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# Enhancing interdisciplinary STEM education through CNC technology: Integrating disciplines in engineering instruction

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ABSTRACT

Computer Numerical Control (CNC) technology is widely applied in manufacturing, yet most commercial machines are designed for industrial use and are not well-suited for education. This study develops a specialized tool for educational applications of CNC technology and evaluates its effectiveness through interdisciplinary STEM-based instruction. The research combines physics, mathematics, chemistry, and computer science, linking theoretical knowledge with practical experience. Theoretical analysis examined CNC principles and their relation to the four disciplines, while practical work involved producing components with CNC machines to apply these principles in real contexts. Students' perceptions were assessed using statistical methods. The findings indicate that interdisciplinary instruction with CNC technology enhances academic knowledge, strengthens practical skills, promotes problem-solving in engineering and scientific processes, and fosters critical thinking, thereby preparing students for real-world industrial environments.



## 1. Introduction

Computer Numerical Control (CNC) is an automated manufacturing system that operates through computer control. Compared to traditional manually operated machines, CNC technology offers higher precision, speed, and efficiency (Zhang et al., 2025). Teaching CNC machining naturally integrates engineering, mathematics, physics, and technology (Koleda, 2020).

In the context of rapidly evolving technologies, modern education systems require new methods aimed at developing students' scientific and technical competencies. STEM (Science, Technology, Engineering, and Mathematics) education provides an integrated approach that emphasizes the interconnection between subjects rather than treating them in isolation. By strengthening the interdisciplinary links among natural science subjects, STEM improves students' logical thinking and expands opportunities to apply theoretical knowledge in practice. CNC technology, widely used in industry, exemplifies the real-world application of STEM and introduces new opportunities for interdisciplinary teaching in education.

The use of STEM technologies strengthens interdisciplinary connections and proves to be an effective instructional tool. Researchers have noted that STEM approaches increase students' interest in subjects and help develop their logical and creative thinking skills. This is especially important for improving the performance of underachieving students (Deák and Kumar, 2024). For example, I. Lin and colleagues developed an interdisciplinary STEM teaching method using physics programming. In their quasi-experimental study, the experimental group solved physics problems through programming and modeling, while the control group followed traditional methods. The results showed that the STEM group achieved higher results in both programming and physics and demonstrated increased confidence in modeling (Nguyen and Rebello, 2011).

In physics, CNC applications enable modeling motion and using sensors. In mathematics, they facilitate solving complex equations using numerical methods. Physics and mathematics are deeply interconnected disciplines—mathematical methods

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are widely used to describe and model physical laws. Mathematical modeling enhances CNC system precision, optimizes programming codes, and automates control processes (Xu et al., 2024).

In chemistry, STEM technologies assist in modeling reaction kinetics. The integration of CNC technology and chemical processes creates new opportunities for fabricating microscopic structures used in biomedical research. These structures are designed to influence cell growth and biochemical behavior. The synergy between CNC and chemistry enhances the functionality and efficiency of such systems.

Computer science is a core element uniting all STEM disciplines. Data processing, machine learning, and automation tools enhance the educational process. In information technology, platforms like Arduino, Python, and MATLAB allow for real-time data analysis. CNC technology requires automation of manufacturing processes, and informatics ensures the operation of the computer systems that control them. Aspects such as production optimization, data processing, and monitoring systems demonstrate the close link between informatics and CNC technology. The precision and efficiency of CNC systems depend heavily on computer-controlled operations and software (Xu and Newman, 2006).

The integration of physics, mathematics, chemistry, and informatics through STEM technologies promotes the development of scientific and engineering thinking. Through interdisciplinary learning, students combine theoretical knowledge with practical tasks, thereby improving research skills and facilitating the mastery of modern technologies.

CNC technology encompasses the practical aspects of engineering and technical education. Operating CNC machines and managing production processes require knowledge from various STEM fields (Fawad et al., 2023). CNC technology serves as an effective example of such integration by combining mathematical calculations, engineering design, and physical principles (Gershenfeld et al., 2017).

CNC technology includes essential aspects of engineering, mathematics, and technology. The application of CNC machines and programming brings together engineering and computer science. Thus, the connection between STEM interdisciplinary teaching and CNC technology is clearly manifested in educational and design systems. With CNC technology, students engage in real engineering project development and decision-making, which is made possible through STEM disciplines (Liapi and Oungrinis, 2018).

The literature review reveals a clear gap in research on the systematic integration of CNC technology into interdisciplinary STEM education. While global studies highlight the relevance of CNC tools in technical learning, few offer a structured pedagogical model or evaluate their impact in localized contexts such as Kazakhstan. Most existing works lack comparative experimental data, particularly regarding the effectiveness of CNC-based instruction versus traditional methods. This underscores the need for context-specific studies that propose and validate practical frameworks for CNC-integrated STEM education.

This study aims to develop a specialized tool for applying CNC products in educational settings. It also seeks to evaluate the effectiveness of interdisciplinary STEM-based instruction involving CNC technology. By integrating physics, mathematics, chemistry, and computer science through CNC systems, the study intends to foster students' understanding of cross-disciplinary relationships.

## 2. Research methods

This study examined the importance of STEM technology in implementing effective interdisciplinary teaching. The approach fosters the development of students' scientific thinking by establishing connections among physics, mathematics, chemistry, and computer science. STEM integration provides students with opportunities to acquire scientific and technical knowledge through practical, hands-on learning.

The selected keywords "STEM education," "CNC technology," "interdisciplinary teaching," "physics," "mathematics," "chemistry," "computer science," "engineering education," "technology," and "educational integration"—encompass the core components of the STEM teaching methodology. A literature review of scientific studies from the Scopus, Web of Science, and Google Scholar databases revealed that STEM approaches significantly enhance students' understanding of subject interconnections and enable them to complement theoretical knowledge with practical skills.

This study is conducted using a quasi-experimental method. The main objective is to compare the effectiveness of interdisciplinary teaching through the application of STEM principles based on CNC technology with traditional teaching methods. A pretest-posttest control group design was employed during the research.

In addition, modeling and design techniques were applied, allowing students to integrate concepts of physics, mathematical calculations, chemical reactions, and programming skills that were developed using CNC technology. This method builds interdisciplinary knowledge and strengthens students' practical abilities (Chaichana et al., 2022).

Theoretical methods were applied, particularly in the context of STEM curricula, to help establish deep connections between disciplines. These methods allowed students to link theoretical concepts from various scientific fields and apply them in practice (Matias, 2021).

This study was conducted at Khoja Akhmet Yassawi International Kazakh-Turkish University. A total of 114 students participated in the research. They were divided into two groups: Control (56) and experimental group (58). The assessment was carried out through a structured survey. The reliability of the survey instrument was measured using Cronbach's alpha coefficient.

Cronbach's Alpha Coefficient Classification (Izally et al., 2025):

- $\alpha < 0.5$ = Unacceptable
- $\alpha > 0.5$ = Poor
- $\alpha > 0.6$ = Questionable
- $\alpha > 0.7$ = Acceptable
- $\alpha > 0.8$ = Good
- $\alpha > 0.9$ = Excellent

The data collected during the study were processed and analyzed using the SPSS software (Zhang, 2024). First, the normality of the data was assessed using the Shapiro-Wilk test, and the homogeneity of variances was evaluated using Levene's test. Both indicators supported the use of parametric methods ($p > 0.05$). A one-way analysis of variance (One-Way ANOVA) was conducted to compare the academic performance between the experimental and control groups.

The aim of the study was to determine the effectiveness of interdisciplinary teaching based on STEM principles using CNC technology. It was hypothesized that, compared to traditional teaching methods, the STEM-based approach would have a positive effect on students' academic performance, practical skills, and understanding of interdisciplinary connections. Accordingly, the following hypotheses were formulated:

**$H_0$:** Interdisciplinary teaching based on STEM technology does not result in significant differences compared to traditional methods.
**$H_1$:** Interdisciplinary teaching based on STEM technology improves students' academic performance compared to traditional methods.

## 3. Results and discussion

### 3.1. The model of effective implementation of STEM education based on CNC

The analysis of scientific literature confirms the necessity of developing an effective model for implementing STEM education based on CNC technologies. This necessity arises from the growing demand for integrating practical, interdisciplinary, and technology-enhanced approaches into engineering and technical education. Reviewing STEM education models from the early 21st century reveals a focus on integrated programs and localization efforts, emphasizing the need to adapt STEM education to specific contexts (Lukychova et al., 2021). Integrated STEM education connects learning to make it more relevant for students, highlighting the necessity for ongoing research and discussion on the knowledge and experiences required for teachers to effectively teach integrated STEM (Stohlmann et al., 2012). These models underscore the importance of educating students in science, technology, engineering, and mathematics, integrating these disciplines into daily life through engineering design processes (Madahae et al., 2021).

The key feature of our proposed model lies in its aim to systematically implement interdisciplinary STEM education based on CNC (Computer Numerical Control) technology to develop and enhance the practical skills of students in engineering and technical fields. This model fosters students' cognitive interest and supports the development of engineering thinking through the execution of real-world industrial tasks. The model comprises purposeful, motivational-value, content-based, factor-related, conditional, and outcome components, and is designed to improve the quality of STEM education by effectively integrating modern digital tools, project-based learning methods, and industrial simulation technologies. The implementation of the model is carried out in three systematic stages. The preparatory stage involves familiarizing instructors and students with the fundamentals of CNC technology and the STEM approach, preparing the material and technical base, and adapting the curriculum to support interdisciplinary learning. In the main stage, integrated project-based and practical training sessions are conducted, where learners solve real engineering problems using CNC tools and technologies. Finally, the evaluation stage includes the assessment of students' acquired skills, analysis of the model's effectiveness, and the provision of feedback and recommendations for further improvement and scaling of the model. The novelty of this model lies in its systematic integration of CNC technology into interdisciplinary STEM education. It bridges theoretical knowledge and hands-on experience, offering a scalable framework tailored to modern engineering education needs (Fig. 1).

To align with this model, the educational process can be organized through project-based tasks such as designing and fabricating components using CNC machines, integrating mathematics, physics, and engineering principles.

### 3.2. Interdisciplinary STEM teaching based on the integration of physics and mathematics

Physics is fundamentally based on the application of mathematical tools. For example, in topics such as mechanics, optics, and electromagnetism, mathematical calculations and modeling are extensively used. Students learn to solve equations and formulas to understand physical phenomena. STEM-based instruction highlights the close relationship between physics and mathematics, allowing students to deepen their scientific knowledge by verifying theoretical content through problem-solving and experimentation (Ha, 2024).

Rotating Disc Mounted on a Central Shaft. Using this device, students can explore the basic principles of mechanical systems through hands-on experimentation. It demonstrates rotational motion and incorporates key concepts such as kinematics, dynamics, and the conservation of energy. The device operates through a driving torque, and its stability depends on the moment of inertia and frictional forces. During motion, each part of the system rotates with a specific angular velocity. Furthermore, the system acts as a converter of electrical energy into mechanical energy.

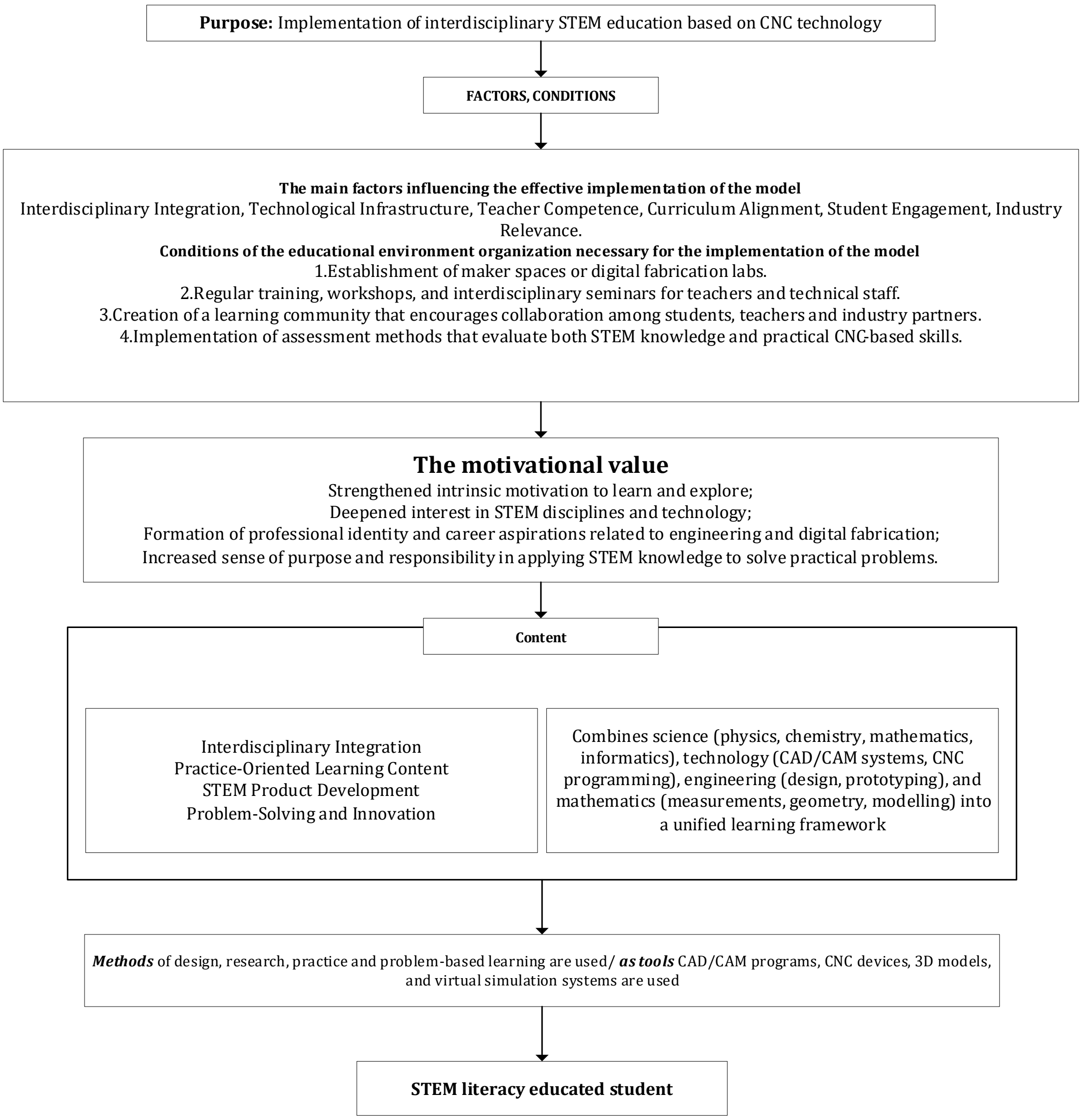


**Fig. 1:** The model of effective implementation of STEM education based on CNC

This device serves as a physical model for studying fundamental laws and understanding the functionality of mechanical systems. Through experiments, students investigate kinematic parameters such as oscillation period, frequency, and angular velocity. By engaging in such practical exploration, they gain deeper insight into theoretical physics laws and develop hands-on experience.

During the experiment, a voltage of 4.2 V was applied to the device, and it was determined that the number of rotations made within t = 1 minute was N = 25. Based on these values, students were tasked with calculating the period, frequency, and angular velocity of the rotating disc.

1. Determining the Period

The period (T) is the time it takes to complete one full rotation. It is calculated using the following formula:

$$T = \frac{t}{N} \tag{1}$$

where, t = 60 seconds – the total observation time, N = 25 – the number of rotations. Substituting the values into the formula: $T = \frac{t}{N} = \frac{60}{25} = 2.4$ seconds

**Conclusion:** The time required for one full rotation is T = 2.4 seconds.

2. Determining the Frequency

The rotational frequency (ν) is the reciprocal of the period:

$$\nu = \frac{1}{\mathrm{T}} \tag{2}$$

**Conclusion:** The rotational frequency of the device is ν ≈ 0.42 Hz.

3. Determining the Angular Velocity

The angular velocity (ω) can be found using the formula:

$$\omega = \frac{2\pi}{T} \quad (3)$$

Substituting the value of the period:

$$\omega \approx \frac{2 \cdot 3.14}{2.4} \approx 2.62 \text{ rad/s}$$

**Conclusion:** The angular velocity of the rotating disc is ω ≈ 2.62 rad/s.

Such experiments allow students to apply mathematical methods to describe physical processes. They explore linear and inverse relationships, investigate the functional dependencies between variables, and thereby recognize the deep connection between physics and mathematics.

### 3.3. Interdisciplinary STEM-based teaching: Integration of physics and chemistry

Physics and chemistry are closely related disciplines, as chemical reactions are governed by fundamental physical laws. For example, molecular motion, thermodynamic laws, and the thermal effects of chemical reactions are key concepts that link the two subjects. The STEM approach helps demonstrate the interdisciplinary relationship between chemistry and physics, allowing students to apply theoretical knowledge in practical tasks. By modeling chemical processes and conducting experimental investigations, students deepen their understanding in both fields.

Ionization Chamber – a detector that measures ionization in gases or air molecules. It is commonly used in physical experiments, especially for detecting radiation and ionizing particles.

The operating principle of the ionization chamber is based on the science of physics. This device ionizes gas molecules using an electric field. When radiation enters the chamber, it collides with gas molecules, causing them to become ionized. These ions, under the influence of the electric field, move toward the electrodes, altering the gas's electrical conductivity and generating a measurable signal in the detection system.

At the same time, chemical processes occur within the ionization chamber. During ionization, chemical reactions may take place between atoms or molecules. For example, nitrogen or oxygen molecules can form new chemical compounds or radicals because of ionization. Thus, a physical process leads to subsequent chemical transformations.

The collaboration between physics and chemistry clearly demonstrates the advantages of STEM technologies. Students not only explore physical principles but also investigate chemical reactions and molecular behavior, effectively bridging theory and practice. This highlights the effectiveness of the STEM approach, as it helps students integrate scientific and technical knowledge to address real-world problems.

STEM-based interdisciplinary learning allows students to explore the connections between physics and chemistry. By studying the operation of the ionization chamber, students gain an understanding of both physical and chemical processes and learn to apply them in experimental contexts. This approach empowers students to develop comprehensive, interdisciplinary solutions, combining science, technology, engineering, and mathematics to address complex challenges in scientific fields.

### 3.4. STEM-based interdisciplinary teaching: The connection between informatics and mathematics

The connection between informatics and mathematics is clear in data processing and the development of mathematical models. Using programming languages and algorithms, students learn to solve mathematical problems, analyze data, and build scientific models. By applying the STEM approach, informatics integrates mathematical methods, providing students with a comprehensive and interdisciplinary learning experience.

This connection is illustrated through the example of a solar-powered fan (Fig. 2). Mathematical formulas and algorithms are used to calculate the energy efficiency of the solar panel, determine the speed of the fan, and model changes in electrical power output. To determine the relationship between solar energy efficiency and the power generated by the panel, students apply integral calculations and statistical modeling. From the perspective of informatics, the device's operation is managed through software programs and control algorithms.

The device converts solar energy into electrical energy and then transforms it into mechanical energy. This process illustrates the law of conservation of energy and the transformation of energy from one form to another. From a mathematical point of view, to calculate the efficiency of the device, parameters such as the area of the solar panels, their efficiency coefficient, and the amount of generated electrical power are used. To determine the electrical power, formula (4) is applied, where voltage and current must be measured:

$$P = I \times U \quad (4)$$

To measure voltage and current, Vernier measuring instruments are used, which connects this process to informatics, since the collected data can be processed through computer software. From a chemical standpoint, solar panels are primarily made from silicon, which operates based on the photoelectric effect. The semiconductor property of silicon explains its ability to absorb sunlight and enable the movement of electrons. From a physical perspective, the device demonstrates the photoelectric effect of light, the generation of electric current, and its conversion into mechanical motion. In addition, the efficiency of solar panels depends on the angle of light incidence and external conditions, which allows the study of light properties. Through the operation of this device, it is possible to explore renewable energy sources and examine their practical applications.

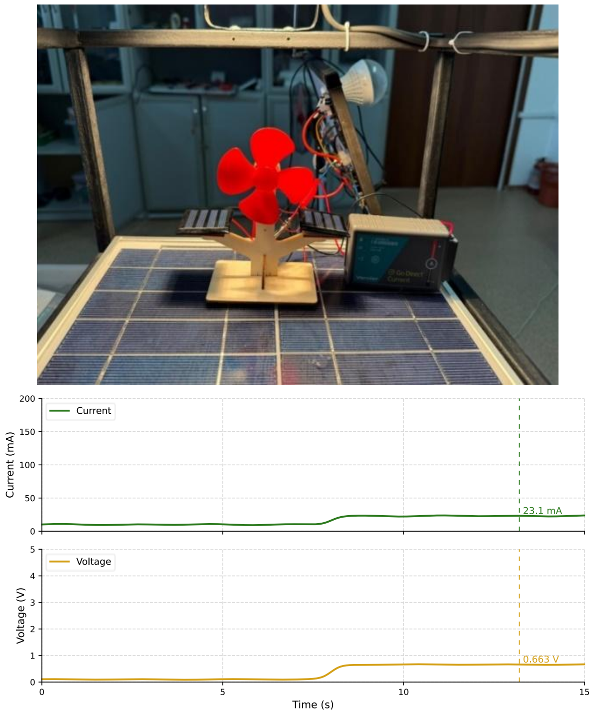


**Fig. 2:** Solar-powered fan system

According to the data obtained from the Vernier device, the voltage was =0.663 and the current was $I$=23.1 mA. Using these values in formula (1), the electrical power generated by the device is calculated as follows:

$$P=0.663\times 0.0231=0.0153\text{W} \ (15.3 \text{ mW}).$$

Thus, the device generates approximately 15.3 milliwatts of power.

If the device operates for 1 minute (60 seconds), to calculate the total generated energy, the formula $=P\times t$ is used. Given the power P=15.3 mW and time t=60s, the energy is calculated as:

$$W=0.0153\times 60=0.919\text{J}.$$

As a result, the device generates approximately 0.919 joules of energy in 1 minute. This value varies depending on the operating time— the longer the operation, the greater the total energy output.

The application of the STEM method teaches students to relate knowledge from one subject to another and solve broader problems. For example, if students learn theory and practice through CNC technology, they can connect the laws of physics and mathematics with the fundamental principles of informatics and chemistry. This interdisciplinary approach prepares students to work with integrated methods in future scientific research.

In general, interdisciplinary teaching based on STEM technology helps students better understand the scientific world, develop their logical thinking skills, and solve real-life problems. The close relationship between physics, mathematics, chemistry, and informatics enables students, through STEM, to integrate knowledge from various fields and apply it in practical contexts.

### 3.5. Organization and implementation of the pedagogical experiment

In our research, we examined the impact of STEM technologies on the process of interdisciplinary teaching. To strengthen the connection between physics, mathematics, chemistry, and informatics, three educational tools were developed using CNC technology.

The process of tool development consisted of several key stages. First, designs were created in LightBurn software, where precise dimensions for each component were specified. During this stage, laser cutting paths were defined, and the cutting and engraving parameters were adjusted according to the material used. All designs were prepared in vector format to meet the technical requirements of the CNC system.

The finalized design files were then uploaded to the Creality Falcon2 Pro CNC machine, and the laser cutting process was initiated. Plywood was selected as the working material, and its surface was carefully prepared. The G-code generated by LightBurn was sent to the device, with cutting speed and laser power calibrated according to the material's thickness.

After the cutting and engraving tasks were completed, all parts were removed from the CNC machine and cleaned. The next stage involved assembling the tools, where the alignment and compatibility of components were verified. Mechanical and electrical components were installed as needed. All necessary fastening, soldering, and calibration work was carried out, and the functionality of the tools was tested. If required, additional adjustments were made, and final testing was performed.

Thus, using computer-controlled CNC technology, it was possible to manufacture highly precise educational tools. The overall process involved:

- -Preparing the designs with LightBurn software,
- -Processing the components with the Creality Falcon2 Pro CNC machine,
- -Assembling and equipping the final tools.

This method significantly improved workflow efficiency and allowed for high precision in the final products.

### 3.6. Evaluating the effectiveness of interdisciplinary teaching based on STEM technology through ANOVA

Within the framework of this study, students received instruction on "Interdisciplinary STEM Teaching Based on CNC Technology" using two different approaches: the control group was taught through traditional methods, while the experimental group was instructed using STEM principles integrated with digital technologies. Mathematical and statistical analyses were conducted on the quantitative data collected during the study. To ensure data reliability, preliminary tests were performed to assess normality and determine the homogeneity of variances. All statistical calculations and analyses were carried out using the SPSS software platform. SPSS was chosen for its user-friendly interface and support for both parametric and non-parametric analyses. It also allows for complex statistical procedures such as ANOVA. Using this platform, the pretest and posttest results of the control and experimental groups were compared to evaluate the effectiveness of interdisciplinary teaching based on STEM technology. The data obtained provided statistical evidence that the experimental method had a significantly greater impact on learning outcomes compared to traditional instruction.

Descriptive statistics of the experimental and control groups highlight the effectiveness of the interdisciplinary STEM-based teaching method. The control group showed a mean score of M = 3.72, SD = 0.521, whereas the experimental group's average was M = 4.06, SD = 0.468. This difference indicates that teaching through STEM methods and using digital technologies enhanced the academic performance of the experimental group compared to the control group (Table 1).

**Table 1:** Descriptive statistics results

| Group | N | M | SD | SE |
|---|---|---|---|---|
| Control | 56 | 3.72 | 0.521 | 0.0696 |
| Experimental | 58 | 4.06 | 0.468 | 0.0615 |

The difference in mean scores demonstrates that students in the experimental group achieved higher results in mastering interdisciplinary connections and completing practical tasks compared to the group taught through traditional methods. This clearly highlights the role of STEM principles and the integration of CNC technology in improving the quality of instruction.

During the study, a one-way analysis of variance (ANOVA) was used to evaluate the effectiveness of interdisciplinary teaching based on STEM technology by comparing the results of the control and experimental groups. This method allowed for the comparison of the outcome indicators of the two groups (experimental and control) and helped determine the impact of the teaching approach (traditional vs. STEM-integrated) on students' academic performance. Based on the data obtained, the effectiveness of the STEM-based approach was compared with that of the control group. The results showed that the performance of the experimental group was significantly higher than that of the control group, and the difference was statistically significant (Table 2).

**Table 2:** One-way ANOVA

| | F | df1 | df2 | p |
|---|---|---|---|---|
| Score | 13.5 | 1 | 112 | < .001 |

To evaluate the effectiveness of interdisciplinary teaching based on STEM technology, a one-way analysis of variance (ANOVA) was conducted. The results of the analysis revealed a statistically significant difference between the scores of the control and experimental groups: $F(1,112) = 13.5$, $p < .001$. The mean score of the experimental group was higher than that of the control group (M = 4.06, SD = 0.468 vs. M = 3.72, SD = 0.521), which demonstrates the effectiveness of STEM-based interdisciplinary teaching in enhancing students' academic performance.

### 3.7. Assessment of the effectiveness of interdisciplinary teaching based on STEM technology

This study is based on evaluating the effectiveness of interdisciplinary teaching based on STEM technology, relying on students' opinions.

The assessment was based on 4 main factors according to the structure of the questionnaire: Physics (Scientific principles and laws), Mathematics (Modeling and calculations), Chemistry (Study of materials and reactions), Informatics (Algorithms and technologies).

Data obtained through students' opinions were assessed using a 5-point Likert scale. Based on the collected data, the mean and standard deviation values were calculated. The results for each component are presented in Tables 3-6. During the study, the effectiveness of using STEM technology in teaching physics was evaluated. According to the results of the survey, the average values ranged from 3.9 to 4.1, indicating that the STEM methodology had a positive impact on the learning process in physics. The standard deviations (SD) ranged from 0.63 to 0.94, showing slight variation from the mean, but no significant differences. The use of the STEM method in teaching physics greatly assisted in understanding physical laws, as well as in creating mathematical models and performing calculations. Students noted that they had gained a deeper understanding of physical laws not only theoretically but also practically. This model played an important role in facilitating the learning process and enhancing scientific understanding (Table 3).

To assess the effectiveness of interdisciplinary teaching based on STEM technology, the reliability of the four-item scale related to the Physics section in the survey was evaluated using Cronbach's alpha coefficient. The calculation yielded a value of α =

0.802, indicating good internal consistency of the survey instrument (α > 0.70). Therefore, the set of questions is considered reliable in measuring students' knowledge related to physical laws and the application of CNC technology.

**Table 3:** Physics (scientific principles and laws)

| | Survey questions | Mean | SD |
|---|---|---|---|
| 1 | I consider understanding physical laws during the use of CNC technology to be very important. | 3.9 | 0.94 |
| 2 | I believe that knowledge about motion and forces in CNC machines helps me understand the production process. | 4.0 | 0.77 |
| 3 | I think that the correct application of physical principles in CNC technology contributes to improving my production process. | 4.1 | 0.70 |
| 4 | I believe that linking physical laws with CNC-manufactured products increases the effectiveness of my work. | 4.0 | 0.63 |

According to the results of the survey conducted to evaluate the effectiveness of using STEM technology in mathematics, the average values ranged from 3.1 to 3.9, which indicates that the application of the STEM method had a positive effect in mathematics. The standard deviations (SD) ranged from 0.64 to 0.7, showing that the responses slightly deviated from the mean. In general, the use of STEM technology in applying mathematical calculations and models made the learning process more effective and helped improve students' mathematical skills.

According to students' opinions, the use of STEM technology in solving mathematical models and calculations is highly effective, which shows that the interdisciplinary connection between science and technology enhances the quality of education (Table 4).

**Table 4:** Mathematics (modeling and calculations)

| | Survey questions | Mean | SD |
|---|---|---|---|
| 1 | I consider the use of mathematical calculations and models during CNC technology applications to be easy and effective for me. | 3.1 | 0.70 |
| 2 | I believe that using my mathematical skills when programming a CNC machine improves the quality of my work. | 3.9 | 0.70 |
| 3 | I think mathematical models and calculations help me make accurate decisions when using CNC technology. | 3.7 | 0.64 |
| 4 | I believe mastering mathematical skills in CNC production increases my efficiency in design. | 3.3 | 0.64 |

To verify the reliability of the survey scale related to the mathematics section, Cronbach's alpha coefficient was calculated. The result was α = 0.794, indicating a good level of internal consistency (α > 0.70). This confirms that the survey questions are reliable in measuring knowledge related to mathematical modeling and calculations in the context of using CNC technology. According to the results of evaluating the effectiveness of using STEM technology in chemistry, the average values ranged from 4.1 to 4.2, indicating that the use of the STEM method in chemistry was rated highly. The standard deviations (SD) ranged from 0.7 to 0.83, which means that the responses deviated only slightly from the mean. The use of STEM technology in studying material properties and understanding chemical reactions plays an important role in expanding students' scientific understanding and enhancing their research skills. In particular, the process of studying the chemical composition of materials and understanding chemical reactions was highly rated. Students noted that the application of CNC technology in the chemistry subject contributes to improving the quality of learning (Table 5).

**Table 5:** Chemistry (study of materials and reactions)

| | Survey questions | Mean | SD |
|---|---|---|---|
| 1 | I consider it important to understand the materials used in CNC-produced products and to know their chemical properties. | 4.1 | 0.70 |
| 2 | I believe that studying the chemical properties of materials used in CNC machines improves the quality of my work. | 4.2 | 0.74 |
| 3 | I think that studying the chemical composition of materials in CNC production deepens my understanding and helps in creating effective products. | 4.1 | 0.70 |
| 4 | I believe that understanding chemical reactions in CNC technology contributes to improving my work. | 3.9 | 0.83 |

To determine the internal consistency of the survey scale related to the Chemistry section, Cronbach's alpha coefficient was calculated. The result was α = 0.807, indicating a good level of reliability (α > 0.70). This suggests that the survey questions are reliable for assessing the understanding of chemical properties of materials in the context of using CNC technology.

The effectiveness of using STEM technology in the subject of informatics was evaluated based on the research results. The average values ranged from 4.1 to 4.3, indicating that the STEM method had a positive impact on informatics. The standard deviations (SD) ranged from 0.64 to 0.74, showing that the responses deviated only slightly from the mean, and the differences were not significant. Participants noted the effectiveness of using CNC system programming, data processing, and control algorithms in the subject of informatics. Students appreciated that these methods help develop practical skills and deepen scientific knowledge during the learning process. Additionally, the STEM approach demonstrated high efficiency in algorithm control and achieving accurate results (Table 6).

To determine the internal consistency of the survey scale for the Informatics section, Cronbach's alpha coefficient was calculated. The result was α = 0.815, which indicates a good level of reliability (α > 0.70). This suggests that the survey questions are reliable for assessing skills in applying algorithms and informatics methods in the context of using CNC technology.

These indicators demonstrated a good level of reliability across all four subject areas. Therefore, the survey instruments can be considered reliable for measuring knowledge, skills, and attitudes related to the use of CNC technology within an interdisciplinary STEM framework.

**Table 6:** Informatics (algorithms and technologies)

| | Survey questions | Mean | SD |
|---|---|---|---|
| 1 | I believe that applying informatics skills during CNC system programming increases the efficiency of my work. | 4.2 | 0.74 |
| 2 | I think that mastering data processing and controlling algorithms in CNC production is easy and effective for me. | 4.2 | 0.74 |
| 3 | I consider the software tools and systems used in controlling CNC technology to be very useful for obtaining accurate results. | 4.3 | 0.64 |
| 4 | I believe that using informatics methods and algorithms in CNC technology improves the quality of my projects. | 4.1 | 0.70 |

The findings of this study highlight the pedagogical value and interdisciplinary potential of integrating CNC technology within STEM-based education. The data collected from students through structured surveys revealed positive outcomes in all four subject areas—physics, mathematics, chemistry, and informatics—demonstrating that CNC-based STEM instruction supports both theoretical understanding and practical skill development.

Firstly, the integration of physics and mathematics through CNC systems allowed students to apply mathematical modeling to physical processes. The experiment involving the rotating disc model enabled learners to explore real-time measurements and apply key formulas to calculate period, frequency, and angular velocity. This hands-on approach bridges abstract theoretical concepts with tangible learning experiences, reinforcing the foundational connection between the two disciplines. Students reported improved comprehension of physical laws and noted that mathematical tools enhanced their ability to analyze and interpret experimental data.

Secondly, in the domain of chemistry, CNC technology supported the investigation of material properties and chemical reactions, particularly through the example of the ionization chamber. By linking the behavior of materials under electrical influence on chemical transformations, students were able to conceptualize how physical systems influence molecular structures and reactions. The high mean scores in the chemistry component of the survey (mean = 4.1–4.2) affirm that students valued this integration and found it meaningful in enhancing their scientific reasoning and research capacity.

Thirdly, informatics and computer science played a critical role in the programming and automation aspects of CNC systems. Students engaged with software such as LightBurn and used data analysis tools and coding algorithms to control CNC operations. The positive response from students in this domain (mean = 4.1–4.3) suggests that the application of informatics not only improved their understanding of control systems but also increased their interest in programming and technological innovation. Moreover, the use of real-world tools like Vernier sensors for power measurement reinforced the connection between coding, data processing, and physical experimentation. Despite moderate responses in mathematics (mean = 3.1–3.9), the data indicate that while students recognized the importance of mathematical modeling, some may require additional support in applying these skills in technical contexts. This finding suggests the need for scaffolding mathematical instruction within CNC activities to build greater confidence and fluency among learners.

Importantly, the implementation of a pedagogical experiment, involving the design and manufacturing of instructional tools using CNC technology, demonstrated the feasibility and effectiveness of interdisciplinary STEM instruction. Students actively participated in design, coding, manufacturing, and analysis stages, illustrating a complete learning cycle that reflects real-world engineering processes. The structured methodology—from software-based design to physical assembly—provided learners with a comprehensive understanding of system integration and technical workflow.

Overall, the interdisciplinary STEM framework using CNC technology enriched the educational process by:

- Bridging theoretical knowledge and real-world applications.
- Encouraging collaborative problem-solving across disciplines.
- Enhancing student engagement through active, hands-on learning.
- Preparing students for modern industrial challenges through exposure to automation and design systems.

These results align with recent research emphasizing the benefits of cross-disciplinary integration in improving student outcomes in STEM fields. The hands-on experiment involving a rotating disc and the calculation of its angular velocity, frequency, and period echoes the experimental approach described by Ha (2024), who emphasized the importance of using real-world models to reinforce theoretical physics concepts.

The present study revealed that while students recognize the value of mathematics in CNC-based projects, the average rating for mathematical components was lower compared to other disciplines. Similar patterns were observed in the work of Doğan et al. (2019), where students engaged in STEM-integrated fabrication projects but expressed lower confidence in mathematical modeling tasks. This suggests a broader instructional challenge in translating mathematical theory into design and automation contexts. It also supports the need for scaffolded instructional strategies that bridge mathematics with real-world applications in technology and engineering.

The exploration of the ionization chamber provided an opportunity for students to examine the interplay between physical and chemical processes, such as ionization and gas conductivity. An et al. (2021) previously reported on the integration of CNC technologies in biomedical applications, where chemical composition and structural precision directly influenced device performance. While their study focused on professional manufacturing, the present research shows that similar interdisciplinary thinking can be fostered at the undergraduate level through educational CNC tools. Both studies underscore the relevance of chemical knowledge in design thinking and materials science, reinforcing the holistic nature of STEM competencies.

The integration of informatics—through algorithm development, data acquisition, and software programming—was rated highly by participants. This finding is consistent with the work of Soori et al. (2023), who noted that CNC systems provide an ideal platform for teaching automation and control through coding practices. Nurizinova et al. (2024) emphasized the effectiveness of teaching physics through computational modeling, noting that programming environments enhance learners' scientific reasoning and engagement. The present study validates these conclusions, as students reported strong gains in their understanding of algorithmic thinking, supported by tools such as LightBurn, Python, and Vernier sensors.

Overall, the findings of this study demonstrate that interdisciplinary STEM instruction supported by CNC technology offers a productive pathway for enhancing student engagement and competence across multiple disciplines. The integration of physics, mathematics, chemistry, and computer science fosters a deeper understanding of the interconnected nature of scientific inquiry and technological innovation. Furthermore, the results are consistent with the meta-analytical conclusions of Arshad et al. (2021), who reported that STEM approaches positively influence students' academic performance, particularly in underserved student populations.

This study confirms and extends existing evidence that using CNC technology in teaching provides a strong interdisciplinary learning tool. It allows students to work with real engineering problems, supports the growth of critical and creative thinking, and helps prepare them for new roles in Industry 4.0 settings. The results show that CNC technology is more than a manufacturing tool; it is also an effective educational resource. By integrating CNC systems into learning activities, educators can promote innovation, creativity, and critical reflection, making the learning process more relevant to modern industrial and technological needs.

## 4. Conclusions

This study was aimed at evaluating the effectiveness of interdisciplinary teaching based on STEM technology and examining the impact of using CNC technology in the field of education. The interdisciplinary integration of physics, mathematics, chemistry, and informatics through the STEM methodology deepened students' theoretical and practical knowledge and developed their scientific and engineering skills.

The research results showed that the use of the STEM method improved students' understanding of the interconnection between subjects. Linking the laws of physics and mathematics with CNC technology facilitated the learning process and enabled students to combine theoretical knowledge with practical experience. Mathematical calculations and models, as well as the understanding of chemical reactions, allowed students to accurately evaluate results in scientific work and make informed decisions. In informatics, the use of algorithms and programming skills improved the quality of education and ensured the practical application of successful projects in production.

According to the survey results, the effectiveness of using the STEM method was clear in all subjects. The average values ranged from 3.9 to 4.3, indicating that the STEM approach had a positive impact on students' learning processes and played a significant role in interdisciplinary teaching. The standard deviations (SD) were low across all subjects, demonstrating that the responses were close to the mean and confirming the consistency and effectiveness of the instruction.

The significance of the research results lies in promoting the further development of interdisciplinary teaching methods in the education system, as well as integrating CNC technology into the learning process. The use of the STEM approach develops students' scientific and engineering competencies and enhances their readiness for professional fields. Thus, STEM technology and interdisciplinary teaching methods represent an effective and promising direction in the education system.

Implementing such a model in broader educational settings can contribute to modernizing curricula, bridging the gap between theory and practice, and preparing students for real-world technological environments. Further research is encouraged to refine the model, assess long-term impacts, and explore its adaptability in various institutional and cultural contexts.

## List of abbreviations

| | |
|---|---|
| α | Cronbach's alpha |
| ANOVA | Analysis of variance |
| CAD/CAM | Computer-aided design and computer-aided manufacturing |
| CNC | Computer numerical control |
| df | Degrees of freedom |

| | |
|---|---|
| G-code | Geometric code |
| I | Electric current |
| ICT | Information and communication technology |
| N | Number of rotations |
| P | Electrical power |
| SD | Standard deviation |
| SE | Standard error |
| SPSS | Statistical package for the social sciences |
| STEM | Science, technology, engineering, and mathematics |
| t | Time |
| T | Period |
| V | Voltage |
| W | Energy (work) |
| ν | Frequency |
| ω | Angular velocity |
| 1D-CNN | One-dimensional convolutional neural network |

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## Compliance with ethical standards

## Ethical considerations

All participants were informed about the purpose of the research, and written informed consent was obtained prior to participation. Participation was voluntary, and anonymity and confidentiality of all data were ensured.

## Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

## References

An J, Chua CK, and Mironov V (2021). Application of machine learning in 3D bioprinting: Focus on development of big data and digital twin. International Journal of Bioprinting, 7(1): 342. https://doi.org/10.18063/ijb.v7i1.342 **PMid:33585718 PMCid:PMC7875058**

Arshad AM, Halim L, and Nasri NM (2021). Impact of integrating science and engineering teaching approach on students' achievement: A meta-analysis. Jurnal Pendidikan IPA Indonesia, 10(2): 159–170. https://doi.org/10.15294/jpii.v10i2.29839

Chaichana C, Wongkalasin S, and Sanrutsadakorn A (2022). A learning platform for computer numerical control (CNC) laboratory. Journal of Computer Science, 18(8): 705–714. https://doi.org/10.3844/jcssp.2022.705.714

Deák C and Kumar B (2024). A systematic review of STEAM education's role in nurturing digital competencies for sustainable innovations. Education Sciences, 14(3): 226. https://doi.org/10.3390/educsci14030226

Doğan MF, Gürbüz R, Çavuş-Erdem Z, and Şahin S (2019). Using mathematical modeling for integrating STEM disciplines: A theoretical framework. Turkish Journal of Computer and Mathematics Education, 10(3): 628–653. https://doi.org/10.16949/turkbilmat.502007

Fawad A, Zahoor MS, Maruthi S, Balasubramanian S, Kumar N, and Raparthi M (2023). Machine learning in precision manufacturing: A collaborative computer and mechanical engineering perspective. Dandao Xuebao/Journal of Ballistics, 35(3): 34–43. https://doi.org/10.52783/dxjb.v35.123

Gershenfeld N, Gershenfeld A, and Cutcher-Gershenfeld J (2017). Designing reality: How to survive and thrive in the third digital revolution. Basic Books, New York, USA.

Ha NTT (2024). Applying physics knowledge and STEAM education in high school: Connecting traditional Vietnamese culture through the moon-shaped lute production project. European Journal of Educational Research, 13(1): 325–339. https://doi.org/10.12973/eu-jer.13.1.325

Izally SR, van der Merwe AJ, and Raubenheimer L (2025). A comparison of objective priors for Cronbach's coefficient alpha using a balanced random effects model. Communications in Statistics-Theory and Methods, 54(2): 575-603. https://doi.org/10.1080/03610926.2024.2315300

Koleda P (2020). Innovation of CNC machining education at the Faculty of Technology. New Trends and Issues Proceedings on Humanities and Social Sciences, 7(1): 84-91. https://doi.org/10.18844/prosoc.v7i1.4870

Liapi M and Oungrinis KA (2018). "Designed for better learning" – An interdisciplinary program bridging pedagogy and architecture to improve the quality of public education in Greece. In the 11th International Conference of Education, Research and Innovation Proceedings, IATED, Seville, Spain: 5926–5935. https://doi.org/10.21125/iceri.2018.2397

Lukychova NS, Osypova N, and Yuzbasheva GS (2021). ICT and current trends as a path to STEM education: Implementation and prospects. CTE Workshop Proceedings 9: 39–55. https://doi.org/10.55056/cte.100

Madahae S, Pisapak P, and Thanyasirikul C (2021). Learning design of STEM education through workshop training for Thai teachers. Journal of Physics: Conference Series, 1835: 012062. https://doi.org/10.1088/1742-6596/1835/1/012062

Matias CE (2021). The handbook of critical theoretical research methods in education. Routledge, New York, USA. https://doi.org/10.4324/9780429056963

Nguyen DH and Rebello NS (2011). Students' understanding and application of the area under the curve concept in physics problems. Physical Review Special Topics—Physics Education Research, 7: 010112. https://doi.org/10.1103/PhysRevSTPER.7.010112

Nurizinova M, Skakov M, Çoruh A, Ramankulov S, and Nurizinov M (2024). The development of digital educational materials on tribology and their application in the formation of the professional competence of future physics teachers. International Journal of Innovative Research and Scientific Studies, 7(4): 1600–1613. https://doi.org/10.53894/ijirss.v7i4.3459

Soori M, Arezoo B, and Dastres R (2023). Machine learning and artificial intelligence in CNC machine tools, A review. Sustainable Manufacturing and Service Economics, 2: 100009. https://doi.org/10.1016/j.smse.2023.100009

Stohlmann M, Moore TJ, and Roehrig G (2012). Considerations for teaching integrated STEM education. Journal of Pre-College Engineering Education Research (J-PEER), 2(1): 4. https://doi.org/10.5703/1288284314653

Xu XW and Newman ST (2006). Making CNC machine tools more open, interoperable and intelligent—A review of the technologies. Computers in Industry, 57(2): 141-152. https://doi.org/10.1016/j.compind.2005.06.002

Xu Z, Selvaraj V, and Min S (2024). State identification of a 5-axis ultra-precision CNC machine tool using energy consumption data assisted by multi-output densely connected 1D-CNN model. Journal of Intelligent Manufacturing, 35: 147–160. https://doi.org/10.1007/s10845-022-02030-y

Zhang L, Yu H, Wang C, Hu Y, He W, and Yu D (2025). A digital solution for CPS-based machining path optimization for CNC systems. Journal of Intelligent Manufacturing, 36: 1261-1290. https://doi.org/10.1007/s10845-023-02289-9

Zhang X (2024). Study on the path of informatization construction of civic education in colleges and universities empowered by digitization. Applied Mathematics and Nonlinear Sciences, 9(1): 1-14. https://doi.org/10.2478/amns-2024-0383