Implementation strategy of IT-integrated STEM methodology at Higher Education Institutions: Case of Turkmenistan

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ABSTRACT

STEM (science, technology, engineering and mathematics) methodology (instruction) becomes one of the most significant core issues of education due to the fact that labor market demands highly qualified specialists with critical thinking, inquiry, problem solving, creativity, collaboration, communication and IT-related skills. In this regard, this paper presents research results related to realization of national strategies, and applied solutions in the implementation of STEM instruction at engineering-based higher education institutions of Turkmenistan. While the research was conducted, national programmes or priorities, course objectives and features, demands of labor market and IT integration were taken into account. The implementation strategy was developed by dividing the course content into lecture (theoretical), laboratory, problem-solving and non-classroom modules. In each division of course content, applicable tasks were worked out in order to deliver course objectives using STEM instruction. These tasks were prepared in accordance with the four pillars of STEM education considering the information technologies and smart systems being used in engineering processes. The developed strategy was tested at "Metrology and standardization" course and promising results were achieved.

CCS CONCEPTS

• **Computer Uses in Education**; • **General**;

KEYWORDS

strategies of implementing STEM instruction, higher education, IT-integrated course objectives, content division of engineering courses

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1 INTRODUCTION

Together with the technological developments, innovative educational strategies and methods have emerged in order to train youth for better future. Moreover, at engineering universities or higher education institutions, it is highly important to establish strong connection between industry and education so that students know the latest technological processes, visualize theoretical knowledge and get prepared for the field works. In this manner, starting from elementary schools up to higher education institutions, STEM or STEAM (science, technology, engineering, art and mathematics) instruction is being implemented in different modes. Due to the fact that STEM instruction aims at teaching learners all the aspects of a topic from scientific, engineering, technological, mathematical points of view and it guarantees perspective, creative and collaborative individuals, state programmes of many countries pay a special attention to the implementation of the teaching methodology at elementary, secondary and higher education bodies. Moreover, STEM instruction including IT training is one of the key parameters in determining economic growth of a country [1]. In this regard, on 11th February of 2022, there was accepted a programme "Revival of a New Era of the Powerful State: The National Program for the Socio-Economic Development of Turkmenistan in 2022–2052" (hereinafter, The National Programme) in which a task related to introducing STEM instruction to engineering-based higher education institutions (HEIs) was set [2]. In fact, The National Programme includes planned duties which are intended to contribute to the Quality Education and to upgrade the teaching methods using ICT tools. This directs universities and institutes to develop STEM-based and IT-integrated course curricula, to efficiently introduce STEM instruction to the undergraduate courses, and to work out feasible strategies of implementing leading STEM experiences to train highly qualified engineers. Therefore, at State Energy Institute of Turkmenistan, considering national, regional and institutional possibilities, a research has been conducted on the implementation strategy of STEM instruction at engineering education. This paper presents the methodology of introducing STEM instruction, which was proposed for the higher education institutions of the country, test results of the offered technique on specific engineering course, and conclusions about the strategy.

2 LITERATURE REVIEW

Although the meaning of STEM is straightforward, there exist various models of STEM implementation such as "STEM as Discipline", "STEM as Instruction", "STEM as Field" and "STEM as Career". While first two models correspond to elementary and secondary schools, "STEM as Field" model is mostly used at higher education institutions in order to improve critical reasoning skills and logical thinking abilities of students [3]. This model encourages student-faculty interactions within and out of the classroom. Whereas, authors of the paper [4] fosters Design Thinking model in which STEM implementation is carried out through design activities. When it comes to engineering-based higher education, introducing STEM education requires thorough research that enlightens curriculum developers and researchers so that they can set appropriate course objectives, divide course content in regards with scientific, engineering, technological, mathematical pillars, and select feasible teaching method for each part. Because, in our era, effective STEM education at universities serves as a medium for the development of global workforce due to the fact that STEM instruction prepares undergraduates for career life [5]. On the other hand, due to the implemented information-communication technologies and engineering solutions in both industrial sectors and teaching methods, modern job market requires integration of STEM and computer sciences as well. For this purpose, there were developed several strategies by researchers and educators. For instance, authors of the paper [6] worked out a solution in which they managed to achieve efficient teaching process by integrating ICT with STEM through implementing mathematical techniques and analysis. Moreover, in order to promote inclusive education and reach learners with hearing disabilities, Arduino-based STEM strategy was developed by authors of the paper [7] and they achieved promising results. Similarly, the research paper [8] presents a developed IT-based instructional tool called POWER methodology that fosters collaboration and self-learning of students from various fields by carrying out group-tasks. However, the last work is directed to out-of-classroom activities and distinguished students, and it introduces STEM instruction by combining students from different disciplines and setting IT-related tasks. Likewise, the scientific papers [9] and [10] reveal conducted research results related to project- and programming-based learning strategies, which were worked out and tested to support digital education of the country, and dedicated for laboratory hours only. This means that in order to realize planned activities in The National Programme, and achieve inclusive and quality education at higher education bodies, more complex approach is required that integrates both ICT-solutions and STEM instruction. Such an approach can be seen in the article [11], but it is restricted to promoting individual working capabilities of students through ICT-based innovative teaching methodologies. On the other hand, a change always encounters some inertia and therefore, teaching methods undergo transformations regularly. In some countries, even STEAM education is already being encouraged at elementary, secondary and tertiary education [12]. Therefore, this paper presents a strategy of implementing STEM education at engineering-based HEIs considering learning environments, content divisions, digital demands and national priorities.

3 DESCRIPTION OF THE IMPLEMENTATION STRATEGY OF STEM INSTRUCTION AT HIGHER EDUCATION INSTITUTIONS

The National Programme declares tasks, activities and duties that have to be realized by relevant institutions. The STEM instruction

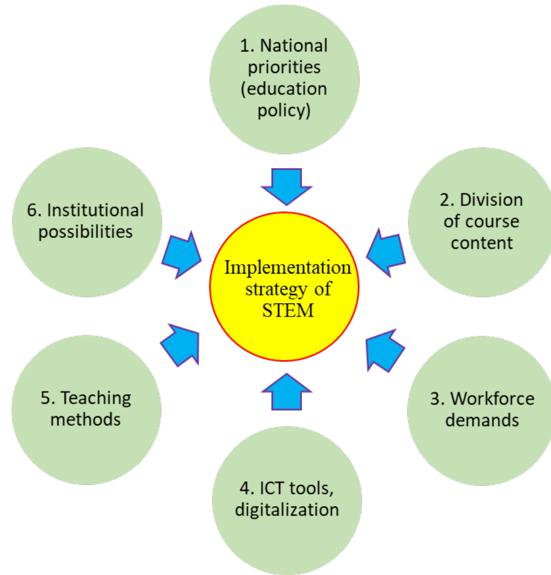

Figure 1: Factors that were considered while developing the implementation strategy of STEM instruction at higher education institutions

is planned to be implemented at engineering-based HEIs in the period of 2023-2030. As a starting point, it is significant to underline that technical courses being taught at engineering-based HEIs of Turkmenistan are mainly divided into four modules: theoretical (lecturing) module, practical (problem-solving) module, laboratory (experimental) module and non-classroom module [11]. This division can be considered as an advantage to distribute STEM-related objectives among those modules. Moreover, the government pays great attention to digitalization of education, industry, services and other sectors of economy as well. There exist several regulations, laws, conceptions and programmes related to digital education, digital economy, digital science and digital transformation. Therefore, while developing this strategy, complex approach was followed, and one criterion was about complying with the educational policy of Turkmenistan. In fact, while developing the implementation strategy of STEM instruction of HEIs, criteria or factors shown in the Figure 1 were taken into account.

As it is obvious from the Figure 1, the development stage of the implementation strategy of STEM-based education included six main factors.

I. ***National priorities (education policy)***. First of all, national education policy related to higher education was studied so that the methodology complies with the priorities of the country. Among national priorities, digital education, STEM education at engineering-based universities, education-industry integration, implementation of AR and VR technologies, ICT usage and internationalization were determined as core issues. Therefore, the study was aimed at the engineering disciplines.

II. ***Division of course content***. As mentioned above, at engineering-based HEIs of the country, technical courses are mainly divided into four modules. Therefore, this type of course division can be taken as an advantage and four pillars of STEM education should be delivered among those divisions. In fact, some objectives of STEM instruction such as comprehending working principles, physical or chemical fundamentals of the course can be covered at theoretical module, while technological and engineering parts can be dealt with at laboratory module, and mathematics-related objectives can be reached at problem-solving module. When it comes to non-classroom module, course curriculum should aim at individual activities for students considering STEM education. The analogous technique of doing so was explained within the paper [11].

III. ***Workforce demands***. Each HEI of the country is founded by corresponding ministry and education is supervised by Ministry of Education. Therefore, it can be derived that HEIs are training specialists mainly for the sectors of their corresponding ministries considering the workforce demands. In this manner, summer schools or field practices can be organized at the industrial-production centers, scientific corners, technological areas and other related plants in order to show technologies being used, engineering work-outs and scientific works to the students. In that way, students will gain the necessary skills for the labor market such as digital literacy, cooperation, critical thinking, communication and problem solving. This will also help to establish faculty-student interactions in informal teaching mode which is found to be one of the key elements that affects students and fosters STEM implementation effectively [3].

IV. ***ICT tools, digitalization***. As it was clearly explained in the papers [9] and [11], integrating ICT tools with the undergraduate education and gaining digital literacy of students are given great attention in engineering pedagogy in order to meet the requirements of the changing world. Therefore, STEM implementation strategy should include IT-based tasks, innovative teaching instruments, appropriate laboratory assignments and digital solutions corresponding to intended discipline. There could be considered using AR/VR technologies including virtual libraries, microcontroller-based experiments or smart systems, electronic educational resources, digital evaluation and assessment tools, and innovative education technologies.

V. ***Teaching methods***. Without any doubt, efficient implementation of STEM instruction requires appropriate teaching methods. Engineering-based HEIs are feasible for interactive and learner-centered teaching techniques such as project-based learning, inquiry-based learning and real-life context-based learning. Moreover, at some technical courses, there are planned project assignments which aim at scientific-mathematical work outs, and carried out by students individually. It can be pointed out that engineering students are highly interested in project-based learning (PBL). As one of the main goals of STEM education is to gain problem-solving skills of students, laboratory or experimental hours should be carried out through PBL technique. Therefore, an appropriate teaching and evaluation method should be chosen by lecturer considering the accessible possibilities and applicable teaching instruments. Here comes the next factor.

VI. ***Institutional possibilities***. Although any implementation strategy of STEM education may be effective or promising, without institutional possibilities it is almost impossible to realize the strategy, as background of HEI serves as a main medium for carrying out the intended activities. Institutional possibilities include technical equipment, innovative educational technologies, laboratory instruments for carrying out STEM-related experiments, and most importantly, capabilities of lecturers as well. Therefore, when STEM instruction is implemented, institutional potential must also be considered and lecturers must be trained regularly so that they can catch up with the latest education-related technological advances and comprehend the fundamentals of STEM education. It should also be underlined that at national HEIs, there are functioning Young Scholars' Councils and scientific groups, under almost each department [8]. These scientific societies should also be considered as institutional potentials because they will contribute to realization of the strategy.

Taking all the above-mentioned factors into account, under the projection of STEM instruction, course objectives were distributed among the different modules of the subject. In that way, implementation strategy fits to the existing higher education system. Table 1 matches the common course objectives of engineering-related subject with four pillars of STEM. These course objectives were worked out as a result of the brainstorming with lecturers of the institute and they are common engineering goals which were developed in regards with the Bloom's taxonomy [13].

As it can be seen from the Table 1, each module contains relevant objectives divided into four groups with respect to STEM pillars. Therefore, while developing course curriculum, it should be considered those STEM-based and IT-integrated objectives, and set specific course objectives taking subject-related digital technologies into account. Afterwards, relevant teaching method must be selected for each topic. In doing so, institutional possibilities also play significant role. In other words, implementation strategy considers continuous qualification improvement of lecturers. By doing so, STEM instruction can be implemented in engineering disciplines on the basis of the existing education system.

4 TESTS

In order to check the validity and efficiency of above-mentioned implementation strategy in realizing STEM instruction at engineering-based subjects, "Metrology and standardization" course was selected, because it is being studied at all technical HEIs of the country. The course covers engineering topics related to instrumentation, measurement of scientific quantities, sensors, transducers, analog and digital signals, automated measurement methods, smart systems and standards. At the fall semester of 2022–2023 academic year, students studying at 2nd year of "Management of Information Security" and "Automation and control at technical systems" disciplines were selected as a group with which the implementation method was tested. The course curriculum included 36 academic hours of theoretical module, 18 academic hours of problem-solving module, 18 academic hours of laboratory module, and 108 academic hours of individual works (non-classroom module). In fact, the "Metrology and standardization" course, lasting only one semester, weighed 180 academic hours in total. At the end of the course, an examination was considered as a part of evaluation. First of all, as a starting point, STEM-related and IT-integrated objectives were developed taking all the pillars of the instruction into account. Table 2 lists course-related general objectives in regards with the divisions of course content. These objectives also include relevant digital competencies.

Table 1: Distribution of common course objectives among STEM elements

Course division / STEM pillars	Science	Technology	Engineering	Mathematics
Theoretical module	- To explain physical, chemical, biological aspects of the topic - To define physical, chemical, biological properties and equations - To describe theory of the related topic	- To list technologies working principles of which are based on the topic	- To relate engineering solutions used in the industry with the topic	- To explain fundamentals of topic using mathematical equations
Problem-solving module	- To make use of scientific equations, physical laws while solving problems	- To manage technologies (computer software) while solving problems	- To interpret engineering tasks as science-related problems	- To solve questions, problems related to the topic - To construct mathematical models - To formulate engineering tasks - To prove the validity of the equation through mathematical methods
Laboratory module	- To infer science-related aspects from the experimental results	- To measure relevant parameters using innovative technologies - To make use of AR/VR technologies and simulations	- To develop IT-integrated smart systems - To work out software part of smart systems	- To model an equation using experimental results - To build dependency diagrams/graphs of physical/chemical quantities
Non-classroom module (field practice*, course project, joining scientific groups, individual works)	- To propose scientific solution to topic-related engineering problems - To work out scientific projects together with the members of scientific groups - To correlate own duty with the aim of group tasks	- To make use of technologies, equipment while preparing course projects - To identify topic-related technologies in the field - To prepare reports using computer software	- To utilize theoretical knowledge by working out reports including engineering-related solutions - To inspect implementation of theoretical knowledge at the field - To construct smart devices to be used for engineering tasks within course projects	- To calculate parameters of course projects - To formulate processes in the software - To assign variables for physical quantities

* Field practices are not part of all the engineering courses; however, they are included in the undergraduate program of each discipline and planned to be realized after each spring semester.

After working out intended overall objectives that will be reached throughout the course, relevant topics and individual works, appealing to the aims of "Metrology and standardization" subject, were selected by the help of which STEM approach was implemented. Topics of theoretical, problem-solving and laboratory modules were closely dependent on each other. In fact, considering the objectives listed in the Table 2, theoretical modules of the subject mainly included knowledge about physical or working principles of measurement instruments, whereas problem-solving part consisted of mathematical equations, and experiments were related to technological and engineering work-outs. On the other hand, individual works were organized in a way that students needed solid background about conducted topics in order to complete their duties assigned by lecturer. For instance, Table 3 shows how topics were selected for different but interrelated modules of the course. It also indicates IT-integrated specific course objectives distributed among four pillars of STEM instruction.

As it is obvious from the course objectives listed in the Table 3, core values of STEM instruction were considered in different modules of the course. In fact, topics of different modules were

Table 2: Course-related general objectives as per course divisions

Course division / STEM pillars	Science	Technology	Engineering	Mathematics
Theoretical module (36 academic hours)	- To explain basics of metrology - To compare measurement methods - To define physical aspects of measurement - To define meanings of metrological terms - To recognize symbols of instruments	- To list devices used for measurement purposes - To name technologies in which metrological instruments are used	- To list engineering work-outs dedicated for measurement - To understand engineering part of metrological instruments/devices	- To interpret instrumentation issues using mathematical equations - To formulate measurement-related problems
Problem-solving module (18 academic hours)	- To recall physical laws related to measurement	- To benefit from relevant computer software while solving problems	- To derive physical parameters of sensors, transducers	- To calculate physical quantities - To solve measurement-related problems - To prove validity of measurement-related equations
Laboratory module (18 academic hours)	- To compare results of experiment with theoretical knowledge - To understand working principles of laboratory instruments	- To simulate physical circuit of an experiment on PC - To carry out experiments using appropriate technologies - To measure physical quantities using relevant instruments	- To properly connect elements of circuits for engineering purposes - To automate systems using relevant instruments, devices and sensors	- To know how to model physical quantities in the programming part - To build graphs, characteristics related to measured quantities
Individual works (108 academic hours)	- To study basics of IoT (Internet of Things) - To prepare detailed scientific report of individual works - To gather necessary information from scientific publications	- To prepare presentations about instrumentation - To analyze physical structure of measurement devices - To benefit from digital libraries and electronic resources	- To learn possible places of engineering instrumentation at the industry - To develop automated/smart measurement systems - To work out IoT-based remote measurement techniques	- To build mathematical models of measurements - To derive mathematical expressions for individual works

worked out in a way that each module targeted the same object from a different perspective.

5 EVALUATION

Level of achieved course objectives or course comprehension of students was evaluated separately for each module. Moreover, the evaluation process was carried out by dividing it into three components with different weights or percentages: midterm examination (25%), results of individual works (30%) and final examination (45%). Midterm and final examinations were aimed at assessing student knowledge gained at theoretical, laboratory and problem-solving modules. Examination methods included Knowledge probe (assessing students' prior knowledge), Minute paper (writing clear and unclear parts of topic), Application cards (possible places of real-world application of topic) [14], essay type questions, real-life context-based problems, computer-aided virtual experiments and practical duties intended for laboratory works. On the other hand, individual works of students were evaluated analyzing their project results, reports and measurement-related duties. Table 4 shows the detailed IT-integrated assessment criteria which were used in order to evaluate student knowledge gained as a result of the implemented STEM instruction.

Table 3: Example of IT-integrated specific course objectives for one topic of each course division

	Theoretical module	Problem-solving module	Laboratory module	Individual works
Topic:	Light intensity measurement	Calculating dependency of resistance of photoelectrical sensor on light intensity	Building volt-ampere characteristics of photo-resistor or LDR (light dependent resistor)	Developing smart systems using photoelectrical sensors
Teaching method:	Real-life context-based learning	Inquiry-based learning	Project-based learning	Programming-based learning [10], POWER methodology [8]
Specific objectives of the topic:	- To know methods of light intensity measurement - To learn theory, working principles (physics) of photoelectrical sensors - To recognize circuit symbols of photoelectrical sensors - To define features of photoelectrical sensors - To explain necessity of light intensity measurement	- To calculate resistance of photo-resistor under varying light intensity - To calculate resistance of photo-resistor under varying voltage - To calculate maximum and minimum values of resistance of photo-resistor - To derive physical parameters of photodiodes - To use physical equations related to photoelectrical sensors - To benefit from relevant handbooks, PC or mobile applications for finding coefficients related to photoelectrical sensors	- To use software intended for drawing a virtual circuit - To physically connect electrical circuit of LDR and light source - To change light intensity using potentiometer - To plot volt-ampere characteristics of LDR using relevant software - To get mathematical equation for volt-ampere characteristics of LDR - To propose possible places of using photoelectrical sensors - To differentiate elements of LDR-connected circuits by their functions	- To study IoT-based remote measurement techniques - To benefit from existing codes to build mobile apps for smart systems - To store measurement data on cloud - To work out IoT-based smart light intensity meter using LDR - To construct smart alarm system for the industry by the help of optical pairs - To get diagrams on cloud, based on measurement results - To prepare presentation about the topic considering real-world applications - To prepare detailed report about individual works

Table 4: IT-integrated assessment criteria

	Theoretical module	Problem-solving module	Laboratory module	Individual works
Assessment criteria:	Knowledge probe, Minute paper, Application cards, Essay-type questions (using Moodle platform), Scientific reasoning skills, Instant feedbacks (using Plickers software)	Real-life context-based problems, Equation derivation, Graph creation, Mathematical skills, Calculating measurement errors and standard deviation, Computing correlation and linear regression (using relevant software)	Computer-aided virtual laboratories, Measurement ability, Circuit development using appropriate software (Fritzing, KiCad, Autodesk Tinkercard, Multisim, MATLAB, DIALux), Software handling skills, Device Identification, Project results, Circuit connection, Instrument recognition, Detection of measurement errors	App development using open sources (RemoteXY, MIT App inventor), IoT-based measurement (using ThingSpeak, Thinger.io), Group projects, Smart measurement techniques, Presentation development, Project proposal skills

The tools or elements of assessment listed in the Table 4 were main criteria that were considered while grading the students. Obviously, these points are directly related to the planned course objectives and STEM-integrated teaching method. In total, 64 students or participants were taught using the proposed strategy, and their knowledge comprehension level and gained IT skills were evaluated regularly, in fact, during and after the course. As a result of complex assessment, the average grades that students achieved in midterm and final examinations were 82.2% and 73.9% respectively, while in individual works it was 77.4%. This means that the average percentage of students' grades was about 77.03% (82.2%*0.25+73.9*0.45+77.4%*0.3), while in previous years this value did not exceed 66%. Moreover, from the feedbacks of the students it was obvious that the implemented strategy was helpful for them to gain relevant software skills that would be necessary for them in their career life. Therefore, it can be concluded up that the implemented STEM instruction was efficient in both achieving IT-integrated course objectives and increasing student awareness of STEM approach.

6 CONCLUSION

The main goal of the research was to work out an implementation strategy of IT-integrated STEM instruction at engineering-based Higher Education Institutions considering national priorities, institutional possibilities, labor market demands, pedagogical aspects, course divisions and ICT tools. To do so, necessary literature review was carried out, all the possible factors were taken into account, and under the guidance of Bloom's taxonomy, intended course objectives were worked out and distributed among course divisions which were theoretical module, problem-solving module, laboratory module and non-classroom module (individual works). While developing course objectives for "Metrology and standardization" subject, improvement of computer literacy or IT competency of students was also considered due to the fact that they need these skills during their career life. In conclusion, the proposed implementation strategy of IT-integrated STEM instruction was tested, and fruitful or promising results were achieved. This strategy is based on complex approach as it includes pedagogical, engineering, IT, mathematical and collaboration aspects.

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