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APPLICATION OF NEW METHODS OF TEACHING BIOLOGY WITHIN THE FRAMEWORK OF STEM

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Abstract

This study examined the current advancement in implementing methods of teaching biology within STEM at the schools of Kazakhstan. Data were collected from 33 teachers and 218 middle-school students representing various educational institutions such as State Lyceums, General Education Schools, and NIS/BIL/RPHMS via questionnaire. Results showed that the number of teachers applying STEM techniques has significantly increased, whereas many students are still not entirely familiar with the practice. One significant issue that both teachers and students have noted is the lack of high-tech equipment available at most schools. Therefore, the second part of the research investigated the possibility of introducing STEM experiments using only readily accessible materials. Ten students from the State Lyceum observed and participated in four STEM-related biological experiments, and their feedback was further recorded. Despite the apparent enhancement of the students' engagement in the studying process and positive reviews regarding STEM experiments, a lack of specialized hardware has remained a significant drawback. Additional consequences and limitations are discussed.

Keywords: teaching biology, STEM methods, Kazakhstani schools.

"Education is the stem, which makes us strong enough to stand in any situation" (VVK).

Undoubtedly, education has always been considered one of the primary human needs that opens up numerous perspectives to individuals and can bring any country to a new level of development. Metaphorically, it is possible to compare the essence of education with the tree's stem. Without a robust foundation, a tree cannot survive harsh weather conditions. Similarly, present-day society requires each individual to be strong and competitive to resist emerging challenges and pave one's way to success. Due to the rapid development of technologies, science education plays a significant role in unleashing human potential and enhancing the living standards of a country in the long run. Because of this, many educated professionals are constantly searching for ingenious teaching methods aimed at improving the quality of education as a whole.

Despite a myriad of reforms designed for now to improve the quality of Kazakhstan's education system, the general level of education remains low, according to the Best Countries Report. Based on the study conducted across 78 countries by the U.S. News and World Report, BAV Group, and the Wharton School of the University of Pennsylvania, Kazakhstan took 71st place (U.S. News & World Report, 2021). The OECD's Programme for International Student

Assessment (PISA) is another internationally accepted program specifically designed to evaluate the quality of acquired knowledge among the 15-year-olds secondary school students. Starting from 2009, Kazakhstani students have taken the examination four times. However, in 2018 the results observed a negative trend. Considering particular indicators of Kazakhstan, the mean score in science performance is one of the lowest among PISA-participating countries and economies, making up a 397 PISA Score. Thus, out of 77 countries, Kazakhstan was ranked 68 (OECD, 2019). The outcome suggests that Kazakhstani students lack critical thinking skills and the ability to interpret problems. Although teachers provide students with decent subject knowledge, not enough attention is given to teaching them to apply these skills in real-life situations. Indeed, students often cannot comprehend why it is necessary to memorise elements from the Mendeleev table by heart in Chemistry and study the structure of the cells in Biology without being capable of discovering their significance in real life. As a result, it is hard for students to form profound integrated knowledge and develop comprehensive thinking skills essential for solving global issues. For instance, while environmental activists are looking for assistance in solving the global warming problem, the modern generation might even be unaware of the existing issue. What is more, knowledge obtained from the separate subjects does not enable students to form a bigger picture. Consequently, the conventional approaches to education are not fully practical, so one of the promising steps to improve education level is introducing innovative teaching techniques.

As one of the ways of solving these issues, STEM education was implemented as a modern teaching approach widely used in developed countries. It is based on an integrative teaching method that combines four branches, namely Science, Technology, Engineering, and Maths. It means that all subjects are taught in connection with one another. The core principle states that it is much easier for students to perceive information empirically (that is, through observation, which is carried out by sensory organs). Alternatively, the simple study of the "dry" theory appears ineffective. Thus, STEM education involves mixing theoretical lectures with practical works that allow students to achieve the most promising results while learning.

STEM covers many scientific branches which have a close relationship with human life. This fact repeatedly underlines the importance and necessity of introducing STEM methods into education. STEM education also develops students' critical thinking skills and the ability to analyse information and find solutions to problems independently. Furthermore, STEM education has become widespread due to the rapid development of technology globally, preparing the young

generation for the rapidly developing technological progress. In addition, based on previous studies, it has been established that with the development of STEM education, economic growth is observed, which, in turn, benefits the country (Mallory Croak, 2018; Sullivan and Bers, 2018). STEM education popularises jobs related to science and technology among young people, including jobs related to I.T., engineering, manufacturing, etc. Kazakhstan also tries to keep up with other nations, providing local school students with new learning possibilities. Overall, access to STEM education at schools will allow Kazakhstan to be competitive in the global market in the long run.

Considering the statistics mentioned above, STEM education has not yet been successfully implemented in the schools of Kazakhstan. Thus, it is evident that teachers are struggling while selecting effective methods of teaching STEM in the classroom. For now, it is crucial to understand whether biology teachers have already encountered STEM in their practice and how their attempts have influenced students' understanding of STEM. Additionally, since one of the striking obstacles remains the availability of scientific equipment, finding alternative ways of introducing STEM methods to the classroom will make a breakthrough in science education in Kazakhstan. Addressing this issue will show the practical benefits of STEM methods application in teaching biology and will contribute to enriching students' learning possibilities. Ultimately, our findings can positively affect Kazakhstani students' performance in international assessment measures.

The work focuses on discovering answers to two main research questions. Are schoolteachers and students generally aware of STEM education and methods? To what extent is it possible and effective to teach biology within STEM without high-tech equipment? It is possible to determine two main objectives of our research work arising from the stated research questions. The first part of the research is aimed to discover through the questionnaire whether teachers in Kazakhstan are already aware of STEM and what methods of teaching it they have found to be valid. Additionally, it is essential to evaluate students' current experience in STEM-related projects and their general awareness and attitude to the matter.

Secondly, four STEM-related biological experiments will be tested throughout the work in the setting of the State Lyceum. Therefore, conclusions regarding the affordability and effectiveness of these methods will be recorded and presented. It is compulsory to understand whether schools in Kazakhstan are ready to deal with STEM in 2022 and if the number of those aware of STEM has risen after the implemented reforms.

Finally, suppose the experiments manage to prove the fact that implementing STEM is not always complicated and costly. In that case, we will be able to provide teachers with suggestions on how to introduce STEM to students in the classroom.

Methodology

Sample

The two questionnaires were constructed with the help of the Google Forms tool for teachers and students independently, with Russian and Kazakh languages of instruction to overcome potential language barriers. One of the most accessible and readily available tools to gather data for research in social science is a questionnaire. Before developing items for the questionnaire, it was necessary to consider the potential benefits and drawbacks of the research method itself. The pros and cons listed in "Developing a questionnaire" (Gillham B., 2007) were examined and adjusted to the research. Additionally, it was crucial to consider the language of instruction to increase the sample size and determine if any potential difference could occur between Kazakh and Russian classes. The variance was expected to arise due to the lack of online learning resources available in the Kazakh language. While developing questions, the primary consideration was to capture disputable issues regarding STEM and assess both teachers' and students' readiness to reinforce unconventional methods. Meanwhile, the questions presented could be easily comprehended by respondents without imposing any confusion or difficulties on them, taking only 5-10 minutes of their time. Most questions were with multiple-choice answers to achieve simplicity, including several five-level Likert items (Likert R., 1932). Overall, the questioned audience reached 33 teachers and 218 students from Almaty.

Items development

The first questionnaire was designed specifically for school science teachers (i.e., Biology, Chemistry, and Physics). Each respondent completed 13 questions. The survey inquired about the following issues: type of educational institution, working experience, familiarity with the term STEM, implementation of STEM at school, the necessity of introducing STEM methods into schools, specific conditions allowing for application of STEM methods, readiness, and required professional skills to teach STEM, and potential difficulties. Furthermore, some questions were aimed to compare the teachers' perception of the effectiveness of modern teaching techniques with the conventional approaches. The final questions focused on conditions for successful implementation of STEM education and currently available school resources. Specifically, the

items evaluated teachers' knowledge of the subject area, essential technical and laboratory equipment, support from the school administration, advanced training courses in the STEM field, the collaboration of teachers of various disciplines, course materials, motivation of students, the parents' support, and the number of teaching hours available.

The second questionnaire was distributed among school students of Nazarbayev Intellectual Schools (NIS)/Bilim-Innovation Lyceums(BIL)/Republican Physics and Mathematics School(RPhMS), state lyceums, and general education schools. The questions tested the students' general awareness regarding STEM practices, their perception of STEM, and the possibility of benefiting from STEM through a future career. Additionally, learners evaluated the school readiness to use STEM methods and the level of importance of STEM adoption in schools in Kazakhstan. Finally, students shared their previous experiences of participation in STEM-related projects and responded if such techniques have previously been implemented at their schools.

Experiment

The second part of the study was undertaken by testing the effectiveness of implementing easily accessible methods of teaching biology within the STEM framework. The main target was to deepen students' comprehension of the Biology subject by conducting simple demonstrations that are not costly and require only basic equipment available at each school.

Firstly, four biological experiments were selected with the help of the website https://www.sciencebuddies.org/. The experiments were chosen by taking into consideration such criteria as affordable equipment and materials, correspondence to the school biology curriculum, and duration of the experiments.

The experiments were the following:

1. Do-It-Yourself DNA
2. How Water Moves Through Plants
3. How Do Viruses React To Soap?
4. Exploring Enzymes

Over four weeks, the focus group of 10th-grade students of the State Lyceum observed the demonstrations and gained hands-on experience by direct participation in conducting experiments. Due to the fact that the chosen class studies Biology and Chemistry as primary subjects, one extra hour a week is administered to state exam preparation and revision of the material. The main teacher has kindly agreed to collaborate with the researchers and allocated one hour a week for

conducting teaching sessions. Another important criterion when selecting experiments was their real-life application.

The usefulness of the methods was further registered and evaluated via written feedback from students—ten students filled in a form through the online service SurveyMonkey (https://www.surveymonkey.com). Designed questions inquired about students' attitudes towards performed experiments and learning outcomes they have possibly brought. Additionally, the respondents left their comments regarding the possible future changes in using STEM methods, including frequency of application, the need for a high-tech laboratory and specific preferences during Biology lessons.

Interview with the STEM biology teacher

One of the teachers who participated in the questionnaire agreed to collaborate and talk about using STEM methods in the classroom. The interviewee is currently employed at the General Education School in Almaty as a headteacher responsible for introducing innovations. Thus, the interviewee started to learn about STEM and how to implement it, which led to organizing the Young Teachers Club. This club aimed to educate over 25 young specialists in STEM methods and innovative technologies. For instance, club members have learned to use different methods in the classroom, such as PBL, IBL, and laboratory work. The school also aims to open a garden with different types of plants where students can learn what kind of plants can be planted at school and how to take care of them. According to the interviewee, the club positively impacts the learning process. For example, it reveals the desire to learn! Children start to participate fully in the learning process, offer new ideas, work in a group, and help each other.

However, the interviewee noted several drawbacks that might negatively affect enhancing STEM education in Kazakhstan: teachers' motivation to develop their skills, overcrowded classrooms, and the lack of methodological materials in the Kazakh language. The interviewee believed that advanced laboratory equipment is necessary, but a lack of it should not be the reason not to implement STEM. Educators should be creative in utilizing any available materials to provide STEM education to their learners. Overall, the interviewee emphasized the importance of creating learning environments for teachers.

Discussion and Conclusion

Teachers' perception of STEM methods application

The data collected in this research indicate that general awareness regarding the STEM

methods application among school teachers has significantly increased. Previous research had shown that two-thirds of the surveyed teachers did not know how STEM education was implemented in their schools. Additionally, 70.7% of teachers had never participated in STEM education events. Most teachers had either rarely (57%) or never (22%) encountered the term STEM. On top of that, 62.8% of teachers were unaware of the STEM abbreviation (Caravan of Knowledge, 2020). However, contrary to the hypothesised association, our findings have shown that 80% of teachers, mainly young specialists with about one year of working experience employed at General Education Schools, are actively and nearly effortlessly introducing STEM techniques into the Biology classroom (fig. 1).

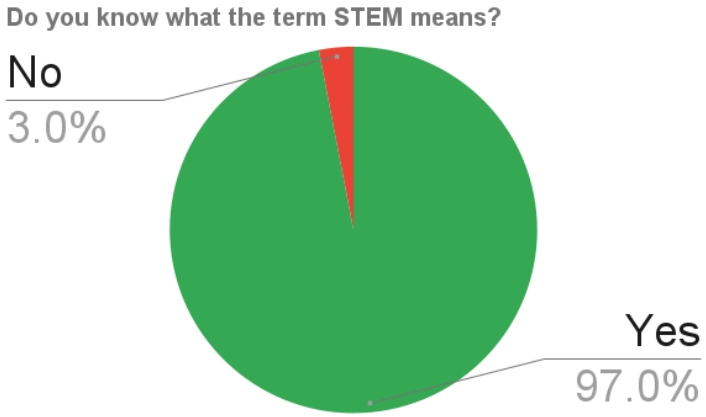

Fig. 1 Interviewed teachers' awareness of STEM

At the initial stage of the study, the percentage of teachers using STEM at low-funded schools was significantly lower than in highly-funded education institutions. However, the results showed a different trend once the questionnaire was distributed among teachers of one General Education School (fig. 2). Most young teachers with less than one year of work experience actively engaged in STEM practices are employed at that institution. These findings are verified by the interview of the headteacher who teaches Biology at that school. Apparently, these teachers are members of the "Young Teachers Club" mentioned before.

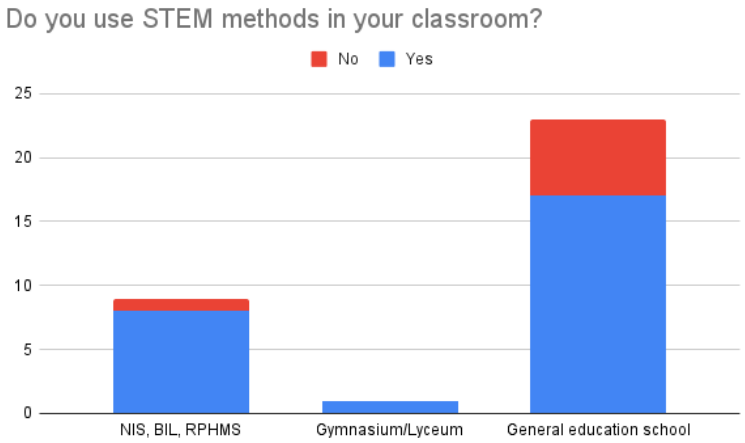

Fig. 2 Interviewed teachers' usage of STEM methods in the classroom

As was previously mentioned by our interviewee, the example of the school is unique. Usually, low-funded General Education Schools are not involved in STEM (Caravan of Knowledge, 2020) because they believe STEM is purely dependent on high-tech equipment. Our questionnaire results have also shown that almost 50% of the interviewed teachers believe that STEM education is dependent on special equipment and only 30% of the respondents acknowledge the possibility of teaching STEM with available tools (fig. 3).

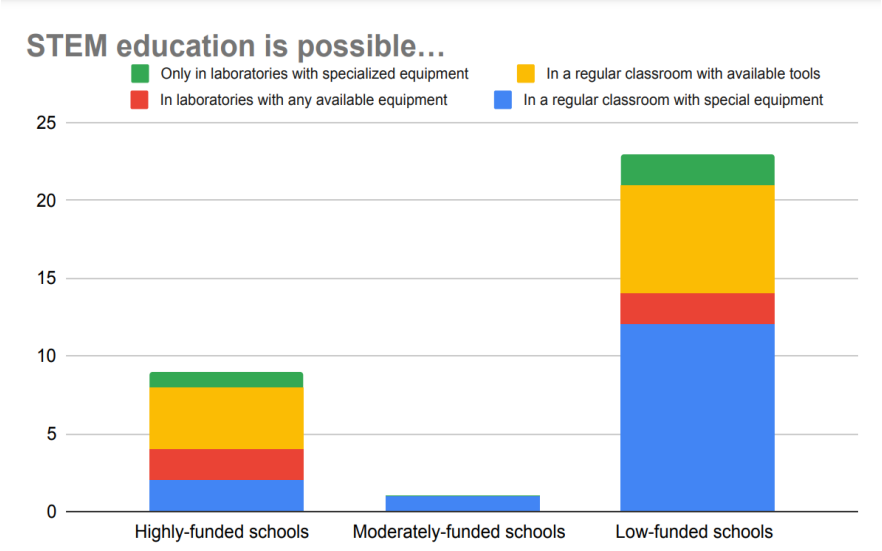

Fig. 3 Necessary conditions for implementing STEM

However, as Wiswall, Stiefel, Schwartz, & Boccardo (2014) have written, STEM can be taught by using various methods. Our interviewee has also noted a wide choice of methods (PBL, IBL, simple laboratory works and experiments with readily accessible equipment). For instance,

demonstrations conducted as a part of the research did not require expensive equipment. Despite this, materials essential for these demonstrations are not usually purchased by schools. Consequently, it is challenging, and teachers cannot cover these expenses with their budget. Thus, low-funded schools should purchase at least essential tools as an alternative to high-tech equipment. Without the support from the school, STEM introduction will be exceedingly difficult. Surprisingly, according to the questionnaire, 80% of teachers are confident in their STEM teaching qualifications (fig. 4). However, the previous studies have shown the opposite statistics. According to the study conducted by the Caravan of Knowledge (2020), a vast majority of teachers noted that they need more courses and seminars to learn about STEM education (78.9%). We can assume that our statistics were influenced by the fact that many interviewed teachers participate in the "Young Teachers Club" described by the previously interviewed headteacher. Because of that, we can say that the practice of organising teacher training clubs with a peer-to-peer learning approach is an efficient strategy, and the rest of the schools should note it.

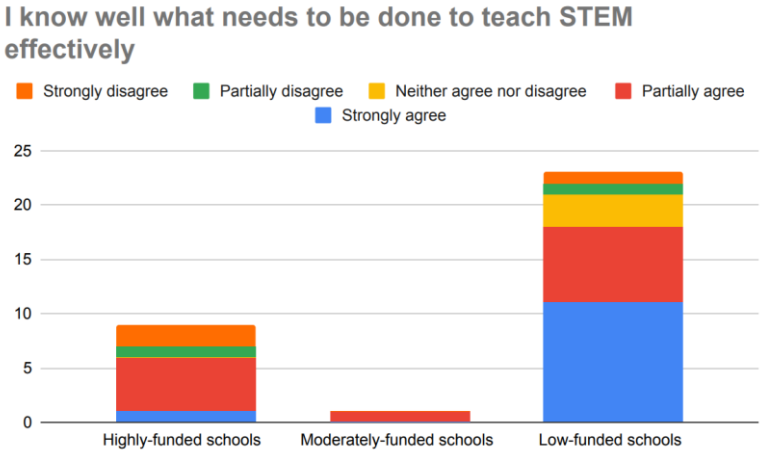

Fig. 4 Teachers' self-assessment of professional training

Considering the benefits of STEM and its importance, teachers' responses focused purely on the advantages of STEM for students' development. As mentioned before, teachers most often say that STEM helps students develop practical skills and apply them in life. Generally, their views are similar to those mentioned by Wiswall, Stiefel, Schwartz, & Boccardo (2014), as they have noted how STEM education contributes to promoting a competent workforce. Meanwhile, teachers are either unaware or underestimate the benefits that STEM methods can bring to them. According to Ismail Z. (2018), one of the striking benefits of STEM lies in improving teachers' professional development. Our interviewee also mentioned the enhancement of students' performance as a

benefit for teachers. There is an interconnection between the students' attitude to lessons and teachers' motivation to work. Surely, STEM methods can spark students' interest, which, in turn, leads to increased job satisfaction among teachers. Despite this, we believe that teachers must fully recognise that applying STEM methods is also a significant step in teachers' career and professional development. If they do so, it will help teachers to preserve motivation for a long time and achieve even more effective results. Thus, the school administration must also provide each teacher with sufficient support. On top of that, we have observed both from the questionnaire and the interview that teachers understand the importance of modern teaching approaches and are ready to implement them.

Students' perception of STEM methods application

The data obtained in this research from the questionnaire among students suggests that the students' awareness regarding STEM varies drastically depending on the funding of the school they attend (fig. 5). Previous research conducted by Caravan of Knowledge (2020) implies that 63.5% of Kazakhstani schoolchildren have not yet familiarised themselves with STEM education. However, according to data obtained in this study, awareness of STEM in both State Lyceums and General Education Schools is extremely low, with only 46% and 26% of students knowing about STEM, respectively. In comparison, only those studying at highly-funded schools are more familiar with the STEM practice (60%) (fig. 5).

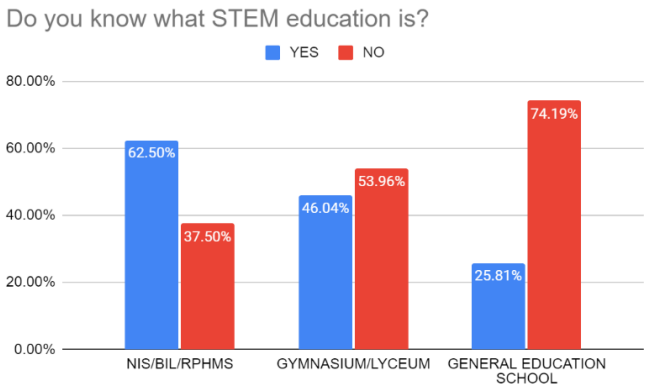

Fig. 5 Interviewed students' awareness of STEM

Additionally, the analysis of students' replies regarding STEM being used at their schools has shown a drastic difference between highly-funded and low-funded schools. Only 6% of students from General Education Schools participated in STEM methods at schools, whereas the figure for highly-funded institutions is 13 times higher (fig. 6).

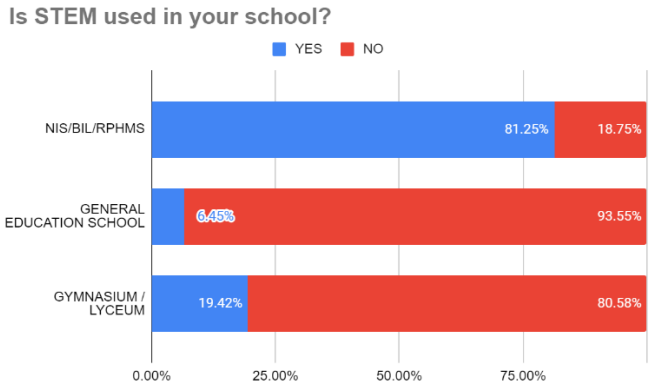

Fig. 6 Interviewed students' replies about the usage of STEM at schools

Moving on to the next essential aspect, the study evaluated students' motivation to participate in STEM-related projects. According to the questionnaire results, students' choice varies depending on the funding of their schools as well. Currently, students from State Lyceums have the lowest motivation, with almost 30% willing to participate in STEM projects in the future (Fig. 7). The results support the claims of Wiswall, Stiefel, Schwartz, & Boccardo (2014) that many students are used to memorising theory by heart instead of being engaged in practice. However, the feedback recorded from State Lyceum students after conducting STEM experiments has revealed that students unanimously agreed that the classes raised their interest in studying biology. Furthermore, 90% of the students approved that they would enjoy participating in similar activities more often. Thus, it is possible to finalise that students simply lacked previous experience in STEM and could not visualise it in the classroom. The data contribute to a clearer understanding of why the motivation level in these education institutions is lower.

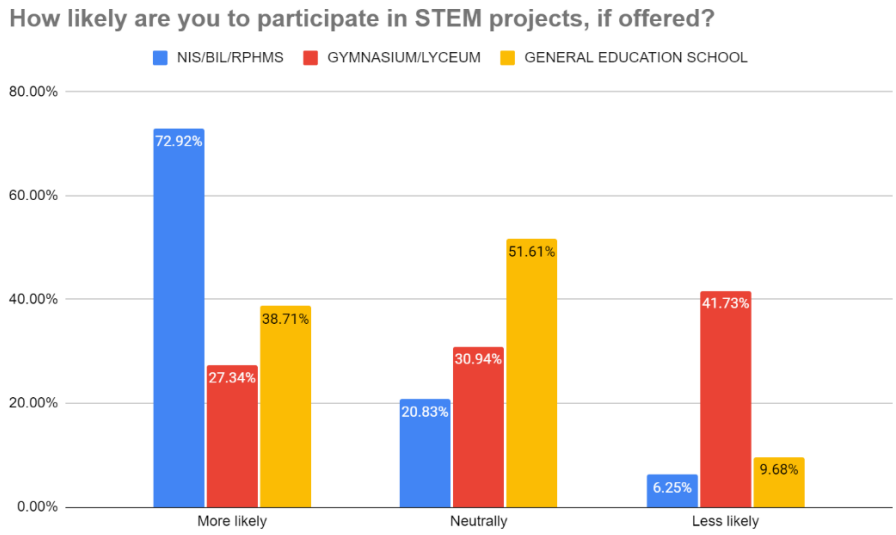

fig. 7 Students' participation in STEM projects

The interview with the STEM biology teacher revealed that it is difficult for students to participate in group work, due to their unwillingness to collaborate with peers. However, according to Net Mod View, Nazir Amir, and Chin Lu Chang, (2015), the introduction of STEM-PjBL methods increases not only analytical and critical skills but also communicative skills that improve the quality of work in a group. This data highlights the necessity to implement various STEM methods across schools in Kazakhstan.

The survey's results also showed that over 60% of students from every type of school believe that the introduction of the STEM methods into the learning process can be advantageous in their future careers (fig. 8). If a large proportion of students support this claim, it can further have a positive impact on the future development of Kazakhstan. It goes in line with the previous studies that show that many developing countries worldwide are trying to attract young people to the scientific field. For example, based on a study by J.Williams (2011), the main reasons for the popularisation of STEM among young people are the future economic growth of the country and the development of competitiveness.

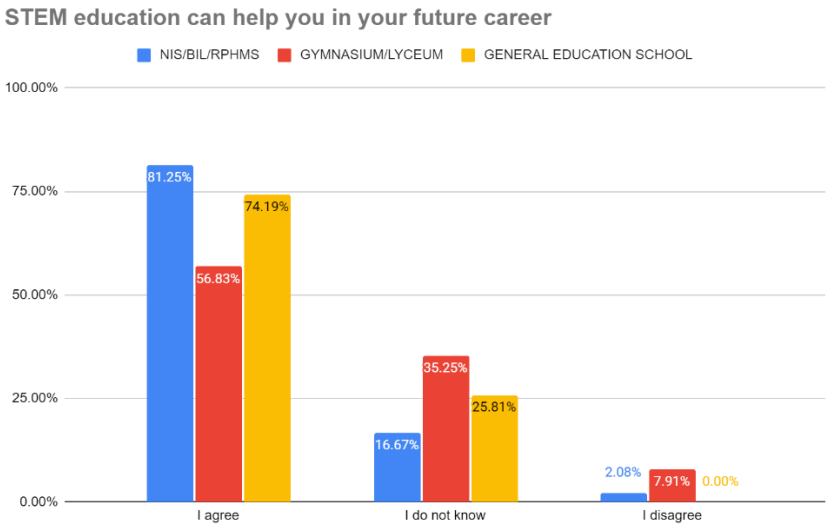

Fig. 8 Role of STEM in the future career

Finally, the initial objective of the study was to determine the possibility of using STEM without high-tech equipment. Over four weeks, we conducted four biological experiments which did not require any expensive hardware. For instance, one of the experiments was DIY DNA extraction which was noted by the majority of students as the most engaging activity. These results build on existing evidence from Ragnhild Gya and Anne Elizabeth Bjune (2021), who researched DIY experiments as an excellent possibility for students to receive real-life scientific experience.

Despite this, all the interviewed students unanimously believe that the presence of a laboratory with high-tech equipment in schools is essential for the successful implementation of STEM. However, as was mentioned earlier by Johnson (1989) and throughout this research, there is a vast range of other methods of introducing STEM into the classroom.

There are particular shortcomings to the study that can be specified. The generalizability of the results is limited by school types sampling. The interview with the headteacher from General Education School has proven that the STEM teaching program at that institution is unique. As a result, the findings cannot confirm that most General Education Schools follow the same course and are actively engaged in STEM practices. There was also a prevalence in the student sample size across moderately-funded schools compared to low and highly-funded institutions. Research methods of teaching Biology within STEM appears to be a challenge since the primary idea of STEM lies in the concept of integration. Therefore, it is impossible to evaluate the efficiency of STEM teaching methods from a single subject perspective properly. The absence of "Science" as

a separate subject and adequately qualified teaching staff hinders fully successful STEM implementation.

Another significant limitation is the unavailability of essential hardware at schools, especially at a Lyceum where the experiments were tested. It is an obstacle both for teachers and students. Buying necessary materials and reagents for demonstrations is an additional financial burden for teachers, and student's safety is compromised by the non-availability of a fume cupboard.

Conclusion

As Kazakhstani schools aim to provide their students with high education standards, the introduction of STEM methods has become one of the essential courses of development. This study's questionnaire revealed that many teachers slowly initiate STEM implementation in the classroom and even form special clubs to educate themselves through peer-to-peer learning. However, a large proportion of students are unaccustomed to STEM and claim that this technique has not been implemented at their schools, which is specifically true of moderately and low-funded schools. The research also focused on discovering the possibility of overcoming financial obstacles and introducing biological STEM experiments into the State Lyceum without high-tech hardware. Based on students' feedback, even such practices can increase students' engagement in the learning process and facilitate learning. Thus, it is possible to conclude that introducing STEM methods can be affordable; though, the availability of a laboratory at each school still remains a requirement, at least for students' safety. Additionally, a wide range of alternative methods can be used to incorporate STEM.

A complete transition to STEM-integrated teaching will transform the students of Kazakhstan into more scientifically-educated individuals with highly-developed analytical skills. Teachers should be willing to investigate unconventional teaching methods and encourage their students to study to accomplish this goal. At the same time, governments and policymakers must ensure sufficient support by providing essential facilities for all educational institutions equally.

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