limit opportunities for hands-on experiments. Teacher training is therefore crucial, not only in terms of mastering new content and methods but also in adopting new pedagogical attitudes that support active learning.

3.1 Kondenzácia - UL KEGA 013UK-4/2021

Učiteľ poskytne žiakom kocky ľadu (alebo rozdrvený ľad) v nádobe, aby nedošlo k ich roztopeniu na lavici, prípadne na podlahe. Hrozí nebezpečenstvo šmyku. Do 150 ml vody, pri teplote vzduchu 22,1 °C a relatívnej vlhkosti 48,2 % sme potrebovali 4 kocky ľadu s objemom 6 ml.

d) Dávaj do vody v banke opatrne po jednej kocke ľad. Hneď, ako spozoruješ, že sa na skle banky tvorí rosa, zisti teplotu na teplomere.
Napiš si do zošita teplotu, kedy sa začala tvoriť rosa $t_r = 9,1$ °C

Žiaci by mali mať približne rovnaké hodnoty teploty vody v banke, pri ktorých sa začala tvoriť rosa, pretože v miestnosti je rovnaká relatívna vlhkosť a rovnaká teplota vzduchu. Žiaci by mali priebežne premiešavať vodu v banke špajdlou.

Odpovedz (Lapitková et al., 2010, s. 33):

- 1.** Aká bola teplota vody v banke, pri ktorej sa vodná para zo vzduchu začala skvapalňovať?
Teplota vody v banke, pri ktorej sa vodná para začala skvapalňovať, bola teplota tvorby rosy 9,1 °C.

Výsledky experimentu závisia od podmienok v triede – teploty vzduchu a relatívnej vlhkosti. V našom pokuse pri teplote vzduchu 21,2 °C a relatívnej vlhkosti 48,2 % bola teplota tvorby rosy 9,1 °C.

- 2.** Predstav si, že by bolo v triede viac vodných pár ako pri tomto pokuse. Aká by musela byť teplota vody v banke oproti nameranej teplote, aby sa vodná para vo vzduchu začala skvapalňovať?
Ak by bolo vo vzduchu v triede viac vodných pár ako pri tomto pokuse, tak teplota vody by musela byť oproti nameranej teplote vyššia.

Figure 3. A sample worksheet for a teacher

Looking forward, the Slovak experience highlights the importance of aligning curriculum, textbooks, and teacher education. Continued research and international collaboration could further support the development of effective physics teaching strategies and ensure that reforms lead to lasting improvements in pupil outcomes.

CONCLUSION

Physics education in Slovak primary schools is undergoing a significant transformation. The new curriculum emphasizes empirical inquiry, constructivist approaches, and the gradual progression from observation to abstraction. Graphical methods, experiments, and cognitive conflict are used as central strategies to foster scientific literacy and critical thinking.

By respecting pupils' cognitive development and engaging them in active learning, Slovak physics education aims to provide a foundation for lifelong learning and scientific understanding. Although challenges remain in terms of resources and teacher support, the reform represents a meaningful step toward aligning education with the needs of the 21st century.

ACKNOWLEDGEMENTS

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Експерименти за испитивање капацитативног и индуктивног отпора

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Апстракт. Наизменична струја је укључена у свим наставним програмима у Европи. Капацитативни отпор, индуктивни отпор и импеданција су укључени у врло малом броју наставних програма, а у још мање предвиђају се експерименти за посматрање или испитивање ових физичких величина. Овај рад презентира већи део експеримената који ученици могу да раде или могу наставници да користе у облику демонстрационих опита. Експерименти су интересантни и не траже посебне предзнања или експерименталне вештине. Шта више, резултати су такви да могу врло лако иницирати когнитивни конфликт и развој критичког мишљења.

Кључне речи: експерименти, индуктивни отпор, капацитативни отпор, импеданција, фазно померање.

УВОД

Наизменична струја се изучава у средњем образовању у свим државама Европе. Слично је и у државама у нашем окружењу. У Републици Србији и Републици Хрватској, наизменичне струје се уче у трећем разреду гимназије [1, 2].

У Републици Македонији, наизменичне струје се уче у другом разреду гимназије [3].

Нажалост, у наставним програмима или у било ком другом материјалу за наставнике и ученике експерименти из овог дела физике или се уопште не предлажу или се предлажу елементарне демонстрације, које показују врло мало и које не потиче мисловни процес код ученика. Према наставном програму за физику у Републици Србији, препоручени демонстрациони огледи са наизменичном струјом су: генератор-пренос енергије од извора до потрошача, фазни померај наизменичне струје и демонстрациони трансформатор. У наставном програму у Републици Хрватској нема препоручених експеримената који се односе на наизменичну струју. Али, на сајту и-наставе Министарства знаности и образовања, у видео лекцијама постоје експерименти [5]. У Републици Македонији предлажу се демонстрације које укључују посматрање осцилограма наизменичне струје, промену индуктивног

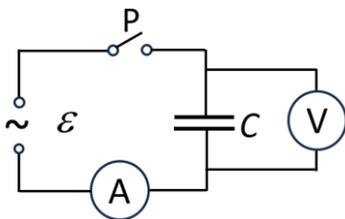
отпора, промену капацитативног отпора, модел трофазног генератора и рад трансформатора.

ЕКСПЕРИМЕНТИ ЗА ИСПИТИВАЊЕ КАПАЦИТАТИВНОГ И ИНДУКТИВНОГ ОТПОРА

Овај рад предлаже неколико експеримената са наизменичном струјом. Експерименти који могу да се раде на часу су једноставни и не траже од ученика да поседује посебне експерименталне вештине. За извођење део ових експеримената чак није потребна специјална и скупа опрема, већ обични амперметри, волтметри и извор наизменичне струје, који се могу наћи у сваком физичком кабинету.

Зависност капацитативног отпора од капацитета кондензатора

За овај експеримент потребни су кондензатор, амперметар, волтметар, прекидач и извор наизменичне струје. Од ових елемената се формира струјно коло чија шема је приказана на Слици 1. а.



а)



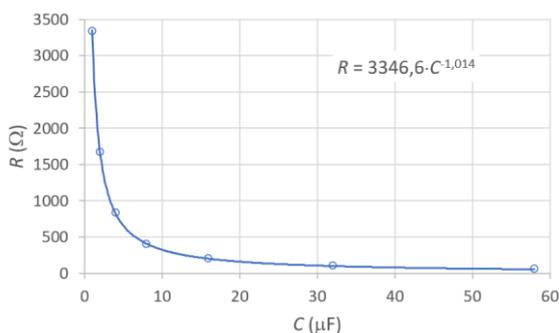
б)

Слика 1. Шема и физичка изведба струјног кола за испитивање капацитативног отпора од капацитета кондензатора

Препоручује се употреба блок кондензатора. Може се користити и електролитски кондензатор ако је његов радни напон пуно већи од напона на извору. У противном, постоји опасност да се кондензатор оштети. Изведба ове шеме је дата на Слици 1.б. У овом случају употребљен је само амперметар, а напон се чита на скали извора. Мења се вредност капацитета и мери се напон и јачине струје. Помоћу Омовог закона једноставно се може израчунати капацитативни отпор:

$$R = \frac{U}{I}$$

На сл.2 је дат графички приказ експерименталних резултата обрађених у Excel-у. Фитовање резултата показује да је степен капацитета износи 1,014, што је врло близу теоријској вредности 1.

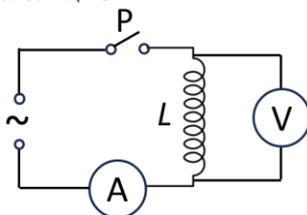


Слика 2. Графички приказ експерименталних резултата за зависност капацитивног отпора од капацитета кондензатора

За испитивање зависности од фреквенције потребан је сигнал генератор. Школски генератори обично имају малу снагу, па је јачина струје која тече доста мала и грешке мерења су доста велике. Зато се препоручује да се овај део истраживања уради квалитативно и да се увиди раст јачине струје са растом фреквенције. Притом треба одабрати фреквентни опсег у коме ће инструмент, односно амперметар, давати добре вредности. Ови инструменти су пројектовани за рад на фреквенцијама реда величине десетина херца. Ако је фреквенција испод десет херца, онда игла на амперметру почиње да осцилује под утицајем промене струје. Ако је фреквенција струје око стотину херца и више, онда игла не може довољно брзо да реагује на промене, амперметар почиње да прави велике грешке и отклон почиње да пада са повећањем фреквенције, што је нелогично. Стога, фреквентни опсег у коме ће се зависност испитати треба да буде између 20 Hz и 80 Hz. На Youtube-у може се видети видео изведба ових експеримената [6].

Зависност индуктивног отпора

За овај експеримент потребни су калем, гвоздено језгро за калем, сијалица, амперметар, извор праве струје, извор наизменичне струје, прекидач и жице. Шема овог струјног кола је дата на Слици 3.



Слика 3. Шема струјног кола за испитивање индуктивног отпора

На место амперметра, може се укључити сијалица. Најбоља варијанта је ако се у серији укључе и амперметар и сијалица. У првој фази експеримента циљ је да се упореди рад кола са правом и наизменичном струјом и не мери се никаква зависност.

Укључује се извор праве струје, сијалица се пали и у калему се ставља гвоздено језгро. Притом се не примећује никаква промена у колу. Ако се експеримент

понови, али са извором наизменичне струје, примећује се нагли пад јачине струје, сијалица сија слабије. Ако се језгро извади из калема, сијалица поново сија пуним сјајем. Промена је врло ефектна и драстична и врло лако може да побуди дискусију и когнитивни конфликт. Овај експеримент се може видети на Youtube-у [7].

Испитивање зависности индуктивног отпора је сложеније од оног код капацитативног отпора, зато што истовремено је активан и омски отпор, па сва мерења ће имати систематску грешку која ће бити једнака омском отпору. Да би се смањило утицај омског отпора треба употребити калем чији индуктиван отпор је пуно већи од омског отпора. У противном мора се прво измерити омски отпор, а онда индуктивни. Ако се калем прикључи на извор праве струје, мере се напон U_p и јачина струје I_p и помоћу Омовог закона може се добити омски отпор $R_0 = \frac{U_p}{I_p}$. Ако

се калем прикључи на извор наизменичне струје измере се напон U_n и јачина струје I_n помоћу Омовог закона може се добити импеданција калема, $Z = \frac{U_n}{I_n}$. Одатле може

се добити индуктивни отпор $R_L = \sqrt{Z^2 - R_0^2}$. Ако је потребно, може се одредити и индуктивност калема. Пошто је индуктивни отпор $R_L = \omega \cdot L = 2\pi f \cdot L$, може се израчунати индуктивност као $L = \frac{R_L}{2\pi f}$ ($f=50$ Hz, фреквенција градске мреже).

ВРЕМЕНСКА ПРОМЕНА НАПОНА И ЈАЧИНЕ СТРУЈЕ КОД КОНДЕНЗАТОРА И КАЛЕМА

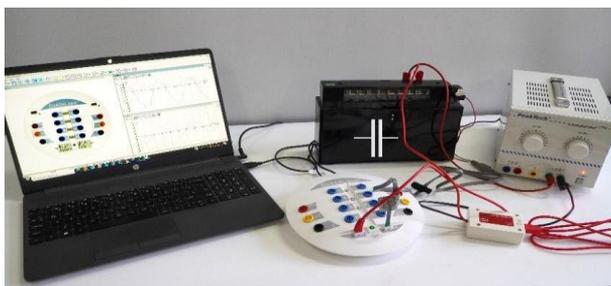
За следеће експерименте потребна ја опрема којом може да се следи временска промена напона и јачине струје. За такво нешто може се употребити осцилоскоп или сензори са одговарајућим софтвером, драјвером и компјутером.

У нашем случају примењен је систем Coach 7, који је намењен за школска истраживања и за студентске експерименте на универзитетском нивоу.

Временска промена напона и јачине струје код кондензатора

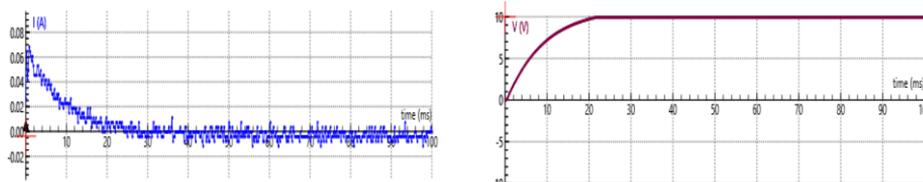
Кондензатор у колу праве струје

Кад питате ученике дали права струја тече у колу са кондензатором, они ће одговорити негативно. Али једносмерна струја може тећи у колу са кондензатором. Да би ово проверили потребно је исто струјно коло као оно на Слици 1.а, при чему је потребан извор праве струје, а на место волтметра и амперметра, прикључују се одговарајући сензори. Физичка изведба овог кола је дата на Слици 4.



Слика 4. Струјно коло за праћење временске промене напона и јачине струје у колу са кондензатором. Напон и јачина струје се следе помоћу система Coach 7.

Резултат овог експеримента је дат на Слици 5.



а) Временска промена јачине струје

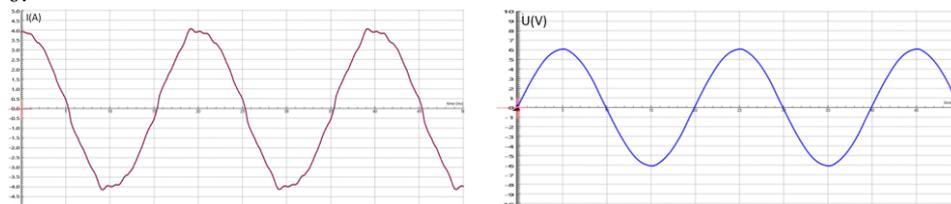
б) Временска промена напона

Слика 5. Временска промена јачине струје и напона у колу са кондензатором и извором праве струје у моменту кад је коло укључено.

Јасно се види да прво почиње да тече струја у колу, чија јачина пада са временом, док напон касни у односу на струју и расте током времена, при чему за око 25 ms, кондензатор је потпуно наелектрисан, струја престаје да тече, а напон је максималан. Шум код сигнала струје је доста велик, зато што је струја слаба. Њена максимална вредност у почетку је око 0,07 А или 70 mA. Може се добити сигнал са мањим шумом ако се употреби кондензатор са већим капацитетом, зато што је у том случају капацитативни отпор мањи и струја је већа.

Кондензатор у колу наизменичне струје

Опрема и струјно коло за овај експеримент се разликују само у извору, који треба да буде са наизменичном струјом. Резултат овог експеримента је дат на Слици 6.



а) Временска промена јачине струје

б) Временска промена напона

Слика 6. Временска промена јачине струје и напона у колу са кондензатором и извором наизменичне струје.

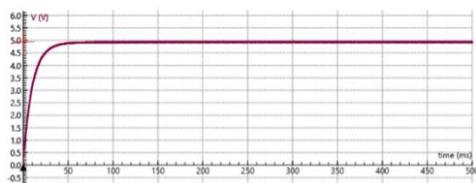
Као и у претходном експерименту, јасно се види да прво протиче струја, а напон касни у односу на струју, при чему овде се види да је фазно кашњење тачно $\pi/2$. Слично као и у претходном експерименту, капацитет кондензатора утиче на капацитивни отпор кола, што са своје стране утиче на јачину струје. Са добро одабраном вредношћу капацитета може се добити добар сигнал са малим шумом.

Временска промена напона и јачине струје код калема

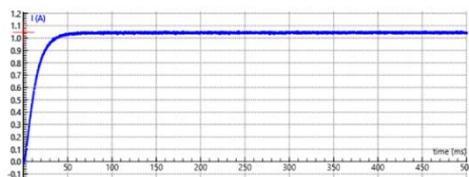
Калем у колу праве струје

Шема струјног кола за овај експеримент је дата на Слици 3, при чему на место амперметра и волтметра су прикључени одговарајући сензори са системом Coach 7.

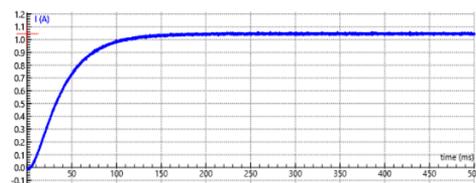
Резултат овог мерења може се видети на Слици 7. На Слици 7.а је приказ временске промене напона на калему, а на Слици 7.б јачине струје која тече кроз калем у моменту укључења. Може се видети да су напон и струја синхронизовани и да струја достиже максималну вредност за око 70 ms. Мора се узети у обзир да индуктивност износи само 9 mH, што значи да индуктивни отпор не утиче пуно на режим рада струјног кола. Ако се индуктивитет повећа на 80 mH, онда промена напона остаје иста, али струја касно више и достиже максималну вредност за око 150 ms (Слика 7.в). Ако се индуктивитет калема драстично повећа, на 1160 mH, промена напона и даље остаје иста, али промена јачине струје је драстично различита у односу на претходне две промене (Слика 7.г). У овом случају, јачина струје не достиже максималну вредност у посматраном временском периоду од 500 ms. Даље мерење показује да је потребно време од око 1 s да би струја постигла максималну вредност. Ово је одличан резултат и види се да струја касни у односу на напон.



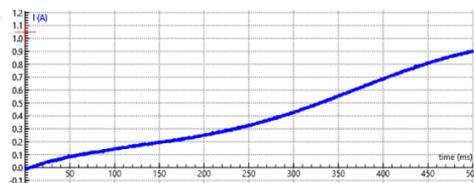
а) Временска промена напона



б) Временска промена јачине струје за калем са индуктивитетом од $L=9\text{ mH}$



в) Временска промена јачине струје за калем са индуктивитетом од $L=80\text{ mH}$

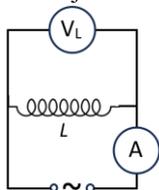


г) Временска промена јачине струје за калем са индуктивитетом од $L=1160\text{ mH}$

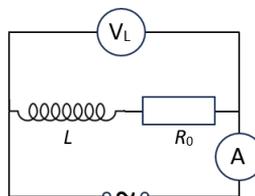
Слика 7. Временска промена напона и јачине струје у колу са калемом и извором праве струје у моменту кад је коло укључено.

Фазна разлика између напона и струје код калема у колу наизменичне струје

На Слици 8.а је приказана шема струјног кола за овај експеримент. Као и у претходном експерименту, на место волтметра и амперметра су прикључени одговарајући сензори са системом Coach који омогућају да се прати временска промена напона и јачине струје.



а) Идеални индуктивитет у струјном колу са наизменичном струјом.



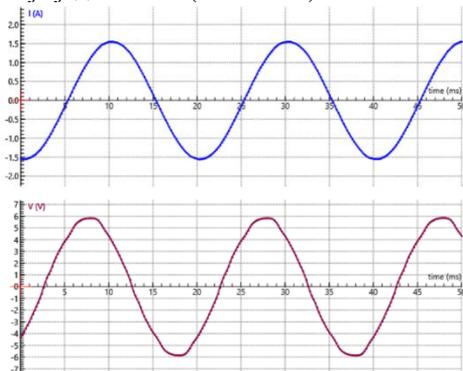
б) Еквивалентна шема реалног калема са индуктивитетом L и омским отпором R_0 у струјном колу са наизменичном струјом.

Слика 8. Индуктивитет у струјном колу са наизменичном струјом.

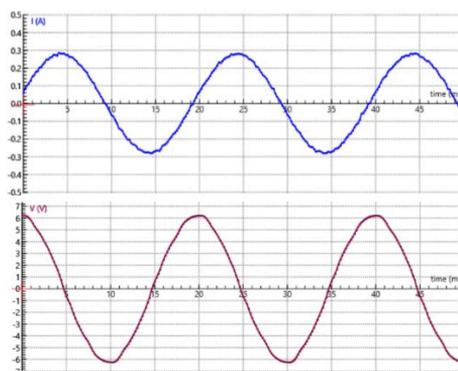
У овом случају мора се узети у обзир да поред индуктивног отпора, калем поседује и омски отпор, па еквивалентна шема је приказана на Слици 8.б, што значи, кад се мери напон на калему, да се у суштини мери укупан напон на једном идеалном индуктивитету и идеалном омском отпору који су повезани серијски. То значи да ће укупан отпор на овом калему (Z) бити векторски збир индуктивног (R_L) и омског отпора (R_0) калема, односно да ће његов интензитет бити:

$$Z = \sqrt{R_0^2 + R_L^2} = \sqrt{R_0^2 + \omega^2 L^2} \quad (1)$$

То је разлог што у експерименту фазна разлика између напона и јачине струје није једнака $\pi/2$ (Слика 9.а).



а) $L = 9 \text{ mH}$, $R_0 = 2,5 \Omega$.



б) $L = 80 \text{ mH}$, $R_0 = 2,5 \Omega$.

Слика 9. Индуктивитет у струјном колу са наизменичном струјом.

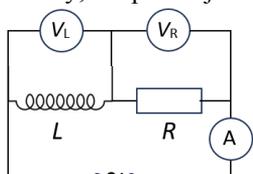
Из графика на Слици 9.а се види да у тренутку времена $5,5 \text{ ms}$ када је јачина струје нула, напон нема максималну вредност од 6 V , већ је око $4,5 \text{ V}$. У овом калему, коефицијент самоиндукције је 9 mH , па ако израчунамо индуктивни отпор, добијамо:

$$R_L = \omega \cdot L = 2\pi f \cdot L = 2\pi \cdot 50 \cdot 0,009 = 2,83 \Omega$$

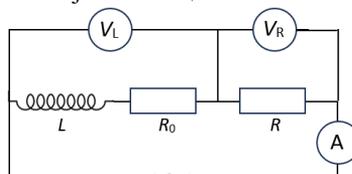
Што се врло мало разликује од омског отпора калема од $2,5 \Omega$. Да би се смањио утицај омског отпора у односу на индуктивни отпор, у калему се ставља гвоздено језгро и већ са коефицијентом самоиндукције од 80 mH , индуктивни отпор је десет пута већи од омског, при чему се добија задовољавајући резултат (Слика 9.б). Са повећањем коефицијента самоиндукције, фазна разлика је све ближа вредности $\pi/2$, али при томе укупан отпор, односно импеданција све више расте, јачина струје је мања, а шум сигнала је све већи. То значи, да је потребан компромис да би се добио добар сигнал: индуктивни отпор треба бити довољно велики да би се разликовао од омског и да се добије добра фазна разлика, али да биде довољно мали да би јачина струје била велика у односу на шум.

Фазна разлика између напона на омском и индуктивном отпору

Да би се следила фазна разлика између напона на омском отпорнику и напона на индуктивитету, потребно је струјно коло чија шема је на Слици 10.



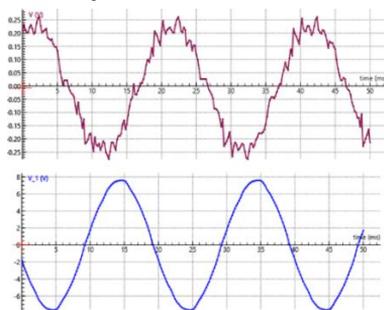
а) Идеални индуктивитет и омски отпорник у струјном колу са наизменичном струјом.



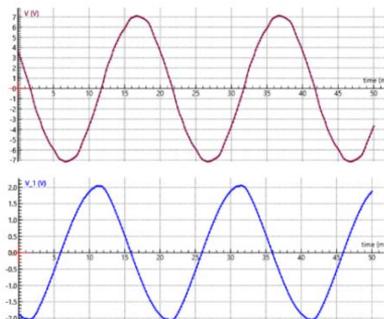
б) Еквивалентна шема реалног калема и омског отпорника у струјном колу са наизменичном струјом.

Слика 10. Шема струјног кола за праћење фазне разлике између напона на омском отпорнику и индуктивитету.

Да би се добио добар сигнал, са малим шумом и са добром фазном разликом, потребно је добро одабрати карактеристике отпорника и калема. На Слици 11.а види се да је максимални напон на калему само око $0,25 \text{ V}$, док је на омском отпорнику око 8 V . Сигнал напона на калему је са релативно великим шумом, а вредност фазне разлике није ни близу $\pi/2$. Да би се повећао максимални напон на калему, а тиме и смањио шум, потребно је повећати његов индуктивитет, чиме је повећан и отпор. На Слици 11.б види се далеко бољи сигнал на калему и фазна разлика која износи $\pi/2$.



а) Калем са $L = 9 \text{ mH}$, $R_0 = 2,5 \Omega$ и омски отпорник $R = 150 \Omega$.



б) Калем са $L = 1160 \text{ mH}$, $R_0 = 2,5 \Omega$ и омски отпорник $R = 50 \Omega$.

Слика 11. Индуктивитет у струјном колу са наизменичном струјом.

ЗАКЉУЧАК

Наизменична струја је укључена у свим европским школским системима. У највећем броју држава изучавају се основни појмови: које су разлике у односу на једносмерну струју, како ради трансформатор и како се преноси електрична енергија на даљину. У неким државама ученици уче и о индуктивном и капацитативном отпору, као и о импеданцији [1-4]. У још мање држава учи се о фазном померају. Демонстрације којима се показује зависности ових физичких величина или експерименти којима се испитују ове зависности се предлажу у само неколико држава. Овај рад показује да су ови експерименти једноставни и не траже неко посебно предзнање и специјалне експерименталне вештине. Они су интересантни, а резултати и ефекти неких од њих су чак и неочекивани и због тога иницирају когнитивни конфликт код ученика, дискусију и тражење одговора, што води до развитка критичког мишљења.

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Vectors as a Unifying Language for Mathematics and Physics Teaching

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Vectors represent a powerful conceptual bridge between mathematics and physics, providing a unified language through which quantitative relationships and real-world phenomena can be expressed and understood. Their study enables learners to transition from abstract mathematical concepts to tangible physical applications, fostering deeper interdisciplinary understanding and analytical thinking. The presentation suggests the systematic integration of vector instruction across all educational levels, demonstrating why vector concepts should be introduced, developed, and applied from primary through university education.

At the primary level, the concept of vectors can be introduced through activities emphasizing direction and magnitude rather than formal symbolism. For instance, when describing movement on a map, students begin to visualize motion using arrows, intuitively grasping the idea of a resultant path. Similarly, simple force-based tasks, such as combining pushes or pulls on an object, develop an early sense of opposing or balanced forces, laying the foundation for future vector reasoning. Even though formal symbolism can be postponed for later grades, mathematical basics should be introduced in order for the application to be accordingly used and geometrical understanding to be achieved.

At the high school level, formalization becomes essential. Students learn to perform operations with vectors and analyze more complex physical phenomena. For example, calculating the resultant of two forces acting at an angle introduces geometric vector addition, while resolving a projectile's velocity into horizontal and vertical components deepens understanding of motion under gravity. Problems involving equilibrium of forces, such as determining the tension in two supporting ropes holding a sign, exemplify how vector decomposition provides a systematic method for solving real-world problems in mechanics. Understanding the notion of electromagnetic fields can not be completely accomplished without the use of vectors.

At the university level, vector concepts become indispensable tools in advanced physics and engineering. Applications include analyzing electric and magnetic fields using vector field notation, evaluating work and flux through dot and cross products, and modeling particle motion under multiple force interactions. These topics demonstrate the generality and elegance of vectors as the mathematical framework underlying physical laws and scientific modeling.

Integrating vectors consistently across mathematics and physics education promotes conceptual continuity and cognitive coherence. When learners encounter vectors as a shared language rather than a topic isolated within one discipline, they develop

transferable reasoning skills, spatial intuition, and problem-solving strategies applicable across scientific contexts. Consequently, this pedagogical alignment not only enhances comprehension but also strengthens interdisciplinary thinking—preparing students for higher-level scientific inquiry and professional practice in STEM fields.

However, a persistent issue in many educational systems is the uncorrelated sequencing of vector instruction, where vectors are introduced in mathematics only after their application in physics has begun. This misalignment often forces physics teachers to address mathematical content beyond their intended scope. The central question thus arises: *Does abandoning mathematical formalism risk lowering the educational standard necessary to keep pace with modern technological development?* Ultimately, the challenge remains for educators to find the balance between accessibility and rigor, ensuring that each teacher contributes to building a coherent and progressive understanding of vectors across disciplines.

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Biology and Physics for Sustainable Development: Towards Students' Ecological Literacy

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Abstract: Education for Sustainable Development (ESD) represents an educational strategy that integrates different school subjects with the aim of enabling primary school students to acquire the knowledge, skills, and values necessary for a responsible relationship with the environment. One of the key goals of ESD is the development of students' ecological literacy, which in this paper is examined through the analysis of learning outcomes and curriculum content in biology and physics, as well as their integration with chemistry, geography, and technology within an interdisciplinary learning framework. The findings indicate that topics such as energy and photosynthesis, climate change, the greenhouse effect, and human health can establish strong links between the natural sciences, thereby fostering systems thinking and critical reflection among upper primary school students. The paper presents examples of interdisciplinary project-based activities, including experimental work, which contribute to the development of sustainability competences. It is concluded that interdisciplinary approaches in science education are of fundamental importance for the development of ecological literacy and that their implementation can significantly enhance teaching practice and support the formation of sustainable values among students.

Keywords: education for sustainable development; ecological literacy; interdisciplinary learning; biology and physics; primary school

INTRODUCTION

Education for sustainable development (ESD) is a key component of modern education and involves the development of knowledge, skills, attitudes and values that enable students to behave responsibly towards the environment and resources [1]. One of its central goals is the development of ecological literacy, a concept often referred to in the literature as environmental literacy or ecoliteracy. Although these terms are often used in different ways and sometimes have insufficiently precise meanings [2-5], contemporary research emphasizes that their common essence is aimed at empowering individuals to understand and act responsibly in relation to environmental challenges.

The most widely accepted meaning of ecological literacy implies awareness and care for the environment and its problems, as well as knowledge, skills and motivation for solving them and preventing new challenges. In a narrower sense, ecological literacy includes an understanding of key ecological principles and the ability to think systems, which enables informed decision-making based on scientific research [6-8]. In addition to the cognitive dimension, authors from the field of humanities emphasize the value and identity aspect of ecological literacy, aimed at creating sustainable human communities and societies [9, 10].

The development of ecological literacy in the school context requires overcoming traditional boundaries between subjects and applying interdisciplinary learning. Particularly important in this process are biology and physics, whose contents provide a basis for understanding key environmental problems – energy flows, climate change, pollution and biodiversity conservation [11]. Therefore, the aim of this paper is to highlight the importance of integrating the content of biology and physics in fostering ecological literacy among primary school students, while simultaneously incorporating relevant content from chemistry, geography, and technology education, by analyzing learning outcomes, curricular opportunities, and the application of interdisciplinary teaching strategies.

THEORETICAL BACKGROUND

Interdisciplinarity in education for sustainable development

Education for sustainable development (ESD) requires overcoming the boundaries of individual teaching disciplines and establishing an integrated approach to learning. Interdisciplinarity is a key because it enables students to understand complex environmental challenges through connecting different perspectives and learning methods [12, 13]. Natural sciences – biology, physics, chemistry, geography - along with technique and technology, provide a unique basis for developing systemic thinking in students, as each of them deals with different aspects of sustainability.

Biology enables the understanding of processes in living systems, such as photosynthesis, biodiversity and human health. Physics sheds light on energy flows, the laws of thermodynamics, and the physical basis of climate change. Chemistry deals with the breakdown of pollutants, understanding acid rain and air quality. Geography provides insight into the spatial dimensions of environmental problems, while engineering and technology offer practical solutions for the sustainable use of resources [11, 14]. The integration of these disciplines fosters in students the ability to see environmental challenges as multi-layered phenomena, connecting natural laws with social and technological solutions [15].

Contemporary literature emphasizes that interdisciplinary approaches enable not only the acquisition of knowledge, but also the development of key competencies for sustainable development, including critical thinking, collaboration, and decision-making based on systemic understanding [16, 17]. In this way, interdisciplinary learning contributes to the formation of environmental literacy and ecological identity of students, which is one of the key goals of ESD [18, 19].

Pedagogical approaches for implementing interdisciplinarity

In order to effectively implement interdisciplinarity in education for sustainable development, it is necessary to implement active pedagogical approaches. Project-based learning has proven to be one of the most effective models, as it allows students to explore real problems, develop their own ideas and propose solutions, while integrating knowledge from multiple disciplines [20, 21]. Projects related to local environmental

challenges further encourage students to learn through experience and develop community responsibility [11, 22].

Experimental work, as a form of research learning, enables students to examine natural phenomena through practical activities and think critically about cause-and-effect relationships. This not only strengthens the understanding of natural laws, but also encourages the development of competencies for solving problems in real situations [23].

Field teaching occupies a special place in education for sustainable development because it provides an authentic experience of connecting knowledge from different fields. Through direct contact with the natural environment, students learn to recognize environmental problems and develop empathy for the environment, which is recognized as a key prerequisite for the formation of sustainable values [24].

The combination of these approaches enables the implementation of interdisciplinary learning in practice and contributes to the realization of the basic goals of ESD – developing environmental literacy, empowering students to make informed decisions and forming sustainable values.

Analysis of the curriculum of biology, physics, chemistry, technique and technology and geography in the function of the development of environmental literacy

Interdisciplinarity in education for sustainable development is most clearly seen through the learning outcomes of various subjects and their integration possibilities in the function of developing environmental literacy. The analysis shows that in the upper grades of primary school, there is a significant potential for connecting content, especially within topics related to climate change, energy and protection of natural resources [25, 26].

Within *biology*, the emphasis is on understanding the relationship between ecological factors and biodiversity, identifying trophic levels in food webs, studying the consequences of human activities on resources and proposing nature protection actions. These outcomes develop awareness of cause-effect relationships in ecosystems and encourage a responsible attitude towards the environment.

Learning outcomes in *physics* are focused on the forms and transformations of energy, heat transfer and conservation laws, which enables understanding of the physical foundations of global warming and rational use of energy.

Chemistry provides knowledge about combustion reactions, gases involved in the greenhouse effect, and air and water pollutants. In this way, students connect chemical processes with real environmental problems such as smog and acid rain.

Through *technique and technology*, an understanding of energy efficiency, rational use of resources and the application of renewable energy sources is developed, thus students learn to critically evaluate technical solutions and design sustainable projects.

Geography contributes to environmental literacy by analyzing climate factors and global changes, studying the consequences of economic activities and researching the possibility of applying clean energy sources, which allows students to connect local environmental challenges with global processes.

In this way, the integration of content from all five subjects provides the basis for the development of systemic thinking, critical reflection and active engagement of students in solving environmental problems.

Integration of content through the theme "Energy and Climate Change"

Based on the above learning outcomes, an interdisciplinary project activity called "Energy and Climate Change" can be designed, in which students would explore this topic from multiple perspectives through different subjects.

Within *biology*, the task would be to examine how climate change affects local biodiversity - they would conduct a mini-survey in the school's surroundings, record the plant and animal species present and compare the results with literature or digital atlases. Based on this, they could create a biodiversity map of the school yard and indicate possible changes that would occur due to an increase in temperature or a decrease in precipitation.

Through *physics*, teams of students would carry out an experiment with two containers - a closed one and an open one - exposed to sunlight or a light bulb. During the measurement of the temperature in a certain time interval, the students would record the data, present it tabularly and graphically, analyze the temperature rise curves and relate the results to the greenhouse effect.

Within *chemistry*, the focus would be on gases that contribute to the greenhouse effect (CO₂, CH₄, NO₂). Students could perform a simple experiment – e.g. burning a candle under a glass jar and measuring the extinguishing time - and then to analyze the resulting gases and their effect on the air. As an extra task, they would research examples of acid rain and explain the chemical reactions that lead to it.

Technique and technology would allow students to investigate energy consumption in households. Based on the collected data (electricity bills or household examples), they would calculate the average energy consumption, and then propose technical solutions to reduce it - such as the use of LED bulbs, energy-saving devices or better insulation of the space. As the final part of the activity, they would come up with a concept project of "Green Houses of the Future".

Through *geography*, students would study climate maps of Serbia and the world, identify changes in the distribution of precipitation and temperatures and relate them to economic activities and people's quality of life. As an assignment, they could create a poster or digital presentation on "How climate change affects my city/my country" and suggest possible adaptation measures.

In the end, all the results would be combined and presented through a school exhibition or panel discussion, whereby the students would integrate the findings from all disciplines and make their own proposals for improving the quality of life in their community.

In this way, the teaching of biology, physics, chemistry, technique and technology, and geography ceases to function in isolation, but by interconnecting content and methods, an environment is created in which students develop environmental literacy – knowledge and understanding of natural processes, awareness of the consequences of human activities, and competence to propose sustainable solutions.

CONCLUSION

Education for sustainable development represents one of the key directions of modern education because it equips students for responsible understanding and action in relation

to environmental challenges. The results of the analysis show that the integration of the content of biology, physics and chemistry, with the support of geography and technology, opens up opportunities for the development of environmental literacy among elementary school students. Topics that connect energy flows, photosynthesis, climate change, air quality and human health are particularly important, as they enable students to develop systemic thinking and observe cause-and-effect relationships between natural phenomena.

Pedagogical approaches such as project learning, experimental work and field teaching are recognized in the literature as particularly effective in implementing interdisciplinarity, because they provide students with the opportunity to learn through experience, think critically and actively participate in solving problems in their community. In this way, environmental literacy ceases to be only a theoretical concept, but becomes a practical competence that shapes the values and attitudes of students.

It is concluded that the application of interdisciplinary approaches in the teaching of natural sciences has the potential to improve teaching practice and contribute to the formation of sustainable values among young generations. This fulfills one of the central goals of education for sustainable development – training primary school students to be active and responsible citizens, ready to contribute to the preservation of the environment and the sustainable development of society.

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Granular Physics for the High-School Lab

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We present a pair of classroom-ready experiments on granular materials that connect planetary cratering and mobility on sand with core high-school physics. In the first part (crater formation), students drop steel spheres into dry sand, measure crater diameter, and use log–log plots to determine the scaling $D_c \sim E^\alpha$, typically finding $\alpha \approx 1/4$, for gravity-dominated impacts. The activity highlights how impact energy $E_p \approx mgh$ is spent lifting excavated grains, while also discussing when strength-dominated behavior $\alpha \approx 1/3$ may appear in cohesive or moist media. In the second part (rolling and arrest), a sphere rolls down a shallow ramp onto sand and stops after distance L ; students discriminate between solid-like (constant) drag, predicting $L \sim E_k$, and fluid-like (viscous) drag, predicting $L \sim E_k^{1/2}$. Together, the experiments foreground mechanism finding via scaling laws, encouraging evidence-based model selection rather than rote formula use. They align with the first year standard curricula (energy, forces, friction, kinematics, graphing) and require only low-cost materials: sand, a tray, steel balls, a simple ramp, and rulers. The protocols emphasize repeatability, uncertainty estimation, and the use of logarithmic transformations to linearize power laws and extract slopes. Optional extensions include image-based crater metrology, estimating an effective friction coefficient from fits, and exploring moisture/packing effects. Typical classroom results reproduce the expected exponents and invite discussion of deviations due to preparation, depth effects, or measurement bias. The pair can be completed in one double period or split across two lessons, with clear roles for inquiry, collaboration, and formative assessment. By translating contemporary granular physics into accessible labs, the module deepens conceptual understanding and showcases how careful measurements reveal the mechanisms hidden in complex, real-world materials.

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Од апстрактног знања до примене у физици: Зашто ученици имају потешкоће са математиком у физици?

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Апстракт. Један од основних проблема су којим се суочавају ученици током средњошколског СТЕМ образовања је решавање реалних проблема, односно процес физичко-математичког моделирања, при чему је неопходно успоставити везу између апстрактног математичког света и конкретних физичких феномена. Аутори рада тврде да ова потешкоћа није резултат недостатка рачунске способности, већ фундаменталне епистемолошке дисконекције између ова два наставна предмета. Математика се често предаје као самодовољан систем апстрактних правила, док физика користи математику као алат за моделирање физичког света. У раду су анализирани четири области: алгебра, вектори, тригонометрија и комплексни бројеви. Циљ је да се прикаже како њихов третман на часовима математике често уклања контекстуално значење и процедуралну флексибилност која је неопходна за физику. Кроз компаративне примере се показује да ученици могу успешно решити једначину по непознатој x , али имају проблем кад треба непознатој доделити физички идентитет, као што је померај или импулс. Њима је прилично лако да манипулишу векторима као уређеним паровима реалних бројева, али не успевају да их користе као репрезентацију силе или брзине. На крају рада се предлажу педагошке стратегије које би евентуално могле премостити овај јаз, подстичући интегрисаније и функционалније разумевање математике као језика физике.

Кључне речи: математичко образовање, физичко образовање, интеграција математике и физике, контекстуално разумевање.

Professional development of mentor teachers

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Abstract. Education is a process that requires constant learning and monitoring of the development of new technologies. Therefore, the teaching profession is understood as a continuous process of development and advancement. The model for the development of the teaching profession involves mentoring work with trainee and novice teachers (mentees) and continuous professional development of mentor teachers. The task of mentors is to provide professional support to mentees to develop their competencies. Therefore, it is important to empower the mentor and provide him with holistic professional support in order for the mentoring process to be successful.

Keywords: mentoring process, mentor training, monitoring and evaluation of mentees.

INTRODUCTION

The role of educational institutions is to empower young people to be the drivers and bearers of social development. This requires continuous training for teachers, so that they are able to adapt the process of acquiring knowledge in a way that is acceptable and interesting to students. Therefore, teachers must constantly monitor the development and progress of technology, engage in lifelong learning, and be sensitive to the continuous evolution of needs for new ways of transferring knowledge and student engagement. In order to better prepare and enable students, trainee teachers, and novice teachers (mentees) to properly respond to student demands in all three domains of development (cognitive, affective, and psychomotor), a mentoring process has been introduced. This process consists of two parts, one that takes place at higher education institutions and the other that takes place in schools, under the supervision of a more experienced teacher (mentor). This kind of support system, which is based on a greater number of practical lessons and gradual guidance of the young teacher through all stages of this profession, is very beneficial for the mentee. However, mentors were often appointed without prior introduction to the mentoring process and empowerment to adapt this important process to their own needs, as well as the needs of their mentees [1,2]. Therefore, the goal of this paper is to introduce mentors to methods of monitoring and evaluating mentees with the aim of improving their work.

MENTOR TRAINING

Effective professional development of mentors is achieved through a holistic approach to the mentoring process (Figure 1), where the following come to the fore:

- planning (planning activities that will lead to the professional development of mentors and mentees),
- monitoring (monitoring the work of both mentors and mentees),
- checking (checking all phases of the development of planned activities of both mentors and mentees),
- providing feedback (the mentee should express the comprehensibility of the instructions received, as well as an assessment of the interaction with students and the mentor in order to seek ways of possible improvement; the mentor should, through providing feedback, encourage the mentee to examine his or her own activity and suggest its improvement), and
- (self)evaluation (summarizing all previous steps, both the mentor and mentee should mutually evaluate the activities carried out, but also see their progress through self-evaluation [3]).

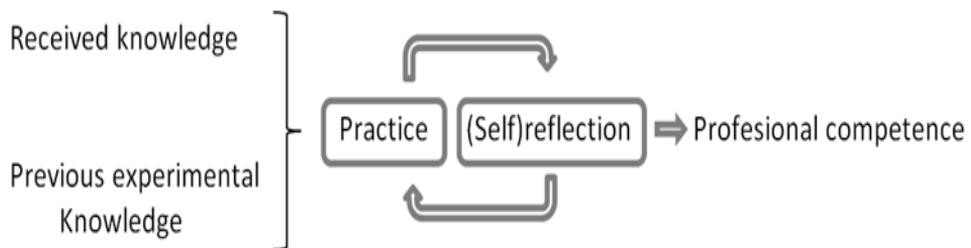


Figure 1. Reflective Model of Professional Development, adapted from [4]

Going through these basic steps, the discussion between mentor and mentee focuses on quality control and quality assurance, which involves identifying and setting up mechanisms, procedures, and processes for achieving it.

Examples of tasks

Example tasks are taken from the Handbook [3].

Creation of a form for monitoring and evaluating mentees

Objective: to develop mentors' competencies in monitoring and evaluating mentees

Procedure:

List questions that may be considered important for monitoring the work of mentees, and then suggest a method of assessment. The following questions can serve as starting ideas:

Professional development of mentor teachers

- To monitor the work of mentees in the administrative part:
 1. How do they plan their activities in the school year calendar?
 2. Do they write lesson plans with clear sequential content?
 3. How do they keep records of student performance?

- To monitor the work of mentees in relation to the teaching subject:
 1. Do they use probing techniques in their learning activities?
 2. Do they apply appropriate teaching methods?
 3. Do they use appropriate examples and illustrations?

- To monitor the work of mentees in relation to students:
 1. Do they use relevant questions to assess student knowledge?
 2. Do they allow enough time for students to answer questions?
 3. Do they provide students with written feedback on the assessment?
 4. Are they aware of students' individual learning needs?

Mentor self-assessment

Objective: to acquire the skill of assessing the learning and mentoring process, to identify strengths in different domains, to articulate possible directions for future personal and professional development

Procedure:

Table 1 presents a list of self-assessment criteria. Within this list, it is necessary to consider the role of the mentor in different domains, as well as the steps of future development.

Table 1. List of self-assessment criteria

| Strengths and experience | The role of a mentor | Areas for development |
|---------------------------------|--|------------------------------|
| | <i>Establish and maintain a positive relationship</i> | |
| | Understand typical mentee needs | |
| | Discussion of expectations | |
| | Maintaining contact with mentee | |
| | Open and honest communication | |
| | Empathy | |
| | Flexibility, reliability, responsibility | |
| | Understanding | |
| | Paraphrasing what is said and to check if instructions are well understood | |
| | Confidentiality | |

| | | |
|------------|--|--|
| | <p style="text-align: center;"><i>Development support</i></p> <p>Observation and discussion Analysis of the joint work of mentees and mentors A collaboration plan Modeling teaching strategies Support for setting goals and monitoring progress Support for defining steps for development Self-reflection Clarification of ideas and explanations Encouraging testing of beliefs and assumptions Encouraging problem solving</p> | |
| | <p style="text-align: center;"><i>Providing support in the logic domain</i></p> <p>Introducing key stakeholders Explaining key materials Communicating important dates in advance Explaining important procedures and instructions Supporting resource gathering Sharing strategies and techniques</p> | |
| | <p style="text-align: center;"><i>Emotional support</i></p> <p>Praise and reward system Support in interactions with colleagues, parents, administration Share enthusiasm and opinions when it comes to teaching and the learning process</p> | |
| | <p style="text-align: center;"><i>Strive for mentoring development</i></p> <p>Evaluate the teaching and learning process Invest time and effort as a mentor Show initiative and leadership Join a mentoring community for continuous learning</p> | |
| Goals | | |
| Next steps | | |

Progress plan

Objective: (self)assessment and identification of possible areas for improvement within professional competencies

Procedure:

Table 2 outlines a template for a progression plan for a given timeframe. The template can be completed by both mentors and mentees to track the achievement of the intended competencies.

Table 2. Progression plan (1 year)

| Development goals | Competencies | Indicators | Promotion criteria/Expected results | Comments, thoughts |
|---|---------------------|-------------------|--|---------------------------|
| Short-term goals (e.g. end of semester) | | | | |
| Long-term goals (e.g. end of school year) | | | | |

CONCLUSION

The goal of mentoring is to develop the pedagogical competencies of mentees while simultaneously achieving professional development for the mentor. The following are key to ensuring the quality of mentoring work: immediate feedback, constant control, analysis of elements of the pedagogical work of mentees and mentors, evaluation and analysis of achieved results, identification of shortcomings and support for their elimination. In fact, successful mentoring work involves a well-planned monitoring and evaluation system, clear requirements and the setting of objective criteria, as well as measurable and achievable goals for professional development planning that can be tracked through diagrams.

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Primena Escape room-a u nastavi prirodnih nauka

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U savremenom obrazovanju znanje je ključno, ali istovremeno učenici moraju da steknu ključne veštine 21. veka [1]. Ova potreba nameće obavezu nastavnicima i istraživačima da primenjuju inovativne metode koje povećavaju angažovanost i motivaciju učenika. Jedan od efikasnih pristupa u ovom smislu jesu obrazovne igre [2], a posebno escape room (ER), interaktivna igra zasnovana na rešavanju problemskih zadataka i saradnji, koja se pokazala kao odlična didaktička igra za unapređenje nastave prirodnih nauka.

ER je problemski orijentisana aktivnost u kojoj učesnici, radeći u timu, rešavaju niz logičkih, praktičnih ili konceptualnih zadataka u ograničenom vremenu, kako bi postigli određeni cilj – „pobegli“ iz zamišljene situacije [3]. U obrazovanju, termin edukativni escape room (EER) predstavlja aktivno okruženje za učenje u kojem se od učenika traži da primene svoje znanje i veštine [4]. Korišćenjem EER, učenici prelaze od pasivnih primalaca znanja do aktivnih učesnika, angažujući se u istraživanju, rešavanju problema i izazova, dok se istovremeno razvijaju motivacija, timski rad, liderstvo i komunikacione veštine [5]. EER se sve više integrišu u nastavu prirodnih nauka, gde ih nastavnici i učenici ocenjuju kao pogodne za obradu, uvežbavanje i formativnu procenu znanja [6]. Ipak, EER se češće koriste za ponavljanje i utvrđivanje znanja, nego za učenje novih veština [7].

Nastavnici se često suočavaju sa izazovima pri osmišljavanju EER, uključujući potrebu za adekvatnim prostorom, specifičnom opremom i značajnim utroškom vremena, kao i integrisanjem nastavnih ciljeva u zadatke. Zbog toga su neki počeli da koriste digitalne formate, omogućavajući učenicima učešće putem onlajn platformi i otklanjanje prostorno-tehničkih ograničenja. Ipak, digitalni formati ne pružaju u potpunosti praktično iskustvo, autentičnu atmosferu i osećaj „bektva“ kao fizički EER. Efikasno rešenje predstavlja sekvencijalna primena oba formata, kako bi se iskoristile njihove prednosti i nadomestila ograničenja [2].

Dosadašnja istraživanja pokazuju da su EER primenjivani u različitim oblastima, uključujući medicinu, farmaciju, biologiju, hemiju, fiziku, astronomiju itd [8]. Poseban izazov javlja se u nastavi fizike, koju učenici često doživljavaju kao apstraktnu i tešku. Upravo EER omogućavaju približavanje fizike učenicima kroz interaktivne zadatke i praktične simulacije na razumljiv i podsticajan način. EER često integrišu nastavne sadržaje više predmeta. Na primer, EER pod nazivom „Maskirani naučnik“ objedinjuje nastavne sadržaje koji se odnose na model atoma, radioaktivnost i Periodni sistem elemenata [4].

Istraživanja pokazuju da učenici imaju pozitivan stav prema korišćenju EER, ističući njihovo aktivno uključivanje i razvoj društvenih i timskih veština [9].

Imajući u vidu sve prethodno navedeno, može se zaključiti da su EER efikasan i praktičan alat u nastavi fizike i prirodnih nauka. Oni ne samo da podstiču aktivno učenje, motivaciju i timski rad, već učenicima omogućavaju primenu stečenog znanja u rešavanju realnih problema. Zbog svoje fleksibilnosti, mogućnosti prilagođavanja različitim sadržajima i integracije sa digitalnim platformama, EER imaju značajan potencijal za široku primenu u obrazovanju i unapređenje nastavne prakse.

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Wave Optics: Demonstration of Fresnel–Arago Laws and Laboratory Exercise for Determination of Laser Light Wavelength

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Abstract. The purpose of this work was to create an experimental setup that provides a simple yet effective way to demonstrate the Fresnel–Arago laws and to realize a laboratory exercise with red and green laser light. In our approach, a birefringent calcite crystal is used as a beam splitter. The setups are improved by adding a diverging lens (commonly used for image magnification) resulting in a large interference pattern, visible to a wide audience. Quick and easy construction, relatively simple processing of the interference image, without the use of expensive devices, obtaining a clear, sharp and large interference image and the good agreement between the nominal and measured laser light wavelengths, make this setup very suitable for realization as a student exercise.

Keywords: Fresnel-Arago laws, wave optics, Iceland calcite, diverging lens, laboratory exercise

INTRODUCTION

Wave optics is an indispensable part of educational programs and is very suitable for demonstrations at the high school and university levels [1, 2]. In 1819, based on experimental results, Fresnel and Arago formulated laws that connect polarization and interference - phenomena characteristic of the wave nature of light. The four Fresnel-Arago laws are [3]:

1. Two linearly polarized light waves of orthogonal polarizations do not interfere.
2. Two linearly polarized light waves of identical polarization interfere.
3. Two linearly polarized light waves of orthogonal polarizations obtained from a natural (unpolarized) light source do not interfere if brought to common linear polarization.
4. Two linearly polarized light waves of orthogonal polarizations obtained from a linearly polarized light source interfere if brought to common linear polarization.

These laws have been the subject of scientific research in the last few decades. References [4, 5] provide their theoretical interpretation, while in [3, 4-6], experimental setups are proposed for their demonstration. Modern theoretical works provide very comprehensive explanations of the interference of polarized light. However, a complex mathematical approach was used for their derivation, with which many students are not acquainted. On the other hand, the formulations of Fresnel–Arago laws, which have

played a basic role in elucidating the concept of polarization of light, are much more accessible for students. Therefore, these laws can represent a good basis for understanding the interference of polarized light.

In our laboratory, we realized an experimental setups where two lasers (red He–Ne and a laser with green diode) were used as light sources and birefringent calcite as a beam splitter, although in previously published research, only a He–Ne laser was used ($\lambda = 633 \text{ nm}$). The reason for this is that the most pronounced interference pattern is obtained in that wavelength range [7]. Our setups were improved by adding a diverging lens (standardly used for image magnification), which produces a large and sharp interference image with clearly defined and parallel fringes at a short distance from the calcite.

A significant advantage of this setup is the possibility of implementing an experimental exercise aimed at determining the wavelength of the used laser. By including the magnification of the diverging lens, the expression that relates the distance between adjacent interference fringes on the screen (Δx) to the wavelength of light (λ) is modified.

EXPERIMENTAL SETUP

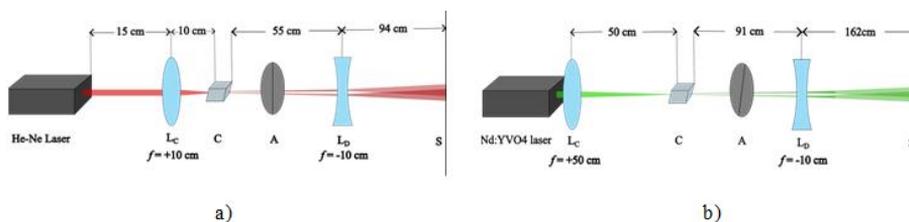


Figure 1. Schematic diagrams of experimental setup (a) with He–Ne laser, (b) with Nd: YV04 laser. L_C -converging lens, L_D -diverging lens, C-Icelandic calcite, P-polarizer, A-analyzer, S-screen [3]

Figure 1 shows schematics of the experimental setups for the demonstration of the Fresnel–Arago laws and the realization of the experimental exercise. In these experiments, two lasers were used as light sources: He–Ne laser (Lasos, model LG 08180–93, $\lambda = 633 \text{ nm}$, output power 1 mW, beam diameter 0.5 mm, beam divergence $< 2 \text{ mrad}$), and diode pumped Yttrium–Vanadate (Nd:YV04) solid state laser (Phywe, model LG 08762–99, $\lambda = 532 \text{ nm}$, output power 1 mW, beam diameter 2 mm, beam divergence $< 1.2 \text{ mrad}$).

Birefringent Icelandic calcite rhomboid is used as a beam splitter. Two rays, linearly polarized in mutually normal planes (so-called ordinary and extraordinary), emerge from the calcite. The calcite was rotated around the horizontal axis until the output beams reach the same intensity.

A converging lens (+100 mm or +500 mm) is used to focus the laser beam onto the calcite entrance plane [4, 7] to achieve slightly diverging output beams, as they must (at least partially) overlap to obtain an interference image. The role of the divergent lens (–100 mm) is to magnify the interference image and thus make it visible to a wide audience. It is placed in a position where the rays more or less overlap, forming an enlarged image on the screen.

Phywe linear polarizer with an adjustment step of 1° and efficiency $>99,9\%$ from 450 to 750 nm were used as an analyzer. The analyzer was placed optionally, depending on the desired effect.

RESULTS AND DISCUSSION

Demonstration of Fresnel–Arago laws

In previous chapter it is said that diverging lens was placed at the position of greater or lesser overlap of the beams. Namely, the lasers we used work in the first transverse mode (TEM_{00}) and have a Gaussian intensity distribution in the beams' cross section. Therefore, depending on the level of beams overlapping at the position where the divergent lens is placed, a different intensity distribution of the interference fringes will be obtained. With an increase of the spots overlapping, the intensity in the central part of the image increases, and vice versa.

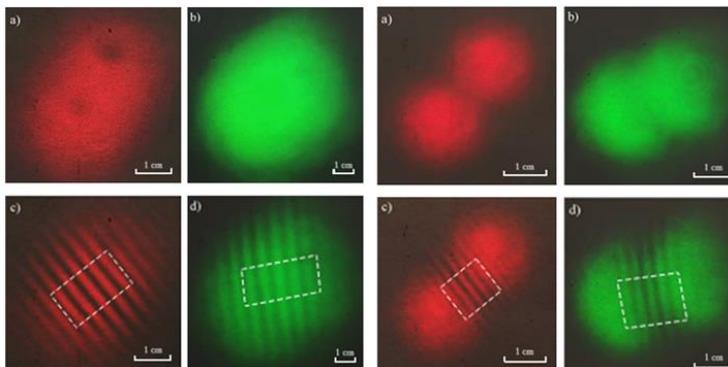


Figure 2. Greater overlap of spots on the screen. (a) and (b)-without analyzer;(c) and (d)-with analyzer.

Figure 3. Less overlap of spots on the screen. (a) and (b)-without analyzer;(c) and (d)-with analyzer.

Figures 2 and 3 show photos of the obtained effects for greater and smaller overlap of spots on the screen, respectively. When the analyzer is omitted from the setup images presented in figures 2(a), (b) and 3(a), (b) are obtained. It is clearly observed that there are no interference fringes, i.e. that there is no interference of ordinary and extraordinary rays, which was expected because they are polarized in mutually normal planes (first Fresnel–Arago law).

Then, the analyzer is placed between the calcite and the diverging lens, whose plane of polarization is parallel to the plane of polarization of the incident beam. The role of the analyzer is to bring the ordinary and extraordinary rays into the same plane of polarization. Clearly visible interference fringes are shown in figures 2(c), (d) and 3(c), (d). This effect is a confirmation of the validity of the second and fourth Fresnel–Arago law.

Figures 4 and 5 show the part of the photo of the interference fringes used to obtain the intensity distribution (dashed rectangles in figures 2(c), (d) and 3(c), (d)) and corresponding intensity distributions for greater and lesser overlap of beams, respectively. It can be seen that the interference fringes are sharp, parallel and equidistant. For the purposes of this research, a program was created to determine the intensity distribution of interference fringes based on a photograph. The program is easy to use and allows for very precise determination of the position of the maximum intensity of interference fringes. Detailed instructions for its use can be seen in [8].

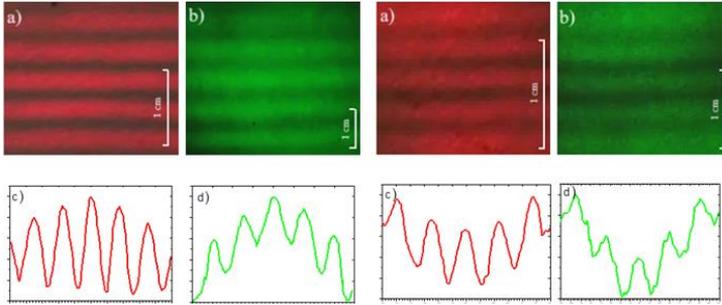


Figure 4. Greater overlap of spots on the screen. (a), (b)- part of the photo used to obtain the intensity distribution; (c), (d)- intensity distribution. [3]

Figure 5. Less overlap of spots on the screen. (a), (b)- part of the photo used to obtain the intensity distribution; (c), (d)- intensity distribution. [3]

Determination of the laser light wavelength

A significant advantage of the presented setups is the possibility of implementing an experimental exercise aimed at determining the wavelength of the used laser. The expression relating the distance between adjacent interference fringes on the screen (Δx) to the wavelength of light (λ), given in [5] and [7], is modified by including the magnification of the diverging lens [3]:

$$\Delta x = \frac{L \lambda}{d} u \quad (1)$$

where λ - the wavelength of the laser light, L - the distance from the calcite to the diverging lens, d - the distance between the centers of the spots on the output plane of the calcite, $u = d_s/d_L$ - the magnification of the image with a diverging lens, which is calculated as the ratio of the distance between the centers of the spots on the screen (d_s) and the distance between the centers of the spots on the diverging lens (d_L). The idea is to obtain an interference image at a small distance from the calcite, (where the image is small and unsuitable for processing) and to enlarge it with a diverging lens.

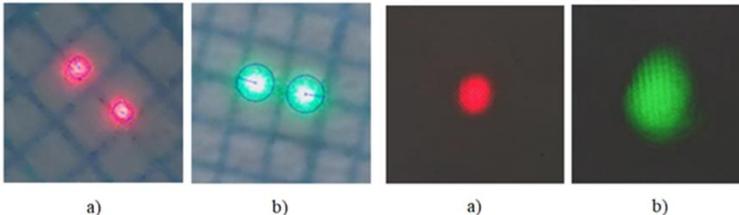


Figure 6. Photos of beams' spots on the exit surface of calcite. a) for red and b) for green light

Figure 7. Interference images on the screen without the diverging lens. a) for red and b) for green light

The value of Δx is determined based on the graphs shown in figures 4 c) and d). To determine the value of d , a piece of graph paper is placed on the exit surface of the calcite (figure 6). The photo is inserted into the application for quantitative image processing

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(e.g. Digimizer image analysis software), the coordinates of the spots' centers are determined and the distance between them is calculated.

In order to determine the value of d_L , instead of a diverging lens, a screen is placed. A small interference image is visible on the screen. By turning the analyzer by 45° to one side or the other, it is possible to see an ordinary or extraordinary beam spot on the screen. Both spots are photographed from the same distance. The photos are analyzed by application for quantitative image processing and d_L is calculated. The procedure for determining the value of d_S is the same as for d_L .

The interference images were photographed by a smartphone's digital camera with a resolution of 100 megapixels. Absolute measurement errors are estimated based on the value of one pixel in the image, which depends on the resolution of the camera and the distance from which the image was photographed. In order to reduce the relative uncertainty, each image was photographed from the smallest possible distance and with the maximum possible magnification to obtain a sharp photo.

Measured values and calculated wavelengths with estimated uncertainties for red and green laser light, with diverging lens in setup, are shown in Table 1 [3].

Table 1. Measured values and calculated laser light wavelengths with diverging lens

| | He-Ne laser | Nd:YV04 solid state laser |
|--------------------------------------|--------------------|---------------------------|
| $L \pm \Delta L$ (mm) | 550 ± 1 | 910 ± 1 |
| $\Delta x \pm \Delta(\Delta x)$ (mm) | 3.507 ± 0.009 | 7.36 ± 0.02 |
| $d \pm \Delta d$ (mm) | 1.144 ± 0.002 | 1.209 ± 0.005 |
| $d_S \pm \Delta d_S$ (mm) | 16.985 ± 0.012 | 28.55 ± 0.02 |
| $d_L \pm \Delta d_L$ (mm) | 1.477 ± 0.006 | 1.552 ± 0.008 |
| $u \pm \Delta u$ (mm) | 11.50 ± 0.06 | 18.4 ± 0.1 |
| $\lambda \pm \Delta \lambda$ (nm) | 634 ± 7 | 531 ± 7 |

Additionally, measurements were also made for the setup without the diverging lens. For the red laser light, only the diverging lens was removed, the screen remained in the same position. For green laser light, due to the significantly lower contrast and smaller divergence angle, the screen had to be moved to 5.4 m where the interference fringes were clearly visible and the image, captured by the camera, was sharp enough. Photos of interference fringes are shown in figure 7 a) and b). The required quantities were measured and the values substituted into the expression $\Delta x = D\lambda/d$ (D —distance from calcite to the screen). The calculated wavelengths, in this case, are shown in Table 2:

Table 2. Measured values and calculated laser light wavelengths without diverging lens

| | He-Ne laser | Nd:YV04 solid state laser |
|--------------------------------------|-------------------|---------------------------|
| $D \pm \Delta D$ (mm) | 1490 ± 1 | 5400 ± 2 |
| $\Delta x \pm \Delta(\Delta x)$ (mm) | 0.821 ± 0.009 | 2.36 ± 0.03 |
| $d \pm \Delta d$ (mm) | 1.144 ± 0.002 | 1.209 ± 0.005 |
| $\lambda \pm \Delta \lambda$ (nm) | 630 ± 9 | 528 ± 7 |

A slightly larger deviation from the nominal values of the wavelengths for the used lasers than when a diverging lens was used is probably due to the fact that the interference images are small and insufficiently sharp.

The results, obtained by using the both methods, show a very good agreement with the used lasers' wavelengths - 633 nm for the He-Ne laser and 532 nm for the Nd:YV04 laser. The used experimental setups enabled us to measure the laser wavelengths with the error less than 1.5%.

CONCLUSION

In this work the experiment for an easily feasible demonstration of the Fresnel–Arago laws and the realization of the laboratory exercise is described. The experiment was realized using red and green laser light. The settings, improved by adding the diverging lens, are quickly and easily formed and allow obtaining a sharp, clear and large interference image. By analyzing the interference image and by measuring the distances between the optical elements, the laser light wavelengths are calculated, the values of which agree very well with the nominal lasers' wavelengths and the measurement uncertainties are less than 1.5%. We believe that the presented experiment which connects the phenomena characteristic of the wave nature of light (polarization and interference) will contribute to a deeper and more complete understanding of these occurrences.

ACKNOWLEDGEMENTS

The authors would like to thank Stefan Jovanović for making the program for reading the light intensity from a photo. Discussions with Nikola Cvetanović are highly appreciated. This work was supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia No: 451–03–137/2025–03/200162 and by the Science Fund of the Republic of Serbia through the Project ATTOPLASMAS # 7750277.

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Impact of the Covid-19 pandemic on the performance of elementary school pupils in physics problems related to electric current

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Abstract. In the paper the changes in the knowledge of physics after the Covid-19 pandemic in Slovenia are presented. The focus is on the electric current as it is a topic, discussed at the end of the school year in the last (9th) grade of elementary school. We compare the results of the national assessment of knowledge test in two years before (2016 and 2019) and two years after (2023 and 2024) the pandemic by an in-depth analysis of a representative sample of 100 tests for each year. Analyzing the answers to open questions provides a better insight into the common misconceptions or lack of knowledge of physics related to electricity. The main question remains: Are we indeed able to detect the changes in knowledge of physics due to the Covid-19 pandemic?

Keywords: knowledge of physics, Covid pandemics, elementary school, national assessment.

The Eötvös effect and the Eötvös rotating seesaw

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The Coriolis force is an inertial (or fictitious) force that acts on a body moving within a rotating reference frame, which is accelerating relative to an inertial frame. It is named after Gaspard-Gustave de Coriolis [1], who first described the phenomenon in 1835. Like all fictitious forces, the Coriolis force is proportional to the mass of the body. In vector form, it can be written as follows:

$$\mathbf{F}_c = -2 m \boldsymbol{\Omega} \times \mathbf{v}$$

where m is mass of the moving object, $\boldsymbol{\Omega}$ is angular velocity of the rotation and \mathbf{v} is velocity of the moving object. The Coriolis force exerts two types of action on a body moving on the surface of the rotating Earth. The component parallel to the surface always acts to the right in the northern hemisphere and to the left in the southern hemisphere, relative to the direction of motion. The combined effect of the component orthogonal to the surface of Coriolis force and the centrifugal force alters the effective gravitational acceleration. Working in fields of environmental physics and meteorology we often need just the parallel to surface component of the Coriolis force. However, here we will concentrate on the often neglected orthogonal-to-surface component.

Between 1901 and 1905, Oscar Hecker [2] and his team from the Geodetic Institute of Potsdam studied the geographical variation in gravitational acceleration on moving ships in the Atlantic, Indian and Pacific oceans. While analyzing Hecker's data, Loránd Eötvös [3] noticed a correlation between the direction of the ship's movement and systematic deviations in the measured gravitational acceleration values [4]. The values were lower when the ship was moving eastward and higher when moving westward. At Eötvös's recommendation, Hecker repeated his measurements in 1908 using two ships on the Black Sea - one traveling eastward and other westward. The results were perfectly consistent in showing variations in gravitational acceleration. Since then, the modification of gravitational acceleration due to the vertical component of the Coriolis force has been known as the Eötvös effect.

In 1915 Eötvös constructed the rotating seesaw [5]. The device consists of a rod mounted on two needle bearings, with two larger cylindrical weights placed at its ends. In the non-rotating state, the rod remains in equilibrium. When the seesaw begins to rotate, one of the weights moves eastward, while the other moves westward. According to the Eötvös effect, the apparent weight of the two bodies changes in opposite directions. If the force acting on the bodies oscillates at the natural frequency of the seesaw, the amplitude of the seesaw's motion gradually increase due to resonance. The motion of the balance is detected by the observing the displacement of the light beam reflected from a mirror mounted on the rod. In this way, Eötvös provided new experimental evidence for the

Earth's rotation, independently from the famous Foucault pendulum experiment [6]. A schematic representation of the rotating seesaw is shown in Figure 1.

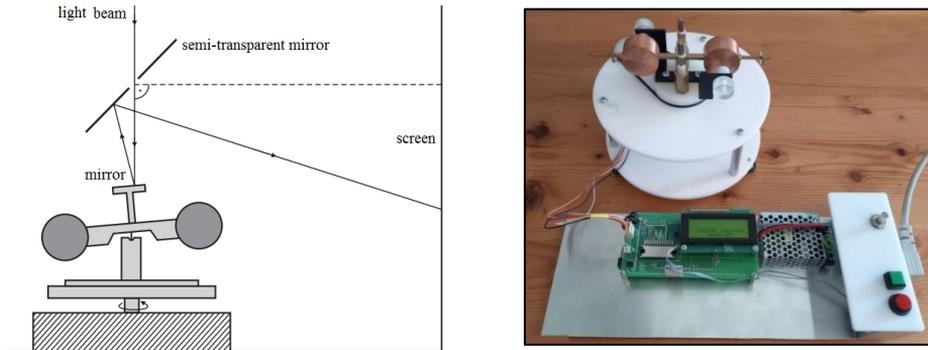


Figure 1. Schematic representation of the Eötvös rotating seesaw (left), and the modern version of the device (right)

Eötvös solved the problem of rotation of the seesaw by employing a precision clockwork mechanism. Nowadays, this can be achieved using a microcontroller-driven stepper motor and rubber belt transmission [7] (see Figure.1). The angular velocity can be adjusted using a potentiometer, and its value is displayed on an LED screen. The seesaw is equipped with strong magnets positioned near the copper weights, producing damping proportional to the velocity of the weights due to eddy currents induced in them. Our aim is to represent the Eötvös rotating seesaw experiment using a modernized version of the device.

ACKNOWLEDGEMENTS

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Enhancing gifted student activities and creativity through AI and microcontrollers - case study

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Abstract. In an era of technological expansion, where it (technology) acts as a driver of innovation in various spheres of society, (physics) teaching, as the most important pillar of society, must change. Thus, technology, especially artificial intelligence (AI), can be used to support potentially gifted students, in order to fully meet their cognitive demands. The paper will present a case study of a potentially gifted eighth-grade elementary school student, as well as his opinions and expectations regarding the application of AI and microcontrollers in physics teaching. The student who participated in the case study showed above-average interest in physics during the sixth and seventh grades, which was the reason for the focus of this study on this student.

Keywords: AI, microcontrollers, gifted students, student activities, creativity.

Correction of Kepler third law for the stars of Milky Way

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Abstract. In this paper, the radial and transverse equations in polar coordinates for a modified Newtonian gravitational potential will be solved. The gravitational potential will be modified by a correction which is different from Einstein's gravity. In Einstein's gravity, the Schwarzschild radius term will be replaced with some arbitrary critical length. The correction of constant of the Kepler's third law $\left[\frac{GM}{4\pi^2} = 1 \frac{AU^3}{year^2}\right]$ is about five percent. Kepler's third law gives good agreement for planets of solar system. The correction are related on the Stars (S2, S38, S55, S62, S4711, S4712, and S4714) of Milky Way. The next correction of Kepler's constant for stars of Milky Way was obtained: $\frac{a^3 4\pi^2}{T^2 GM_{BH}} = 0.95 - 1.05$, where a is semimajor axis, T is orbital period of star around the black hole, and M_{BH} is the mass of black hole in the center of galaxy.

Keywords: Kepler third law, Einstein potential, Milky Way

1. GENERAL EQUATION OF MOTION IN TWO DIMENSIONS [1]

The equation of motion of a particle in a central field is given by following expression:

$$m\vec{a} = f(r)\vec{e}_r, \quad (1)$$

in polar coordinates. From above equation we get two equations, first the radial equation:

$$m \left[\frac{d^2 r}{dt^2} - r \left(\frac{d\varphi}{dt} \right)^2 \right] = f(r). \quad (2)$$

Second equation is transverse differential equation:

$$m \left(r \frac{d^2 \varphi}{dt^2} + 2 \frac{dr}{dt} \frac{d\varphi}{dt} \right) = m \frac{d}{dt} \left(r^2 \frac{d\varphi}{dt} \right) = 0. \quad (3)$$

From transverse equation we get next expression: $r^2 \frac{d\varphi}{dt} = constant = J$, where J is angular momentum per unit mass. The angular momentum of particle is constant when it moves under the action of a central force.

2. ENERGY EQUATION OF THE ORBIT [1]

The square of the velocity in the polar coordinates is given by next equation:

$$v^2 = \left(\frac{dr}{dt}\right)^2 + r^2 \left[\frac{d\varphi}{dt}\right]^2. \quad (4)$$

Central force is conservative, so the total energy of system $E = T + V(r)$ is constant, T is kinetic energy and $V(r)$ is potential energy. The equation of energy is given by following expression:

$$E = T + V(r) = \frac{m}{2} v^2 + V(r), \quad (5)$$

$$E = \frac{m}{2} \left[\left(\frac{dr}{dt}\right)^2 + r^2 \left[\frac{d\varphi}{dt}\right]^2 \right] + V(r). \quad (6)$$

Now we can substitute the relation for angular momentum per unit mass (transverse equation) and get the next equation:

$$\left(\frac{dr}{dt}\right)^2 + \frac{J^2}{r^2} + \frac{2V(r)}{m} = \frac{2E}{m}. \quad (7)$$

From the energy equation we obtain the following expression for radial velocity:

$$\frac{dr}{dt} = \sqrt{\frac{2E}{m} - \frac{2V(r)}{m} - \frac{J^2}{r^2}}, \quad (8)$$

i.e

$$\frac{dr}{dt} = \sqrt{2\varepsilon - 2v(r) - \frac{J^2}{r^2}}, \quad (9)$$

where ε is energy per mass and $v(r)$ is gravitational potential per mass.

3. DETERMINATION THE RADISU R IN FUNCTION OF TIME T IN MODIFY GRAVITATIONAL POTENTIAL [2,3]

Einstein gravitation potential is:

$$v_{Einstein}(r) = \frac{V_{Einstein}(r)}{m} = -\frac{GM}{r} \left[1 + \frac{r_s}{r}\right], \quad (10)$$

$$v_{critical}(r) = \frac{V_{critical}(r)}{m} = -\frac{GM}{r} \left[1 + \frac{r_c}{r}\right], \quad (11)$$

where M is the mass of gravitation center, G is gravitation constant $G= 6.67 * 10^{-11}Nm^2/kg^2$, $r_s = \frac{2GM}{c^2}$ is Schwarzschild radius, c is velocity of the light, and r_c is critical length.

Now we start from the equation of energy:

$$\frac{dr}{dt} = \sqrt{2\varepsilon + \frac{2GM}{r} \left[1 + \frac{r_c}{r}\right] - \frac{J^2}{r^2}}, \quad (12)$$

$$\frac{dr}{dt} = \sqrt{2\varepsilon + \frac{2GM}{r} - \frac{J^2 - 2GMr_c}{r^2}}. \quad (13)$$

We substitute $J_1^2 = J^2 - 2GMr_c$ and we get following equation [2,3]:

$$J_1 dt = \pm \frac{dr}{\sqrt{\frac{2\varepsilon}{J_1^2} + \frac{2GM}{rJ_1^2} - \frac{1}{r^2}}}. \quad (14)$$

After that we get next form of equation:

$$J_1 dt = \pm \frac{dr}{\sqrt{\frac{2\varepsilon}{J_1^2} + \left[\frac{GM}{J_1^2}\right]^2 - \left[\frac{1}{r} - \frac{GM}{J_1^2}\right]^2}}. \quad (15)$$

We take following expressions $\left[\frac{e}{L}\right]^2 = \frac{2\varepsilon}{J_1^2} + \left[\frac{GM}{J_1^2}\right]^2$ and $\frac{1}{L} = \frac{GM}{J_1^2}$, where $L = a(1 - e^2)$ semilatus rectum, e is eccentricity, a is semimajor axis. For $e < 1$ and $E < 0$, we have closed orbit i.e ellipse or circle. For $e = 1$ and $E = 0$ we have parabolic orbit and for $e > 1$ and $E > 0$ we have hyperbolic orbit. In our case the orbit is ellipse and the equation becomes:

$$r = \frac{L}{1 + e \cos \varphi}. \quad (16)$$

Our orbit equation becomes:

$$J_1 dt = \pm \frac{dr}{\sqrt{\left[\frac{e}{L}\right]^2 - \left[\frac{1}{r} - \frac{1}{L}\right]^2}}. \quad (17)$$

Then we take next substitution:

$$r = \frac{1}{x} = \frac{L}{1 + e \cos \varphi}. \quad (18)$$

Our equation becomes finally:

$$J_1 \frac{T}{2} = \int_0^\pi \frac{L^2 d\varphi}{[1 + e \cos \varphi]^2} = \frac{L^2 \pi}{[1 - e^2]^{3/2}}, \quad (19)$$

where T is period of orbit.

For orbital period we get:

$$T = \frac{L^2 2\pi}{[1 - e^2]^{3/2} J_1} = \frac{L^2 2\pi}{[1 - e^2]^{3/2} [J^2 - 2GM r_c]^{1/2}}. \quad (20)$$

Then we get

$$T = \frac{L^2 2\pi}{J[1 - e^2]^{3/2}} \left[1 - \frac{2GM r_c}{J^2} \right]^{-1/2}, \quad (21)$$

$$T \approx \frac{L^2 2\pi}{J[1 - e^2]^{3/2}} \left[1 + \frac{GM r_c}{J^2} \right]. \quad (22)$$

Also we use the approximation that the $\frac{GM}{J^2} = \frac{1}{L}$ in next expression:

$$T^2 = \frac{4\pi^2}{GM} a^3 \left(1 + \frac{2r_c}{L} \right). \quad (23)$$

It can be used that $\frac{2r_c}{L} = \alpha$ and our equation becomes:

$$T^2 = \frac{4\pi^2}{GM} a^3 (1 + \alpha). \quad (24)$$

Inverse law is:

$$\frac{4\pi^2}{GM_{BH}} \frac{a^3}{T^2} = 1 - \alpha. \quad (25)$$

So for α parameter which is correction of Kepler's third law we get next expression:

$$\alpha = 1 - \frac{4\pi^2}{GM_{BH}} \frac{a^3}{T^2}. \quad (26)$$

The value of α can be positive and negative.

4. CONCLUSION

In Table we present the properties of stars of Milky Way. In table we have next quantities The name of stars of Milky Way, the simimajor axis and period of rotation of stars, relation between the power of three of semimajor axis and the square of orbital period and finally we get values of constant α . Dates for stars are used from [4].

| Star | $a(AU)$ | $T[years]$ | $a^3(AU^3)$ | $T^2(year^2)$ | $a^3(AU^3)/T^2(year^2)$ | α |
|-------|---------|------------|-------------|---------------|-------------------------|----------|
| S2 | 1044.2 | 16.0 | 1130547271 | 256 | $4.447 * 10^6$ | -0.035 |
| S38 | 1178.1 | 19.2 | 1635108092 | 368.64 | $4.436 * 10^6$ | -0.032 |
| S55 | 896.9 | 12.8 | 721492917 | 163.84 | $4.404 * 10^6$ | -0.025 |
| S62 | 740.1 | 9.9 | 405355438 | 98.01 | $4.135 * 10^6$ | 0.038 |
| S4711 | 619.2 | 7.6 | 237406630 | 57.76 | $4.110 * 10^6$ | 0.044 |
| S4712 | 3720.6 | 112 | 51520374361 | 12544 | $4.107 * 10^6$ | 0.044 |
| S4714 | 837.2 | 12 | 586880807 | 144 | $4.076 * 10^6$ | 0.051 |

The Kepler constant for Milky Way is $\frac{GM_{BH}}{4\pi^2} = 4.297 * 10^6 \frac{AU^3}{y\text{ear}^2}$, where M_{BH} is mass of black hole in the center of galaxy. It is obtained for absolute value of mean critical length:

$$r_c = 0.0384 \frac{L}{2} = 0.192L \approx 0.02L = 0.02a(1 - e^2)$$

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Possibilities of using microcontrollers in STEM education

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Abstract. The global problem of STEM (Science, Technology, Engineering, and Mathematics) science is student demotivation to learn. Therefore, in the last few decades, strides have been made in bringing these sciences closer to students through various student-centered teaching approaches as well as technical-technological innovations. One such approach is STEM education. At the same time, this approach creates a coherent picture of the studied phenomenon through the integration of different sciences. However, the resources required to deliver STEM education can be quite demanding for school conditions. Therefore, as the most economical solution, which fully preserves the characteristics of experiments and empirical verification of theoretical laws, it is the use of microcontrollers. Microcontrollers require a combination of programming and STEM sciences. It is this combination that represents the best answer to the demands of modern society, which is to ensure that students are as well prepared and equipped as possible for life in the 21st century and in a world that is constantly changing. Additional advantage of microcontrollers is low cost, reusability, and safe environment. This is a particularly important issue when looking at nuclear physics, where classical apparatus cannot be applied in school conditions, both because of the safety of students from radioactive sources and because of the sensitivity of expensive and sophisticated apparatus. In addition to nuclear physics and nuclear medicine, microcontrollers can be applied to various thermodynamic systems such as testing meteorological parameters, as well as to all branches of natural and technical-technological sciences.

Keywords: microcontrollers, teaching physics, student-centered approach.

Can teenagers understand the work of contemporary patents in electronics. Examples from two experimental Physics Olympiads

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Abstract. The principle of chopper stabilized (auto-zero) precision direct current amplifiers is the basis to the work of many contemporary operational amplifiers. The main idea is described in many tutorials for electronic engineers. See for example MT-055 TUTORIAL Analog Devices. The original American patent by Edwin Goldberg and Jules Lehmann is from 1949 (U.S. Patent 2,684,999) but only now it is implemented in big number operational amplifiers. The principle can be illustrated by two batteries, a double switch and two capacitors. This means that can be understood by every student which knows what is a battery, capacitor and can measure the voltage by a multimeter. In other words, every student. We implemented a scheme from tutorials as set-up for student and gave as a problem for two Experimental Physics Olympiads (EPO) in 1914 and 2023 arXiv: 1511.04328v1 and v2. The results confirmed our expectation most of the students performed the sequential tasks and a significant number of last year students explained the result. In other words our best students can reproduce the main idea of an American patent during the 4 hours competition. Practically this is the percentage of the students who continue his education abroad. Some qualitative observations deserve to be considered by physics teachers.

Keywords: Physics Olympiads, electronics, students.

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