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## STEM APPROACH TO PHYSICS STUDY OF FUTURE ENGINES: STUDY OF THE PHENOMENA OF ELECTROMAGNETIC INDUCTION

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### Abstract

**Formulation of the problem.** Actuality of the introduction of the STEM approach during general physics study is determined by the need for the formation of competences for conducting practical-oriented research by students from the first year: scientific and engineering methods of understanding reality help future engineers to form the scientific and technological picture of the world. **Analysis of research.** The phenomenon of electromagnetic induction is a complex subject in the course of general physics; at the same time; it has wide practical application. A modern physical experiment is a universal means for future specialists to acquire relevant research competencies; a computer-oriented system of physical experiment effectively forms the general scientific and professional skills of future engineers. **The purpose of the article** was to study the didactic peculiarities of the use of scientific and engineering (STEM) research methods in the study of the phenomena of electromagnetic induction by the future engineers in the course of general physics. **Methods.** theoretical and empirical methods of scientific research are applied: methods of analysis and modeling; pedagogical experiment; observational and praximetric methods for determining the effectiveness; efficiency and practical suitability of the methodical system. **Results and discussion.** The study of the phenomenon of electromagnetic induction using the computer-oriented system of physical experiment demonstrates the stages of the scientific method of research; which begins with the formulation of the problem; the construction of theoretical models; continues with the hypothesis; followed by experimental verification; the processing of experimental data and their interpretation; the search for additional information; adjustment experiment; the advancement of new hypotheses and their subsequent verification. The STEM approach for the EMI study has been implemented in accordance with the engineering method of research. It was carried out through the design stages; which include: brainstorming; the introduction of methods for implementing the installation; the selection of materials; the creation of a prototype and its multiple testing. **Conclusions.** The application of different approaches oriented both to scientific research in the computer-based system of physical experiment and to the engineering method using STEM training shows practical applicability and effectiveness: implementation of this aim required the attraction and development of various levels of competencies starting from algorithmic actions to creative approach in the case of self-creation of an experimental installation. It is revealed that STEM is an engineering method in educational research by its content and purpose. Further development requires appropriate organizational and pedagogical conditions for the implementation of the methodical system for physics study of future engineers using STEM.

**Keywords:** computer-based system of physical experiment; digital measuring complex; general physics; electromagnetic induction; engineering method; STEM; scientific method; STM32

## 1. Introduction

Global hyperlinks permeate all spheres of life of a modern person. Techniques and processes; modern automated production; interpersonal communication. Various services; in particular; education; tourism and recreation are based on the use of information technologies. We live in the time of the global uncertainty of the closest future; which is often described using a synergistic approach to the currently observed technological; economic; and socio-cultural phenomena. The materials of the current initiatives of the international organization The World Economic Forum claim that the ability to creativity and digital competence will determine the success and welfare of both individuals and countries in the 21st century [1]. Note that in the professional activity of an engineer these qualities are the measure of its competitive ability in the modern labor market [2].

The problem of youth employment in the 21st century is a key to the socio-economic and political processes of the future; today it needs a large-scale and rapid changes in the education system. In this context; the developed countries are initiators and investors of national programs (in particular; STEM education [3]); designed to combine the efforts of the public and private sectors of the economy [4]. According to one of the three leaders of the newly created inter-industry initiative "The Council for the American Worker" I. Trump; the efforts of the US administration are aimed at expanding "access to STEM education for K-12 students; and to help 11 million students and workers by working with Congress to Pass an Improved Perkins Career and Technical Education Bill" [5].

Consequently; all educational institutions are currently in a state of choice of innovative methods and forms of study [6]; [7]. Numerous pedagogical studies in the field of higher professional education indicate such key interconnected problems in the training of future engineers that determine the selection of innovative tools; methods; and teaching technologies: understanding the role and place of physical laws in engineering; skills in conducting a qualitative physical experiment with the use of software - hardware; readiness for independent design and technological activity. At the same time; the necessity of processing of large volumes of digital data from different origins requires the formation and development of critical and creative engineering thinking.

An important feature of modern higher education is use of specific methodologies both at general

scientific and at the specific scientific levels; which also includes the methodology and technique of scientific research [7]. The corresponding teaching task at a technical university can be accomplished on the basis of application of scientific and engineering research methods; the STEM approach and the information-technological platform; which contains data about possible ideas of educational projects; means and possible modern technologies for both real and virtual experiments.

So; firstly; the relevance of the implementation of the STEM approach during general physics study is determined by the need for future engineers in the competence of conducting practical studies from the first year. Secondly; it is important for students; especially future engineers; to recognize the difference between scientific and engineering methods that form different aspects of world outlook in an era of rapid technological changes in the 21st century.

## 2. Analysis of research

A preliminary analysis of the problem showed that the effectiveness and practical applicability of pedagogical innovations is most clearly manifested during the study of complicated for understanding by students physics topics; which at the same time have wide practical application. It includes the phenomenon of electromagnetic induction (EMI) and the law of Faraday that are logically deduced from the classical theory of electromagnetism and Maxwell's laws and are studied in the theory of classical electromagnetism during the first year.

A collective study of the contents of almost two dozen textbooks for higher education revealed the origins of existing difficulties in understanding conceptual foundations of EMI by students [9]. Among the criteria by which the authors [9] carried out the analysis were the presence of tasks that concerned situations "the field varies" and "the circuit moves"; "the fact that a stationary magnetic field does not generate induced EMF;" "differentiates the induced EMF from induced electrical current". At the same time; there is almost complete absence of discussion in the textbooks on "the difference between the surface area of the flux integral and the surface area of the circuit" and that "a phenomenon related to EI can be resolved by means of the field or force model and they are both complementary". However; the most striking was the conclusion according to the criterion "Activities

are proposed; which involve raising hypotheses and/or analyzing variables": 84.2% of the textbooks do not contribute to the formation of skills for studying theories and conducting research; developing the critical thinking of students in the process of seeking explanation for the described phenomena.

In this way; to help students understand the concepts and apply them in the technological contexts and in everyday life; we need to reorganize the methods of teaching students in accordance with the principles of scientific activity [10].

Significant pedagogical experience shows that a modern physical experiment acting as an independent problem-solving task is a universal means for future specialists to acquire relevant research competencies; the practice of solving problems under uncertainty; and stimulates the self-development of the personality of a future engineer **Ошибка! Источник ссылки не найден.**

Classical school laboratory work on the study of EMI is an example of the Faraday law investigation; in particular; the purpose of such works is to obtain an induction current by means of a magnet coil or a simple unipolar generator such as the Faraday drive [11].

Studies at the beginning of the 21st century prove the effectiveness of a computer-based system of physical experimentation (CBSPE) in forming the skills of future engineers and their technological competence [12].

In the training of technical disciplines and physics; the most effective and popular nowadays are computerized (digital) measuring complexes – an integral part of CBSPE where a personal computer plays the role of a center for the processing of data (information) and its external interface is specialized or adapted as measuring and / or registering basis. The study of network data showed that the most popular nowadays in European educational institutions there are digital measuring complexes *Fourier education*<sup>®</sup> [13] and *PHYWE System GmbH*<sup>®</sup> [14]. The basis of such laboratories is a computer gauge - an electronic unit containing an analog-to-digital converter; which can be connected to sensors for measurement of physical quantities and measuring devices; a communication interface with a personal computer; as well as software (*MultiLab*; *Measure*) for data collecting and processing.

The study of EMI using CBSPE by different authors is carried out on qualitative and quantitative levels: observing the pulse of the

electromotive force (EMF) induction [15] and studying the dependence of the magnitude of the induction EMF on the parameters of the coil and the speed of the magnet input into the coil winding; the principle of measuring the EMF induction; methods the received signal processing; and checking the law of Faraday-Maxwell [14].

### 3. The purpose of the article

The purpose of the work is to study the didactic features of the use of scientific (CBSPE) and engineering (STEM) research during the future engineers study of the electromagnetic induction phenomenon in the course of general physics.

### 4. Methods

The theoretical methods of analysis were used in this work for investigation of the pedagogical and scientific-methodical literature; departmental normative documents; traditional approaches to the EMI study in the course of physics of higher educational institutions; innovative experience and generalization of own long-term work experience. The simulation method was used to justify the method of using the STEM approach in physics education. At the empirical stage of the study; pedagogical experiment and observational methods (direct; indirect; observation included); conversations with teachers and students; praximetric methods (timekeeping; analysis of performed work: laboratory reports and design work) were used.

### 5. Results and discussion

Approbation of the methodology is carried out during laboratory works and non-auditing hours at the Department of General Physics of the National Aviation University at laboratory lessons.

The experiment was carried out using the STEM-laboratory of MANLab of the National Center "Small Academy of Sciences of Ukraine" [16]. CBSPE contains the following equipment: coil of copper wire on 1600 turns; neodymium magnets with a diameter of 8 mm and a length of 20 mm and 70 mm; glass tubes with an internal diameter of 10 mm; a length of 300 mm; a voltage sensor *Fourier*; a light barrier; digital data logger *Einstein LabMate*; *MultiLab* software; dial calipers; stand with couplings and legs.

According to [14] and [15]; the magnet is thrown through a glass tube; its walls provide the magnet translational motion in the direction of the coil.

Before getting into the coil; the magnet passes through a turning-point (infrared transmitter and receiver); which makes it possible to measure the speed of a magnet with known linear dimensions:

$$v = l / \Delta t; \quad (1)$$

where  $l$  is the length of the magnet;  $\Delta t$  is the interruption time of the photodetector signal when passing through a constant magnet. Changing the height of the drop of the magnet we can vary its speed  $v$  before the entrance to the coil and; consequently; the rate of change of the magnetic flux

$d\Psi/dt$ ; coiled with the coil turns ( $d\Psi/dt \sim v$ ).

The signal from the  $U_1$  photoconductor and the induction EMF pulse  $\varepsilon_i$  are transmitted to the *Einstein LabMate* input and recorded by the *MultiLab* software in the form of a rectangular pulse  $U_1(t)$  and a graph of a complex shape (Fig. 1). The change in the total magnetic flux (flux-coupling)  $\Delta\Psi$  through the coil during the magnet motion is determined in accordance with the law of electromagnetic induction [16]:

$$\Delta\Psi = \int |U_2| \cdot dt; \quad (2)$$

where  $U_2 = \varepsilon_i$ .

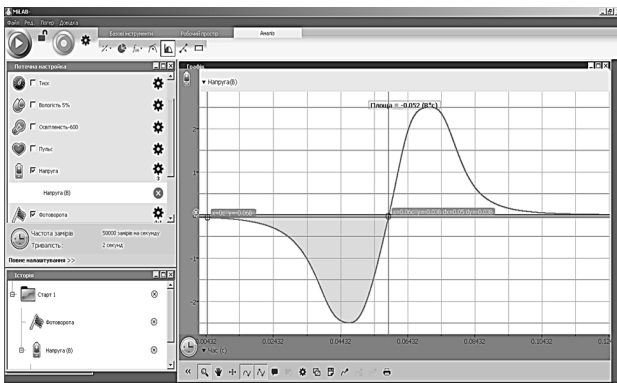


Fig. 1. Dependencies  $U_1(t)$  and  $U_2(t)$  constructed by the program *MultiLab*

The change in the total magnetic flux according to (2) is defined as the area of the figure limited by the graph  $U_2(t)$  and abscissa (the painted part in Fig. 1). This area can be calculated using *MultiLab* software by setting the range using markers. The experiments are carried out for different initial height of the magnet and graphic dependences  $\varepsilon_i(v)$  and  $\Delta\Psi(v)$  are constructed; the results are analyzed. The experiment can be repeated using different coils (for example; halved); and similar

measurements can be made by changing the polarity of the magnet when entering the tube; which will change the sign of the induced voltage to the opposite. The resulting graphic dependencies can be compared by placing them simultaneously in the picture *MultiLab*.

We can also measure the voltage on the top and bottom of the coil as suggested in [14]. In this case; voltage displays on the bottom of the coil appear later and the distance between the peaks will be greater.

Studying the EMI using CBSPE can be applied as a demonstration to the students the stages of the scientific method of research; which begins with the formulation of the problem; the construction of theoretical models; continues with suggestion of the hypothesis with subsequent experimental verification; processing of experimental data; their interpretation; the search for additional information; the adjustment of the experiment; the advancement of new hypotheses and their further verification [7].

We have found that in order to form and develop a corresponding type of thinking; familiarization with the engineer activities during physics study of students of the Technical University engineering method of research can be used.

In contrast to the scientific method; the engineering method involves the creation of a socially-claimed product with certain criteria. The engineering design process can be presented through generalized steps that are repeated in real activity: designing a prototype; testing it; identifying previously unresolved problems; and repeating the previous steps (iteration). So; the expert finds out the deep essence of the subject of design; the needs of the customer; the degree of importance and complexity of the problem; etc. [7].

The STEM approach during the EMI study was implemented through the student's engineering activities for the creation of a laboratory experimental setup (Fig. 2).

It contains two coils made of copper wire having a different number of turns (77 and 235); diverting pipes of variable length; which are connected to a tripod holding the entire structure; a neodymium magnet; a panel with LEDs (Fig. 3; a); a soft brake; hardware-computer complex STM32 (Fig. 3; b) for displaying the PC data sensors; calculations and plotting.

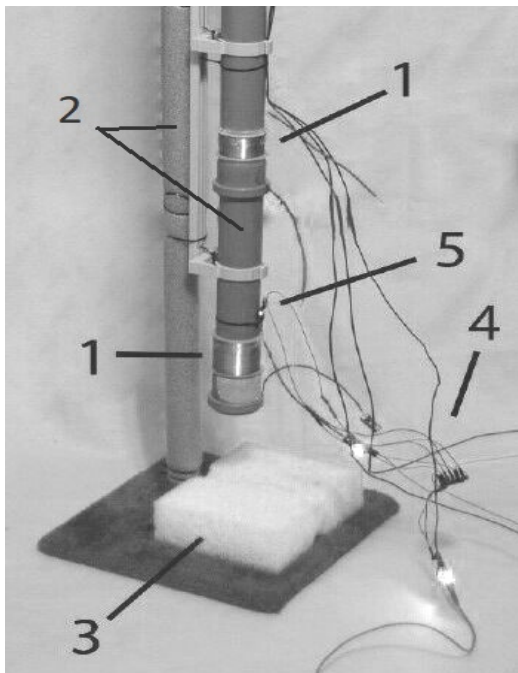


Fig. 2. Installation for the EMI study (lower part):

- 1 – coils; 2 – tripod and guide pipes; 3 – soft brake;
- 4 – hardware and computer complex STM32;
- 5 – Hall sensors

To demonstrate the directional dependence of the polarity of the magnet; a panel with connected in parallel LEDs (Fig. 3; *a*) is used: red (with a transparent lens diameter of 5 mm; voltage drop – 1.9-2.1V; current - 20 mA; wavelength 620 -625 nm; angle 90 degrees) and blue (diameter 5 mm; voltage drop - 3.0 -3.2 V; current - 20 mA; wavelength 462-465 nm; angle 20-25 degrees).

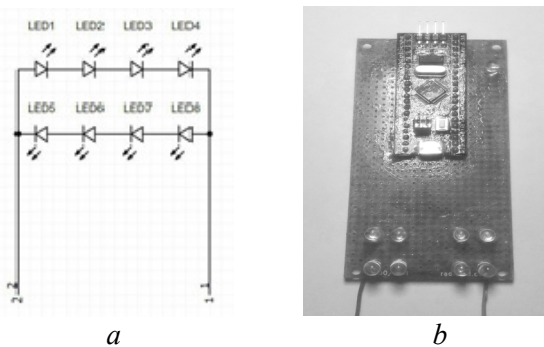


Fig. 3. STM32 with LEDs: *a* – the scheme of the combination of LEDs; *b* – the appearance

The operation of such a demonstration-measuring installation is based on the use of the microcontroller STM32F103C8 (Fig. 3; *b*); the ammeter SH150917 (Fig. 4; *a*); built on the basis of the ACS712 chip

[17] and measuring the voltage with a voltmeter VDC 25 V (Fig. 4; *b*) [19].

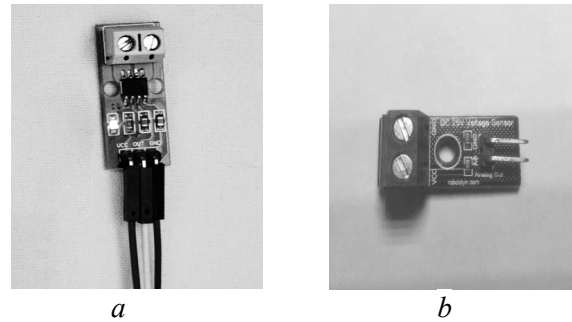


Fig. 4. Means of measurement: *a* - ammeter SH150917; *b* - voltmeter VDC 25 V

The use of the Serial Port Plotter software allows to build graphs for changing the current and voltage. The time intervals of the magnet in the tube were measured according to two Hall sensors operating on the LM393 chip [20] (Fig. 5); on the basis of which the speed of the magnet entering the coil winding is calculated.

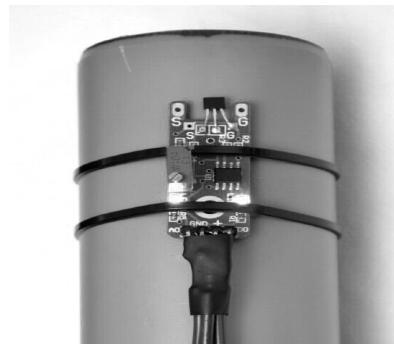


Fig. 5. Module with Hall sensor on chip LM393 in the upper part of the guide pipe.

In this work a neodymium magnet is used; it has the following characteristics: diameter  $D = 45 \text{ mm}$ ; height  $H = 30 \text{ mm}$ ; clutch force  $F = 900 \text{ N}$ ; mass  $m = 390 \text{ g}$ ; magnetization vector  $J = 42 \text{ A/m}$ ; nickel plated surface coating ( $\text{Ni-Cu-Ni}$ ).

The device experiment allows study the basic properties of magnetic induction. It shows the generation of an alternating electric current under the influence of an alternating magnetic field of a moving magnet; it is registered in the form of an EMF pulse.

Further research has shown that the installation can be supplemented by a compact oscilloscope DSO150 (Fig. 6) based on the previously used

microcontroller STM32F103C8 [21]. The device has the following characteristics: maximum sampling rate 1 MSA / s; accuracy of 12 bits; sample buffer size: 1024 bytes; analog bandwidth: 0-200 kHz; vertical sensitivity: 5 mV / under-20 V / sub; input impedance:  $1\text{M}\Omega / 20\text{pF}$ ; maximum input voltage/capacity: 50Vpp; horizontal scan range: 10ms / under-500sec; error: 5%.

Equipped with 2.4-inch TFT display; which can display the maximum; average; minimum and peak values of the signal amplitude. The feature of the DSO150 oscilloscope is the ability to capture an image that allows you to study the parameters of electrical signals.

This device is positioned by the manufacturer as a collection for self-assembly; which reduces its cost.

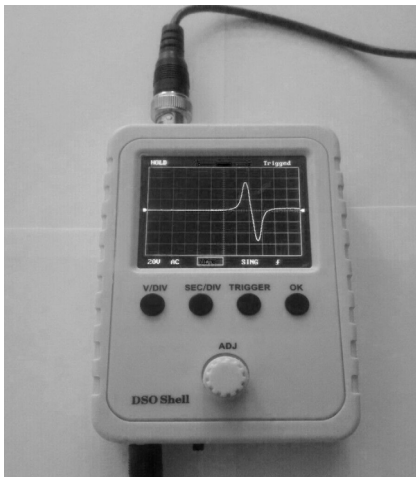


Fig. 6. EMC induction pulse on the oscilloscope display

The construction of the plant in accordance with the engineering method of research was carried out through the design stages; which include: brainstorming; the nomination of methods for implementing the installation; the selection of materials (in particular; the use of a powerful magnet requires the absence of ferromagnets in the experimental installation); the creation of a prototype and its multiple testing. The first tests of the device performance have found that the voltage generated during the change in the magnetic flux in the coil winding is too large for the proposed LEDs; while insufficient for high-voltage LEDs or LEDs. To solve this problem; a voltage stabilizer based on the LM2596 chip was used [22].

The results of the experiment prove the validity of the formulation of the law of electromagnetic induction since the signs of the EMF in the case of

growth and decrease of the flow are opposite. The phenomenon of electromagnetic induction is the cause of the EMF under the influence of which electric current flows in closed conductors [12].

## 5. Conclusions

The conducted research has shown the expediency of using a pilot plant in the laboratory activity of students of higher technical education institutions and also demonstrated the effectiveness of applying different approaches focused on both scientific research in the framework of CBSPE and the engineering method using STEM - a transdisciplinary approach to the future engineers study.

In both cases; the educational aim of the discipline "Physics" that was related with the experimental testing of the laws of the EMI was achieved. Its implementation by students required the attraction and development of various levels of competencies from algorithmic actions in the case of CBSPE application to the creative approach in the case of the independent creation of an experimental setup. The latter turned out to be a rather complicated task realized by the future engineers at the level of the first prototype under the leadership of a teacher for 4 months at extra-class time. Its modifications were presented at the Annual International Student Conferences «Політ-2017; 2018». It should be noted that the cost of construction with equipment and consumables was about \$ 80.

It is revealed that in its content and purpose STEM is an engineering method of educational research. The STEM approach is definitely effective in forming the skills demanded in the 21st century. It demands to use topical and innovative technologies; understanding of fundamental physics laws; and developed critical thinking. Note that now STEM studies in general physics course can be successfully implemented with students; which is characterized; above all; by high internal motivation and cognitive readiness.

Further development of the method requires the organizational and pedagogical conditions for the implementation of the system for physics study of the future engineers using STEM:

- organizational and informational support of the methodical system at the level of departments and higher technical educational institutions in general;
- modern material and technical support of the educational process using a full-scale experiment and ICT;

- developed and systematically updated educational and methodical complex; including electronic; which will contain a bank of tasks oriented on STEM;

- competent and trained pedagogical personnel;

- students who have a sufficient level of basic technical training for higher technical education to conduct STEM training activities.

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**STEM підхід у навчанні фізики майбутніх інженерів: вивчення явища електромагнітної індукції**

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**Постановка проблеми.** Актуальність впровадження STEM підходу у вивченні курсу загальної фізики визначається необхідністю формування компетенцій проведення практико орієнтованих досліджень вже з молодших курсів: науковий та інженерний методи пізнання дійсності формують у майбутніх інженерів наукову і техніко-технологічну картини світу. **Аналіз попередніх досліджень.** Явище електромагнітної індукції – комплексна і складна тема з курсу загальної фізики; яка водночас має широке практичне застосування. Сучасний натурний фізичний експеримент є універсальним засобом для набуття майбутніми фахівцями відповідних дослідницьких компетенцій; комп'ютерно орієнтована система фізичного експерименту ефективно формує загальнонаукові і професійні навички майбутніх інженерів. **Метою роботи** було дослідження дидактичних особливостей використання наукового та інженерного (STEM) методів дослідження у вивченні майбутніми інженерами явища електромагнітної індукції у курсі загальної фізики. **Методи:** застосовано теоретичні і емпіричні методи наукового дослідження: методи аналізу і моделювання; педагогічний експеримент; обсерваційні і праксиметричні методи для визначення дієвості; ефективності і практичної придатності методичної системи. **Результати і дискусія.** Вивчення явища електромагнітної індукції з використанням комп'ютерно орієнтованої системи фізичного експерименту демонструє етапи наукового методу дослідження; який починається з формулювання проблеми; побудови теоретичних моделей; продовжується висуненням гіпотези з подальшою експериментальною перевіркою; опрацюванням експериментальних даних; їх інтерпретацією; пошуком додаткової інформації; коригуванням експерименту; висуненням нових гіпотез і їх подальшою перевіркою STEM підхід у дослідженні ЕМІ було реалізовано відповідно до інженерного методу дослідження здійснювалось через етапи проектування; до яких входять: мозковий штурм; висування способів реалізації установки; підбір матеріалів; створення дослідного зразка та його багаторазове випробування. **Висновки.** Застосування різних підходів; орієнтованих як на наукове дослідження у рамках комп'ютерно орієнтованої системи фізичного експерименту; так і на інженерний метод з використанням STEM навчання виявили практичну придатність; дієвість та ефективність: реалізація поставленої мети потребувала залучення і розвитку різного рівня компетенцій від алгоритмізованих дій до творчого підходу у випадку самостійного створення експериментальної установки. Виявлено; що за своїм змістом і метою STEM є інженерним методом у навчально-науковому дослідженні.



Розробки і подальшого розвитку потребують організаційно-педагогічні умови реалізації методичної системи навчання фізики майбутніх інженерів з використанням STEM.

**Ключові слова:** STEM; загальна фізика; електромагнітна індукція; інженерний метод; комп'ютерно орієнтована система фізичного експерименту; науковий метод; цифровий вимірювальний комплекс; STM32.

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**STEM подход в обучении физики будущих инженеров: изучения явление электромагнитной индукции**

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**Постановка проблемы.** Актуальность внедрения STEM подхода в изучении курса общей физики определяется необходимостью формирования компетенций проведения практико ориентированных исследований уже с младших курсов: научный и инженерный методы познания действительности формируют у будущих инженеров научную и технико-технологическую картины мира. **Анализ предыдущих исследований.** Явление электромагнитной индукции- комплексная и сложная тема курса общей физики; которая имеет широкое практическое применение. Современный натурный физический эксперимент является универсальным средством для приобретения будущими специалистами соответствующих исследовательских компетенций; компьютерно ориентированная система физического эксперимента эффективно формирует общенаучные и профессиональные навыки у будущих инженеров. **Целью работы было** исследование дидактических особенностей использования научного и инженерного (STEM) методов исследования в изучении будущими инженерами явления электромагнитной индукции в курсе общей физики. **Методы:** применены теоретические и эмпирические методы научного исследования: методы анализа и моделирования; педагогический эксперимент; наблюдательные и праксиметричные методы для определения действительности; эффективности и практической пригодности методической системы. **Результаты и дискуссия.** Изучение явления электромагнитной индукции с использованием компьютерно ориентированной системы физического эксперимента демонстрирует этапы научного метода исследования; который начинается с формулировки проблемы; построения теоретических моделей; продолжается выдвижением гипотезы с последующей экспериментальной проверкой; обработкой экспериментальных данных; их интерпретацией; поиском дополнительной информации; корректировкой эксперимента; выдвижением новых гипотез и их последующей проверкой. STEM подход в исследовании ЭМИ был реализован в соответствии с инженерным методом исследования и осуществлялся через этапы проектирования; в которые входят: мозговой штурм; выдвижение способов реализации установки; подбор материалов; создание опытного образца и его многократное испытание. **Выводы.** Применение различных подходов; ориентированных как на научное исследование в рамках компьютерно ориентированной системы физического эксперимента; так и на инженерный метод с использованием STEM обучения обнаружили практическую пригодность; действенность и эффективность: реализация поставленной цели потребовала привлечения и развития разного уровня компетенций от алгоритмизированных действий до творческого подхода в случае самостоятельного создания экспериментальной установки. Выявлено; что по своему содержанию и целью STEM является инженерным методом в учебно-научном исследовании. Разработки и дальнейшего развития требуют организационно-педагогические условия реализации методической системы обучения физике будущих инженеров с использованием STEM.

**Ключевые слова:** STEM; общая физика; электромагнитная индукция; научный метод; инженерный метод; компьютерно ориентированная система физического эксперимента; цифровой измерительный комплекс; STM32.

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