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Integration of Steam Technology and Digital Educational Tools as A Factor in Increasing Students' Motivation for Independent Learning

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Abstract: The article is devoted to the theoretical substantiation of the integration of STEAM technology and digital educational tools to develop students' motivation for independent learning in the study of information technology. A pedagogical model combining motivational, cognitive, activity-based, and reflective components is proposed. Diagnostic criteria, a methodology for organizing interdisciplinary projects, and the design of subsequent empirical validation at three universities in Uzbekistan are described. A separate set of artificially generated indicators is provided to demonstrate the calculations; it does not confirm the effectiveness of the methodology.

Keywords: STEAM, digital learning tools, independent work, motivation, information technology, self-regulated learning, pedagogical model.

Introduction: The relevance of the problem is determined by the contradiction between the increasing proportion of independent work in educational programs and students' varying levels of readiness to plan, perform, and evaluate it. The availability of electronic materials does not guarantee active participation: a student may regularly access an educational platform while completing assignments formally, without independently searching for and analyzing solutions.

Within the framework of this study, learning motivation is considered as a combination of internal and external incentives that determine the direction, intensity, and persistence of educational activity. It is fundamentally important to distinguish motivation from the mere number of completed assignments: a high score may result from external control, whereas autonomous motivation is manifested in initiative, independent choice of solution methods, and continued work after receiving the required grade.

The scientific problem lies in identifying the pedagogical conditions under which STEAM projects supplemented by digital tools become not isolated activities but an integrated mechanism for developing independence. The working hypothesis is that the integration of interdisciplinary tasks, freedom of choice, step-by-step feedback, and reflection will be associated with more pronounced positive changes in autonomous learning motivation compared with a traditional set of independent assignments.

The digital transformation of higher education highlights the need to develop students' independence, their ability to plan learning activities, select resources, evaluate results, and maintain sustained motivation. An increase in the number of digital services does not, in itself, guarantee greater learning engagement: the quality of assignments, pedagogical support, and opportunities for choice are essential.

STEAM (Science, Technology, Engineering, Arts,

Mathematics) enables interdisciplinary learning to be organized around a practical problem. In the discipline of "Information Technology," this approach integrates programming, data analysis, engineering design, and visual communication. Self-determination theory links high-quality motivation to the satisfaction of the needs for autonomy, competence, and relatedness [1].

The aim of the study is to develop and theoretically substantiate a methodology for integrating STEAM and digital tools to increase students' motivation for independent work. The object of the study is students' independent learning activities; the subject is the pedagogical conditions and tools for providing motivational support for these activities.

The theoretical framework combines self-determination theory (Ryan, Deci), the self-regulated learning approach (Zimmerman), and the principles of project-based learning (Bell). The first explains the significance of autonomy, competence, and relatedness; the second describes the cycle of goal setting, monitoring, and reflection; and the third structures learning activities around a practically significant outcome.

The planned institutions for testing the methodology are Andijan State Pedagogical Institute, Gulistan State University, and Namangan State University. The confirmed organizational plan includes 60 students from each institution: 30 in the experimental group and 30 in the control group, for a total of 180 participants. The 2024–2025 and 2025–2026 academic years constitute the stated period of work; since diagnostic measurements have not yet been conducted, future data must be dated according to the actual time of collection rather than attributed to previous periods.

Before the diagnostic assessment begins, it is necessary to approve the research protocol, obtain the required consent, ensure the confidentiality of personal data, and establish participant inclusion criteria. If group allocation is not random, the design should be described as quasi-experimental. Group comparability is assessed based on baseline scores, prior learning experience, and access to digital resources.

The measurement plan includes: (a) baseline assessment; (b) implementation of STEAM learning modules; (c) final assessment using comparable instruments; and (d) where possible, a delayed assessment of skill retention. Retrospective analysis may include only genuinely preserved primary documents, with their origins and limitations specified.

For quantitative assessment, it is recommended to use a pre-approved rubric and examine the internal consistency of the scales. Where possible, the motivation questionnaire should be compared with a validated instrument for measuring autonomous motivation; researcher-developed questions require expert evaluation of their content and pilot testing. Two independent experts may assess practical projects to examine inter-rater agreement.

METHODS

The study is theoretical and methodological in nature. Literature analysis, pedagogical modeling, task design, and the development of diagnostic criteria are employed. The planned experimental sites are Andijan State Pedagogical Institute, Gulistan State University, and Namangan State University. The agreed sample structure comprises 180 students, with 60 from each institution: 30 in the experimental group and 30 in the control group (90 and 90 in total). The specified 2024–2025 and 2025–2026 academic years refer to the stated research period; diagnostic data for these years have not yet been collected and must not be reconstructed retrospectively.

For future validation, it is recommended to separately document the actual measurement dates, participant inclusion criteria, group comparability, and informed consent procedures. If data collection begins in 2026, the corresponding measurements should be dated according to when they are actually conducted.

At the motivational and goal-setting stage, the instructor presents a professionally or socially significant problem, demonstrates quality criteria, and offers a limited but meaningful choice of topics. The choice must not be merely formal: students have the right to justify an alternative topic or implementation method while maintaining common learning outcomes.

At the design stage, students develop a problem map, identify STEAM components, define the expected digital product, and distribute tasks. The digital learning environment records the stages, intermediate results, completion criteria, and individual contributions. This makes it possible to distinguish actual learning

activities from mere presence on the platform.

At the research and practical stage, students collect and verify data, develop a prototype, analyze errors, and iteratively improve the solution. The instructor provides guidance and formative feedback while gradually reducing the amount of external assistance. Initial templates are provided for students with lower levels of digital proficiency, but these do not replace independent problem-solving.

At the presentation stage, assessment focuses not only on the visual appearance of the digital product but also on the validity of the source data, algorithmic correctness, quality of interpretation, and ability to explain interdisciplinary connections. The reflective stage includes comparing the results with the original plan, self-assessment, analyzing unsuccessful solutions, and formulating the next learning goal.

An example of a second project is "Interactive Visualization of Energy Consumption in a Classroom." Science: studying physical factors; Technology: data collection and spreadsheets; Engineering: data processing algorithm; Arts: interface design; Mathematics: descriptive statistics and scenario comparison. The final product is an interactive report containing verifiable source data and an explanation of limitations.

Pedagogical Model and Organization of Learning Activities

The model comprises four interconnected components: (1) motivational — awareness of goals and interest in the learning task; (2) cognitive — mastery of STEAM concepts and digital tools; (3) activity-based — independent planning and project implementation; (4) reflective — self-monitoring, assessment, and strategy adjustment. Digital platforms are regarded as tools for feedback and supporting autonomy rather than as an independent cause of increased motivation.

Stage	Student Activities	Example of a Digital Tool
Orientation	Problem selection, goal setting	LMS, online survey
Design	Task planning, role allocation	Task board, collaborative document
Implementation	Data collection, coding, visualization	Python, Excel
Presentation	Digital product presentation and defense	Presentation, infographic
Reflection	Self-assessment and adjustment	Electronic portfolio

An example assignment is the development of a digital system for monitoring the learning environment. The Science component is responsible for defining a measurable problem; Technology — for data processing; Engineering — for the algorithm; Arts — for interface design; Mathematics — for statistical interpretation. The final product is a prototype accompanied by a description of the solutions, rather than merely a completed file.

The motivational criterion is recommended to be assessed separately from academic performance. Indicators include independent goal setting, interest in continuing the project, willingness to choose more challenging tasks, and a conscious explanation of the usefulness of learning. Questionnaire responses should be compared with observable actions, as self-reports are subject to social desirability bias.

The cognitive criterion encompasses understanding the connections between subject areas, the correct use of digital concepts, data interpretation, and the transfer of knowledge to a new task. The activity-based criterion reflects independence in planning, the quality of the digital product, the justification of decisions, and the ability to correct errors. The reflective criterion includes assessing one's own limitations, documenting corrections, and adjusting strategies.

Recommended rubric: each criterion is assessed on a scale of 0–25 points, with a total score ranging from 0 to 100. Points should be allocated according to observable indicators with clearly defined descriptors; assessment must not be limited to the instructor's subjective overall evaluation. The threshold levels of 0–

55, 56–70, 71–85, and 86–100 are preliminary and require substantive and statistical validation.

To improve measurement quality, it is advisable to conduct pilot testing with a separate small group, check the clarity of the wording, assess score distributions, and examine inter-rater agreement. The final assessment instruments must be applied consistently in both the experimental and control groups.

Diagnostic Criteria

Criterion	Indicators	Points
Motivational	Interest, initiative, awareness of goals	0–25
Cognitive	STEAM/IT knowledge and interdisciplinary connections	0–25
Activity-based	Independent project planning and implementation	0–25
Reflective	Self-assessment, error analysis, adjustment	0–25
Total	Overall score	0–100

Working scale: 0–55 — low, 56–70 — moderate, 71–85 — sufficient, 86–100 — high level. This is a preliminary rubric: the thresholds have not been validated. To measure autonomous motivation specifically, it is advisable to additionally use a validated psychometric scale; the overall score across the four criteria cannot automatically be considered a pure measure of motivation.

ATTENTION: The data presented below and in the accompanying tables are synthetic, specifically constructed to demonstrate calculations. They are not participant measurements and must not be presented as empirical results or evidence of the methodology's effectiveness.

In the demonstration scenario, the experimental group's mean total scores increase from 57.7 to 86.6 (approximately +28.9 points), while the control group's scores increase from 57.3 to 65.0 (approximately +7.7 points). The difference in gains is approximately 21.2 points. All reported figures are hypothetical and serve only to illustrate the principle of comparing changes over time; rounding depends on the original Excel values.

After obtaining real data, the change for each participant should be calculated as Δ = final score − baseline score. The primary between-group indicator can be defined as ΔΔ = mean Δ in the experimental group − mean Δ in the control group. In addition to the point estimate, the 95% confidence interval, effect size, missing data, and the method used to handle them should be reported.

Since students are clustered within three institutions, institutional differences must be taken into account; with a limited number of clusters, conclusions should be generalized cautiously. A regression model of the final outcome adjusted for baseline score and institution, or an appropriate repeated-measures model, may be used for the analysis. The choice of statistical test is determined by the actual structure and distribution of the data.

Illustrative Calculation Results (Synthetic Data)

The artificially generated values from the accompanying Excel file are presented below. They are intended exclusively to demonstrate tables and calculation procedures. They were NOT obtained from students at the three universities.

Group	n	Before (out of 100)	After (out of 100)	Change, points
Experimental	90	57.7	86.6	+28.8
Control	90	57.3	65.0	+7.7

The mean values were calculated as the sum of four scales for each hypothetical participant. These values do not demonstrate statistical significance and do not allow the conclusion that STEAM caused the observed

changes. Real analysis requires individual results, information on the participant selection procedure, and data on confounding factors.

The theoretical significance of the model lies in linking interdisciplinary project-based activities with the psychological mechanisms of learning motivation. However, STEAM is not regarded as a universal solution: the effect may be absent if the project task is too complex, feedback is insufficient, or the digital platform increases cognitive load without improving learning activities.

Particular attention should be paid to distinguishing the influence of the pedagogical model from the novelty effect. Increased interest during the initial classes may be short-lived. Therefore, repeated measurements and assessment of the transfer of acquired skills to new tasks unrelated to the original project are desirable.

The limitations of the planned study include potentially non-random group allocation, differences among instructors and the digital infrastructure of institutions, the subjectivity of self-reports, and the absence of actual diagnostic data at this stage. These circumstances do not allow the conclusion that the methodology has already increased students' motivation.

The practical applicability of the model is associated with the possibility of adapting project modules to different sections of the “Information Technology” course: spreadsheets, programming fundamentals, data processing, visualization, and information systems design. Implementation conditions include instructor training, transparent assessment criteria, and accessible alternatives to paid digital services.

DISCUSSION

The proposed model involves three motivational mechanisms: autonomy through the choice of project tasks, competence through successive achievements, and relatedness through collaborative discussion of results. Digital tools enable feedback provision and progress monitoring. However, potential limitations include differences in access to equipment, students' initial preparation, and the level of pedagogical support. Therefore, empirical validation requires controlling for baseline differences between groups.

For statistical validation, it is recommended to compare changes in indicators between groups, report confidence intervals and effect sizes, and, where necessary, use regression analysis adjusted for baseline levels and university affiliation. Before aggregating diagnostic scores, the internal consistency of the scales and the validity of their interpretation must be examined.

Methodological principles for designing STEAM assignments, a structural-functional model, a preliminary diagnostic rubric, and a plan for quasi-experimental validation at three educational institutions have been proposed. The outcome of the present stage is the development and theoretical substantiation of the methodology, rather than confirmation of its effectiveness.

Future research will involve conducting actual diagnostic assessments with documented dates, analyzing baseline group comparability, verifying measurement reliability, and evaluating changes in motivation with confidence intervals. Only after these procedures can empirically substantiated conclusions be formulated.

CONCLUSION

A conceptual model for integrating STEAM and digital educational tools into students' independent work in information technology has been developed. Stages of project-based activities and preliminary diagnostic criteria have been proposed. The effectiveness of the model has not yet been empirically established; its validation requires collecting actual data with accurate documentation of dates, using validated measurement instruments, and conducting statistical comparisons between groups.

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