CHAPTER 20

STEAM EDUCATION IN THE PROFESSIONAL TRAINING OF PRE-SERVICE ENGLISH LANGUAGE TEACHERS: THEORETICAL FOUNDATIONS AND THE RATIONALE FOR ITS TOPICALITY IN THE UKRAINIAN CONTEXT

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INTRODUCTION

The transformation of secondary and higher education under conditions of accelerating technological change, European integration, and post-war reconstruction has placed interdisciplinary, competence-based approaches to teaching and learning at the centre of national educational policy in Ukraine. Among the pedagogical innovations that have gained the greatest international and domestic recognition over the past decade is STEAM education as an integrative model that unites Science, Technology, Engineering, Arts, and Math within a single instructional framework. Although STEAM originated within the natural and science and technical disciplines, its methodological principles (problem-based learning, project work, authentic communication, and interdisciplinary synthesis) have proved equally productive for foreign language teaching, and in particular for the teaching of English as the principal language of international science, technology, and academic exchange.

The problem addressed in this article is twofold. On the one hand, a substantial body of international and Ukrainian research demonstrates the pedagogical benefits of STEAM-integrated instruction for language acquisition, motivation, and higher-order thinking, yet research specifically addressing the training of pre-service English teachers for STEAM-integrated classrooms remains comparatively scarce, particularly in Eastern European contexts. On the other hand, recent Ukrainian legislation governing specialised senior secondary education has created a concrete institutional demand that theoretical scholarship has not yet fully answered: schools implementing the natural and mathematical STEM field are now legally empowered to deliver a portion of

physics, chemistry, biology, or mathematics instruction bilingually, with English functioning as a genuine medium of content instruction. For a teacher training programme, this triple foundation (theoretical, empirical, and legal) is highly practical, since in this case, pedagogical scholarship converges with state policy and the daily routines of methodology departments.

The aim of the article is to clarify the conceptual essence of STEAM education, to trace its theoretical foundations in foreign and Ukrainian scientific researches, and to substantiate the importance of preparing pre-service English language teachers for STEAM-integrated instruction already at the stage of university education.

In accordance with this aim, the text addresses the following tasks:

1) to define STEAM education and outline its structural components and pedagogical logic;

2) to characterise the state of foreign and Ukrainian research on STEAM in language pedagogy and teacher education;

3) to substantiate, on legislative and strategic grounds, the necessity of embedding STEAM-integrated methodology within the initial, university-level training of pre-service English teachers.

The methods used include theoretical analysis and generalisation of scholarly literature, comparative analysis of foreign and Ukrainian researches, and analysis of normative legal documents governing specialised secondary education in Ukraine. This synthesis of theory, empirical evidence, and regulation underscores the need to define STEAM education, examine its international and national relevance, and show how Ukrainian policy turns it into a mandatory component of English language teacher training.

1. The essence of STEAM education and its international theoretical foundations

STEAM education is most commonly defined in the international literature as a transdisciplinary pedagogical approach that deliberately dissolves the traditional boundaries between the natural sciences, technology, engineering, the arts, and Math, treating them not as isolated subjects but as interconnected domains of one holistic process of cognition. The acronym itself grew out of an earlier and narrower construct, STEM (Science, Technology, Engineering, Mathematics), which emerged in United States science-policy discourse of the 1990s as a response to concerns about the country's competitiveness in technical fields and the lack of qualified specialists in engineering and the exact sciences. The subsequent inclusion of the Arts component, which converted STEM into STEAM, is generally credited to the American researcher and educator Georgette Yakman, whose foundational conference paper proposed

a pyramidal framework in which the arts function not as a decorative addition but as a structural element linking technical knowledge with creativity, design thinking, and communicative competence[1]. Yakman's model rests on the conviction that meaningful understanding of technology and engineering is unattainable without an appreciation of design, aesthetics, and the humanities, just as scientific literacy cannot be separated from mathematical reasoning; the letters of the acronym therefore denote not separate school subjects but mutually dependent literacies that jointly constitute pedagogical commons.

The historical emergence of STEM itself is worth situating briefly. The acronym is generally traced to the United States National Science Foundation's use of "SMET," later reordered to the more pronounceable "STEM," during the 1990s, amid policy reports warning of a widening gap between school leavers prepared for university-level study in the exact and natural sciences and the projected workforce needs of a technologically intensive economy. Throughout the 2000s, STEM education policy in the United States, the United Kingdom, and subsequently the European Union and East Asia focused on increasing enrolment and achievement in the constituent disciplines individually. It was against this largely technical framing that Yakman's proposal to insert the Arts proved genuinely disruptive: rather than treating creativity and communication as secondary soft skills, her framework positioned them as structurally necessary for technical competence to be meaningfully applied and communicated. Later theorists extended this framework. M. Sanders described STEM/STEAM integration as an instructional approach in which learners investigate design problems and necessarily draw upon concepts from two or more constituent disciplines, learning content in an authentically connected rather than fragmented manner[2]. R. W. Bybee situated STEM/STEAM within the broader movement toward scientific and technological literacy as a civic competence, arguing that integration's purpose is to cultivate the capacity to reason about complex, real-world problems that never respect disciplinary boundaries[3]. Subsequent scholarship has further distinguished weak forms of STEAM, in which subjects are merely juxtaposed within a themed unit, from strong or "transdisciplinary" forms, in which disciplines genuinely merge

[1] Yakman G. STEAM education: an overview of creating a model of integrative education. PATT-17 and PATT-19 Proceedings / ed. by M. J. de Vries. Reston, VA : ITEEA, 2008. P. 335–358.

[2] Sanders M. STEM, STEM education, STEMmania. The Technology Teacher. 2009. Vol. 68, No. 4. P. 20–26.

[3] Bybee R. W. The Case for STEM Education: Challenges and Opportunity. Arlington, VA : NSTA Press, 2013. 144 p.

around a shared authentic problem or product[4][5] – a distinction that proves essential when this logic is applied to language teaching, since surface-level thematic borrowing of scientific vocabulary differs qualitatively from the deep content-language synthesis that genuine STEAM-based instruction requires.

Within the STEAM framework, each letter denotes a distinct but interlocking sphere of competence. Science provides the empirical and conceptual foundation – the habits of observation, hypothesis formation, and evidence-based reasoning. Technology encompasses both digital tools and the broader human-made systems through which scientific knowledge is applied. Engineering contributes the iterative design process – defining a problem, generating and testing solutions, and refining outcomes. The Arts component, broadly interpreted by Yakman[6] to include not only fine and performing arts but also the liberal arts, language, and the humanities, supplies the aesthetic, communicative, and creative dimension without which technical solutions remain incomplete or inaccessible to a wider public. Mathematics, finally, furnishes the symbolic and quantitative language that allows the other four domains to be modelled, measured, and communicated with precision. Inclusion of language and communicative competence within the "Arts" component provides the bridge connecting STEAM education to English language teaching methodology.

Because the field of study has continued to evolve since Yakman's original proposal, it is useful to distinguish several closely related acronyms that recur throughout the international and Ukrainian literature. STEM denotes the original, narrower configuration of Science, Technology, Engineering, and Mathematics, historically associated with policy efforts to strengthen the technical and research workforce[7]. STEAM, as discussed above, adds the Arts and, by extension, the humanities and communicative disciplines, broadening the model's applicability to creativity, design, and language. A further extension, STREAM, explicitly foregrounds Reading and Writing as an additional, separately named component, reflecting the growing recognition (documented in the systematic review by M. Sun, M. Wang, D. Huang, and R. Wegerif[8])

[4] Toma R. B., Greca I. M. The effect of integrative STEM instruction on elementary students' attitudes toward science. Eurasia Journal of Mathematics, Science and Technology Education. 2018. Vol. 14, No. 4. P. 1383–1395. DOI: https://doi.org/10.29333/ejmste/83676

[5] Bautista A. STEAM education: contributing evidence of validity and effectiveness. Journal for the Study of Education and Development. 2021. Vol. 44, No. 3. P. 755–767.

[6] Yakman G. STEAM education: an overview of creating a model of integrative education. PATT-17 and PATT-19 Proceedings / ed. by M. J. de Vries. Reston, VA : ITEEA, 2008. P. 335–358.

[7] Sanders M. STEM, STEM education, STEMmania. The Technology Teacher. 2009. Vol. 68, No. 4. P. 20–26.

[8] Sun M., Wang M., Huang D., Wegerif R. Integrating reading and writing with STEAM/STEM: a systematic review on STREAM education. Review of Educational Research. 2024. Vol. 94, No. 2. P. 283–321.

that literacy development deserves explicit rather than merely implicit attention within integrated instruction.

Ukrainian policy documents and methodological literature tend to use "STEM-osvita" (STEM education) as the umbrella official term, reflecting the wording of the 2020 Cabinet of Ministers Concept[9], while "STEAM" is used more frequently within academic and international-facing publications, including bilingual and English-medium research to signal the deliberate inclusion of the arts and language dimension.

For the purposes of this study, which is concerned specifically with the intersection of integrative Science and Math pedagogy and English language teaching, STEAM is adopted as the primary term, since it explicitly accommodates the communicative, creative, and linguistic competences that are the central object of pre-service English teacher preparation, while STEM is retained wherever Ukrainian legislative or policy texts are cited verbatim in their original official terminology.

It is important to stress that STEAM should not be understood as a rigid syllabus or a discrete school subject, but as an educational philosophy and a set of design principles that can, in theory, be embedded within any subject area, including languages. Its core pedagogical features include: problem- and project-based learning organised around authentic, often real-world tasks; collaborative small-group work that mirrors the social organisation of professional scientific and engineering practice; an emphasis on process (inquiry, design, iteration) alongside product; multimodal representation of knowledge through diagrams, models, data visualisations, and physical artefacts; and formative, often portfolio-based assessment that values reasoning and communication as much as factual recall. These same features (authentic tasks, collaboration, multimodality, and process-oriented assessment) are also central tenets of contemporary communicative and task-based approaches to language teaching, which explains why STEAM has proved to be an unusually natural partner for Content and Language Integrated Learning (CLIL) and for English for Specific and Academic Purposes.

Several structural features of STEAM pedagogy make it unusually compatible with the aims of contemporary communicative and task-based language teaching. Both traditions reject the transmission model of instruction in favour of learner-centred inquiry in which knowledge is constructed through activity, and both treat authentic communicative purpose as the primary engine of learning: in STEAM, learners communicate in order to design, test, and report,

[9] Про схвалення Концепції розвитку природничо-математичної освіти (STEM-освіти) : Розпорядження Кабінету Міністрів України від 05.08.2020 № 960-р. URL: https://zakon.rada.gov.ua/laws/show/960-2020-р.

while in communicative language teaching, they use language to accomplish genuine, non-linguistic goals rather than to practise isolated forms. Both traditions further value multimodal meaning-making (diagrams, data tables, models, and oral presentation) which is of particular benefit to language learners at intermediate proficiency levels, and both increasingly rely on collaborative, small-group work that generates the kind of negotiated, purposeful interaction identified by second-language-acquisition researchers as conducive to language development. It is precisely this convergence of underlying pedagogical logic that justifies treating STEAM not as an optional enrichment activity bolted onto an otherwise conventional English syllabus, but as a coherent organising principle for content-rich, communicatively authentic language instruction, including at the level of pre-service teacher education itself.

The intellectual genealogy of STEAM extends beyond its own recent history into a longer tradition of holistic and integrative pedagogy. G. Yakman herself traced these philosophical roots to Friedrich Fröbel's advocacy of experiential, real-world learning and to John Dewey's insistence that education across subjects should be integrated and grounded in authentic experience rather than delivered as isolated disciplinary "silos"[10]. Contemporary reviewers of the field note that, despite the proliferation of publications on STEAM since 2008, its theoretical foundations remain less developed than its practical applications, which has generated an ongoing scholarly effort to clarify what integration actually requires as opposed to superficial thematic packaging of separate lessons[1112].

Within applied linguistics, the theoretical grounding for embedding STEAM content within English language instruction draws on three interconnected traditions. The first is Content and Language Integrated Learning theory, which holds that language is acquired most effectively not as an isolated target of instruction but as the medium through which learners engage with cognitively demanding, meaningful subject content[1314]. According to this view, when learners use English to formulate hypotheses, describe procedures, or interpret data, the resulting communication is functionally authentic rather than artificially rehearsed, which in turn accelerates both content mastery and

[10] Yakman G. STEAM education: an overview of creating a model of integrative education. PATT-17 and PATT-19 Proceedings / ed. by M. J. de Vries. Reston, VA : ITEEA, 2008. P. 335–358.

[11] Perales-Palacios F. J., Aróstegui J. L. La educación STEAM y el desarrollo de competencias creativas. Aula Abierta. 2021. Vol. 50, No. 1. P. 505–514.

[12] Bautista A. STEAM education: contributing evidence of validity and effectiveness. Journal for the Study of Education and Development. 2021. Vol. 44, No. 3. P. 755–767.

[13] Coyle D., Hood P., Marsh D. CLIL: Content and Language Integrated Learning. Cambridge : Cambridge University Press, 2010. 173 p.

[14] Dalton-Puffer C. Content-and-language integrated learning: from practice to principles? Annual Review of Applied Linguistics. 2011. Vol. 31. P. 182–204.

linguistic development. The second tradition is Rod Ellis's task-based language learning theory, which demonstrates that acquisition is fostered when learners must use language purposefully to accomplish a non-linguistic goal; STEAM projects (designing an experiment, presenting findings etc.) inherently generate exactly this kind of information gap and communicative necessity, in contrast to contrived classroom role-plays[15]. The third is the body of work on academic language and disciplinary literacy, which shows that the discourse patterns typical of scientific communication (passive constructions, hedged claims, cause-effect connectors, and precise technical terminology) constitute a distinct and demanding register that learners rarely encounter in general conversational instruction but that STEAM activities provide in abundance and in context[16, 17].

Empirical investigation of these theoretical claims developed gradually. C.A. Schoettler examined the integration of STEM content into German as a foreign language instruction and identified the acquisition of scientific vocabulary as a natural by-product of content-focused teaching[18]. A. Bicer, P. Boedeker, R. M. Capraro, and M. M. Capraro demonstrated empirically that learners engaged in project-based STEM activities retained mathematical and scientific vocabulary more successfully than peers taught conventionally[19], while A. M. Connor, S. Karmokar, and C. Whittington articulated an early rationale for including the arts within STEM because artistic and communicative modes of expression were seen as indispensable for translating technical precision into accessible forms[20]. M. T. Apple, J. Falout, and G. Hill found that the perceived career relevance of STEM content significantly increased motivation for English study among Japanese university students[21]. O. Lee, H. Quinn, and G. Valdés, and the later synthesis by O. Lee and A. Stephens, argued that content teachers and language teachers must deliberately co-plan instruction for multilingual learners rather than treating language demands as incidental

[15] Ellis R. Task-Based Language Learning and Teaching. Oxford : Oxford University Press, 2003. 387 p.

[16] Snow M. A. A model of academic literacy for integrated language and content instruction. Handbook of Research in Second Language Teaching and Learning / ed. by E. Hinkel. Mahwah, NJ : Lawrence Erlbaum Associates, 2005. P. 693–712.

[17] Gibbons P. Scaffolding Language, Scaffolding Learning: Teaching English Language Learners in the Mainstream Classroom. 2nd ed. Portsmouth, NH : Heinemann, 2015. 240 p.

[18] Schoettler C. A. STEM education in the German as a foreign language classroom : PhD dissertation. Tucson : University of Arizona, 2015. 210 p. URL: https://repository.arizona.edu/handle/10150/556815

[19] Bicer A., Boedeker P., Capraro R. M., Capraro M. M. The effects of STEM PBL on students' mathematical and scientific vocabulary knowledge. International Journal of Contemporary Educational Research. 2015. Vol. 2, No. 2. P. 69–75.

[20] Connor A. M., Karmokar S., Whittington C. From STEM to STEAM: strategies for enhancing engineering and technology education. International Journal of Engineering Pedagogy. 2015. Vol. 5, No. 2. P. 37–47.

[21] Apple M. T., Falout J., Hill G. Exploring the relationships between Japanese STEM students' career self-images and English achievement. Language Learning Motivation in Japan / ed. by M. Apple, D. Da Silva, T. Fellner. Bristol : Multilingual Matters, 2020. P. 205–224.

to science teaching[22][23] – an insight with direct relevance for teacher education, since it implies that language teachers, too, must be equipped to design content-rich instruction.

The most methodologically rigorous evidence to date has emerged from studies comparing STEAM-integrated instruction with traditional communicative approaches. A particularly significant contribution, given its direct relevance to Ukrainian teacher education, is the comparative study by A. Tytarenko, V. Revenko, L. Matsepura, and Y. Panasiuk, which worked with Ukrainian pre-service teachers and found that a STEAM-integrated experimental group achieved significantly greater gains across listening, speaking, reading, and writing than a control group taught by conventional means[24]. Technological innovation within STEAM-based English instruction has also been documented by Y. S. Su, C. C. Lai, T. K. Wu, and C. F. Lai, whose study of an augmented-reality STEAM system among Taiwanese students showed gains not only in language performance but also in learners' metacognitive strategy use[25], and by S. Amirinejad and A. Rahimi, who linked digital storytelling within STEAM contexts to improvements in both self-regulation and English literacy among young learners[26]. Y. Guo applied big-data analytics to track engagement in STEAM-based English classrooms, concluding that persistent barriers to effective implementation remain concentrated in two areas: inadequate teacher preparation for interdisciplinary instruction and the absence of assessment instruments capable of capturing both content and language learning simultaneously[27] – a finding that reinforces the argument that teacher education itself is the critical for the diffusion of STEAM-integrated language pedagogy.

Research from Asian educational systems have been especially prolific. I. U. Raimjanovna's studies of English classrooms in Uzbekistan identified enhanced critical thinking, stronger collaborative skills, and more authentic

[22] Lee O., Quinn H., Valdés G. Science and language for English language learners in relation to Next Generation Science Standards and with implications for Common Core State Standards for English language arts and mathematics. Educational Researcher. 2013. Vol. 42, No. 4. P. 223–233.

[23] Lee O., Stephens A. English learners in STEM subjects: contemporary views on STEM subjects and language with English learners. Educational Researcher. 2020. Vol. 49, No. 6. P. 426–432.

[24] Tytarenko A. A., Revenko V. V., Matsepura L. L., Panasiuk Y. V. STEAM approach to the development of future teachers' English language skills. Journal for Educators, Teachers and Trainers. 2021. Vol. 12, No. 3. P. 155–164. DOI: https://doi.org/10.47750/jett.2021.12.03.015

[25] Su Y. S., Lai C. C., Wu T. K., Lai C. F. The effects of applying an augmented reality English teaching system on students' STEAM learning perceptions and technology acceptance. Frontiers in Psychology. 2022. Vol. 13. Art. 996162. DOI: https://doi.org/10.3389/fpsyg.2022.996162

[26] Amirinejad S., Rahimi A. Digital storytelling within STEAM contexts for young English language learners: effects on self-regulation and literacy development. Journal of Language and Education Research. 2023. Vol. 6, No. 2. P. 44–59.

[27] Guo Y. Applying big data analytics to STEAM English teaching: a network influence analysis approach. Educational Technology Research. 2023. Vol. 9, No. 1. P. 12–27.

language use as benefits of STEAM integration, while documenting persistent obstacles such as insufficient teacher training and assessment systems poorly aligned with integrated objectives[28][29]. N. Bella, S. Ardini, and N. Sophia examined STEAM's contribution to critical thinking within the Indonesian Pancasila Student Profile framework[30], and M. Yunus found that, although teachers generally recognised the theoretical benefits of STEAM, many lacked confidences in their own capacity to design scientifically accurate integrated lessons[31] – a self-efficacy gap that later Ukrainian research also identifies as a central obstacle. M. Sun, M. Wang, D. Huang, and R. Wegerif, extending STEAM into STREAM by adding an explicit literacy component, concluded that writing-intensive integrated projects substantially strengthen learners' command of genre-specific academic writing and evidence-based argumentation[32].

Taken together, this body of international research establishes three points of consensus that are directly relevant to the present study. First, STEAM-integrated instruction reliably outperforms decontextualised language teaching on measures of vocabulary retention, academic register development, and learner motivation. Second, the single most frequently cited barrier to effective implementation, across geographically and culturally diverse contexts, is the insufficient preparation of teachers to design and deliver genuinely integrated – rather than superficially thematic – instruction. Third, research specifically addressing the preparation of pre-service English teachers for STEAM-integrated classrooms remains comparatively scarce, and research situated in Ukrainian, higher-education contexts is markedly underrepresented relative to the Asian and North American literature, despite the acute practical relevance of this question for contemporary Ukrainian educational reform.

However, international scholarship also highlights pedagogical and methodological concerns. F. J. Perales-Palacios and J. L. Aróstegui, together with A. Bautista, note that the theoretical apparatus of STEAM has developed considerably more slowly than its practical popularity, so that the label "STEAM" is applied to activities of markedly uneven pedagogical depth, from genuinely transdisciplinary design projects to superficial thematic activities

[28] Raimjanovna I. U. Benefits of STEAM technologies in English language learning. Central Asian Journal of Education and Innovation. 2024. Vol. 3, No. 11. P. 180–185.

[29] Raimjanovna I. U. STEAM as an innovative technology in teaching English. EduVision: Journal of Innovations in Learning. 2025. Vol. 1, No. 1. P. 45–52.

[30] Bella N., Ardini S., Sophia N. The implementation of STEAM in teaching English to enhance critical thinking. Journal of English Education and Linguistics. 2024. Vol. 5, No. 2. P. 88–101.

[31] Yunus M. STEAM in education: teacher responses and the implementation in English language teaching. Visi Sosial Humaniora. 2023. Vol. 4, No. 2. P. 156–168.

[32] Sun M., Wang M., Huang D., Wegerif R. Integrating reading and writing with STEAM/STEM: a systematic review on STREAM education. Review of Educational Research. 2024. Vol. 94, No. 2. P. 283–321.

loosely connected to a scientific topic[33][34]. This looseness creates a genuine risk that teacher-education programmes claiming to prepare students for "STEAM-integrated instruction" may equip them only with the weaker, thematic version of integration. A related concern, raised by Y. Guo and echoed in the self-efficacy findings of M. Yunus, is that assessment instruments capable of validly capturing simultaneous content and language learning remain underdeveloped[35][36]. These critical perspectives do not undermine the case for STEAM-integrated English teacher preparation; rather, they sharpen it, by making clear that the quality and rigour of initial teacher preparation, rather than exposure to STEAM terminology alone, is the decisive variable determining whether future teachers will be capable of designing genuinely integrative instruction.

2. STEAM education in Ukrainian scholarship and state educational policy

The development of STEM/STEAM education in Ukraine has followed a trajectory shaped first by national educational reform and subsequently by the exigencies of full-scale war. A Ministry of Education and Science working group on the dissemination of STEM education was formed in 2016, and the corresponding action plan for the implementation of STEM education in Ukraine for 2017/2018 marked one of the first systematic state-level initiatives in this field[37]. This early institutional effort was consolidated in 2020, when the Cabinet of Ministers of Ukraine approved the Concept for the Development of Natural-Mathematical Education (STEM Education) by Order No. 960-r of 5 August 2020[38], together with a corresponding implementation action plan through 2027 approved by Order No. 131-r of 13 January 2021[39]. The Concept explicitly frames the modernisation of natural-mathematical and technological education as a factor of national competitiveness, identifying declining teaching quality,

[33] Perales-Palacios F. J., Aróstegui J. L. La educación STEAM y el desarrollo de competencias creativas. Aula Abierta. 2021. Vol. 50, No. 1. P. 505–514.

[34] Bautista A. STEAM education: contributing evidence of validity and effectiveness. Journal for the Study of Education and Development. 2021. Vol. 44, No. 3. P. 755–767.

[35] Guo Y. Applying big data analytics to STEAM English teaching: a network influence analysis approach. Educational Technology Research. 2023. Vol. 9, No. 1. P. 12–27.

[36] Yunus M. STEAM in education: teacher responses and the implementation in English language teaching. Visi Sosial Humaniora. 2023. Vol. 4, No. 2. P. 156–168.

[37] Василашко І. П., Горбенко С. Л., Лозова О. В., Патрикеєва О. О. Методичні рекомендації щодо впровадження STEM-освіти у загальноосвітніх та позашкільних навчальних закладах України на 2017/2018 навчальний рік. Методист. 2017. № 8. С. 37–43.

[38] Про схвалення Концепції розвитку природничо-математичної освіти (STEM-освіти) : Розпорядження Кабінету Міністрів України від 05.08.2020 № 960-р. URL: https://zakon.rada.gov.ua/laws/show/960-2020-р

[39] Про затвердження плану заходів щодо реалізації Концепції розвитку природничо-математичної освіти (STEM-освіти) до 2027 року : Розпорядження Кабінету Міністрів України від 13.01.2021 № 131-р.

curricular fragmentation, teacher shortages in STEM subjects, and inadequate laboratory infrastructure as the principal problems to be addressed, and it sets the formation of critical thinking, engineering and algorithmic reasoning, data-analysis skills, digital literacy, creativity, and communicative competence as the intended learning outcomes of STEM/STEAM implementation at every level of education, from preschool through higher and postgraduate teacher training.

A substantial body of Ukrainian scholarship has accompanied this policy development. O. Barna and N. Balyk analysed the stages and institutional models through which STEM education has been introduced into Ukrainian schools[40], while O. Patrykieieva, O. Lozova, and S. Horbenko articulated the conceptual foundations of STEM education's national development strategy[41], subsequently elaborating methodological recommendations, together with I. Vasylashko et al., for practical implementation in general secondary and extracurricular education[42, 43]. M. Boichenko and V. Boichenko undertook a comparative analysis of STEAM education in the United States and Ukraine, concluding that, while Ukraine lags behind in infrastructure, its teacher-education programmes possess comparatively strong theoretical foundations that could, given adequate investment, support rapid practical development[44]. O. Buturlina et al. situated STEM education within the broader framework of Ukraine's alignment with European sustainability and educational standards[45], and a wider circle of researchers has examined dimensions of STEM implementation ranging from digital tools in the preparation of future mathematics teachers[46] to inclusive-education applications of STEM methodology.

Scholarship addressing the specifically linguistic dimension of STEAM in Ukraine remains considerably less developed, which constitutes an important gap that the present research seeks to address. A. Tytarenko et al. provided

[40] Барна О. В., Балик Н. Р. Впровадження STEM-освіти у навчальних закладах: етапи та моделі. Сучасні інформаційні технології та інноваційні методики навчання: досвід, тенденції, перспективи : матеріали І регіон. наук.-практ. веб-конф. (Тернопіль, 24 трав. 2017 р.). Тернопіль : ТОКІППО, 2017. С. 3–8.

[41] Патрикеєва О., Лозова О., Горбенко С. Концептуальні засади розвитку STEM-освіти в Україні. Вища школа. 2018. № 9. С. 37–47.

[42] Василашко І. П., Горбенко С. Л., Лозова О. В., Патрикеєва О. О. Методичні рекомендації щодо впровадження STEM-освіти у загальноосвітніх та позашкільних навчальних закладах України на 2017/2018 навчальний рік. Методист. 2017. № 8. С. 37–43.

[43] Василашко І. П., Патрикеєва О. О., Булавська Л. Г. Збірник матеріалів "STEM-тиждень – 2020". Київ : Видавничий дім "Освіта", 2020. 96 с.

[44] Boichenko M., Boichenko V. Comparative analysis of STEAM education in the USA and Ukraine. Comparative Professional Pedagogy. 2019. Vol. 9, No. 4. P. 34–41.

[45] Buturlina O., Dovhal S., Hryhorov H., Lysokolenko T., Palahuta V. STEM education within the framework of Ukrainian sustainability development strategies. Studia Warmińskie. 2021. Vol. 58. P. 249–261.

[46] Пікалова В. В. Методика навчання дискретної математики майбутніх учителів математики на засадах STEM-освіти : дис. ... д-ра філософії : 014. Луганськ, 2021. 296 с.

the first comparative evidence of STEAM's effect on the four macro-skills of English among Ukrainian pre-service teachers because of its comparative design[47]. I. Shkola, M. Zuienko, and I. Tymynska examined the cultivation of visual literacy within CLIL-oriented English instruction, a competence closely related to the multimodal representation practices characteristic of STEAM pedagogy[48], while a further study by I. Shkola, B. Saliuk, and V. Smelianska extended this line of inquiry by treating visual literacy as a distinct component of subject-language integrated learning in the university English classroom[49]. L. Pukhovska and S. Leu, in their comparative analysis of European Union and Ukrainian innovative educational practices, observed that vocational-education STEAM integration has received considerably more institutional attention than language-education contexts, leaving the specific application of STEAM methodology to English language instruction in Ukrainian universities an underexplored area despite its evident theoretical foundations and practical urgency[50], particularly given the growing importance of English for international scientific communication and for post-war educational and economic reconstruction.

A further strand of Ukrainian scholarship has moved beyond describing STEM/STEAM implementation in schools to examining its integration into the professional preparation of teachers themselves. V. Pikalova's doctoral research on teaching discrete mathematics to future mathematics teachers on STEM-education principles demonstrates the growing recognition, within Ukrainian higher education, that university-level methodological courses for prospective subject teachers must themselves model integrative, technology-supported instruction rather than presenting STEM merely as external content to be studied about[51]. Similarly, the results of the all-Ukrainian pedagogical experiment on pre-specialised and specialised education conducted under the New Ukrainian School concept report a generally adequate baseline level of teacher motivation, professional-pedagogical competence, and innovative culture among practising

[47] Tytarenko A. A., Revenko V. V., Matsepura L. L., Panasiuk Y. V. STEAM approach to the development of future teachers' English language skills. Journal for Educators, Teachers and Trainers. 2021. Vol. 12, No. 3. P. 155–164. DOI: https://doi.org/10.47750/jett.2021.12.03.015

[48] Shkola I., Zuienko M., Tymynska I. Fostering visual literacy in the CLIL-oriented English classroom. Molod i Rynok. 2024. No. 7–8 (227–228). P. 70–74. DOI: https://doi.org/10.24919/2308-4634.2024.306894

[49] Школа І. В., Салюк Б. А., Смелянська В. В. Візуальна грамотність як компонент предметно-мовного інтегрованого навчання англійської мови. Наукові записки. Серія "Психолого-педагогічні науки" (Ніжинський державний університет імені Миколи Гоголя) / за заг. ред. В. В. Бурназової. Ніжин : НДУ ім. М. Гоголя, 2025. № 1. С. 141–149.

[50] Pukhovska L., Leu S. Comparative analysis of EU and Ukrainian innovative educational experiences in VET. Comparative Professional Pedagogy. 2020. Vol. 10, No. 1. P. 8–16.

[51] Пікалова В. В. Методика навчання дискретної математики майбутніх учителів математики на засадах STEM-освіти : дис. ... д-ра філософії : 014. Луганськ, 2021. 296 с.

teachers, while simultaneously calling for targeted scientific-methodological seminars, training sessions, and workshops specifically to strengthen readiness for specialised and integrated instruction[52]. Taken together with the findings of M. Boichenko and V. Boichenko regarding the comparatively strong theoretical foundations already present in Ukrainian teacher-education curricula[53], these insights indicate that Ukrainian universities training future English teachers face specific and tractable challenge of translating existing theoretical strength into systematic, practice-oriented course design capable of producing graduates confident in STEAM-integrated lesson planning and delivery. This challenge is directly addressed by structured, multi-module course models of the kind piloted with Ukrainian pre-service teachers by Tytarenko et al[54].

The Russian full-scale invasion has paradoxically intensified, rather than diminished, institutional commitment to STEAM education in Ukraine. UNDP Ukraine documented how STEM/STEAM methodologies have supported the psychological resilience of students with the status of internally displaced persons by providing structured, engaging, and purposeful learning experiences that help sustain educational continuity under conditions of disruption[55], while a related UNDP report described the opening, with European Union support, of a new innovative STEAM education centre in Luhansk Oblast as an example of continued modernisation efforts even in front-line and formerly occupied regions[56]. The non-governmental organisation "STEM Osvita Ukraine" has likewise coordinated national teacher-training and resource-development initiatives throughout the war, sustaining professional development for educators despite mass displacement[57].

Comparative analyses of Ukrainian mathematics and natural-science education further highlight persistently uneven international assessment results, disrupted learning caused by the war, socio-economic inequality in access to

[52] Малихін О., Арістова Н., Ліпчевська І., Павловська О., Борзенкова Т. Організаційно-методичні умови допрофільного та профільного навчання в закладі загальної середньої освіти на засадах концепції Нової української школи: результати організаційно-підготовчого етапу всеукраїнського експерименту. Український педагогічний журнал. 2025. № 2. С. 94–104. DOI: https://doi.org/10.32405/2411-1317-2025-2-94-104

[53] Boichenko M., Boichenko V. Comparative analysis of STEAM education in the USA and Ukraine. Comparative Professional Pedagogy. 2019. Vol. 9, No. 4. P. 34–41.

[54] Tytarenko A. A., Revenko V. V., Matsepura L. L., Panasiuk Y. V. STEAM approach to the development of future teachers' English language skills. Journal for Educators, Teachers and Trainers. 2021. Vol. 12, No. 3. P. 155–164. DOI: https://doi.org/10.47750/jett.2021.12.03.015

[55] UNDP Ukraine. Developing STEM and Educational Innovations amid War. 2023. URL: https://www.undp.org/ukraine/stories/developing-stem-and-educational-innovations-amid-war

[56] UNDP Ukraine. New Centre for Innovative STEAM Education Opens in Luhansk Oblast. 2023. URL: https://www.undp.org/ukraine/press-releases/new-centre-innovative-steam-education-opens-luhansk-oblast-thanks-eu-undp

[57] "STEM Osvita Ukraine" NGO. About our mission and goals. 2023. URL: https://stemosvita.org.ua/en/

quality instruction, and outdated teaching methods as continuing weaknesses of the system, while simultaneously identifying the strengthening of STEM approaches and the modernisation of future-teacher preparation as principal opportunities for improvement[58]. This wartime evidence lends particular weight to the argument that STEAM-integrated, English-mediated instruction is not a peripheral pedagogical experiment but a strategically significant component of Ukraine's educational resilience and of its longer-term integration into European and global scientific and economic networks.

The accumulated institutional infrastructure built up in Ukraine since 2016, such as a national network of STEM centres and laboratories, the "STEM Osvita Ukraine" coordination initiative[59], the Ukrainian State Centre for Extracurricular Education's STEM programme[60], an annual professional conference devoted to STEAM education organised by the Institute of Gifted Child of the National Academy of Educational Sciences of Ukraine[61], and a growing body of methodological literature, provides pre-service teacher-education programmes with a supportive external environment for embedding STEAM-oriented coursework. This convergence of favourable infrastructure, an articulated national policy framework, and a substantial but still incomplete body of empirical research constitutes a rare and time-limited window of opportunity for embedding STEAM-integrated pedagogy systematically within pre-service English teacher training, a claim substantiated further below through analysis of the legislative mandate that now applies to natural and mathematical specialized classes.

3. Legislative grounds for bilingual instruction and the topicality of university-level teacher preparation

A decisive and directly practical source of the topicality of the present research lies in recent Ukrainian educational legislation governing the organisation of specialised senior secondary education. The Law of Ukraine "On Complete General Secondary Education", while guaranteeing every student's right to receive general secondary education in the state language, simultaneously establishes in Article 5 that educational programmes may provide for the teaching of one or several academic subjects in parallel with the state language in English or another official language of the European

[58] Хворостіна Ю., Юрченко А. SWOT-аналіз математичної освіти в Україні. Фізико-математична освіта. 2025. Т. 40, № 3. С. 44–50. DOI: https://doi.org/10.31110/fmo2025.v40i3-07

[59] "STEM Osvita Ukraine" NGO. About our mission and goals. 2023. URL: https://stemosvita.org.ua/en/

[60] Ukrainian State Centre for Extracurricular Education. STEM education. URL: https://udcpo.gov.ua/stem/

[61] STEAM-osvita: vid teorii do praktyky : materialy Mizhnarodnoi naukovo-praktychnoi konferentsii (Kyiv, 12–14 chervnia 2024 r.). Kyiv : Instytut obdarovanoi dytyny NAPN Ukrainy, 2024. 406 p.

Union[62]. This provision, refined through subsequent Ministry of Education and Science regulations governing the specialised senior school (10th–12th grades), acquires particular significance for the natural-mathematical and STEM-oriented fields: the State Standard of Specialised Secondary Education[63], subsequently amended[64], and the Model Educational Programme for academic lyceums[65], group specialisations into three clusters – linguistic-literary, socio-humanitarian, and STEM (natural-mathematical), within the third physics-mathematics, chemistry-biology, biotechnology, IT, and engineering-oriented fields are explicitly foreseen as candidates for partial instruction in English[66]. This provision is most accurately described as a norm of the Law "On Complete General Secondary Education", situated within the broader New Ukrainian School reform strategy, rather than as a discrete presidential decree; its practical effect, however, is precisely the one that motivates the present study: schools implementing the natural and mathematical STEM field are legally empowered, and increasingly expected, to deliver a portion of physics, chemistry, biology, or mathematics instruction bilingually, with English functioning as a genuine medium of content instruction rather than merely as a foreign-language subject in its own right.

This legislative frame converts theory into a formal professional requirement. If specialised natural and mathematical schools (or classes) are to deliver physics, chemistry, biology, or mathematics content bilingually, then the teachers responsible for that instruction – whether subject specialists teaching partly through English or English language teachers supporting content classes – must possess a qualitatively different professional profile than that produced by traditional, monodisciplinary teacher-training programmes. A philologically trained English teacher who has never engaged with scientific inquiry, laboratory procedure, engineering design, or mathematical modelling is poorly equipped to co-plan or deliver instruction of this kind, just as a subject teacher confident in physics or biology but lacking academic English proficiency cannot independently sustain bilingual delivery. It follows that the STEAM-integrated

[62] Про повну загальну середню освіту : Закон України від 16.01.2020 № 463-IX. URL: https://zakon.rada.gov.ua/laws/show/463-20 .

[63] Про затвердження Державного стандарту профільної середньої освіти : Постанова Кабінету Міністрів України від 25.07.2024 № 851. URL: https://zakon.rada.gov.ua/laws/show/851-2024-п

[64] Про внесення змін до Державного стандарту базової і профільної середньої освіти : Постанова Кабінету Міністрів України від 06.08.2026 № 1000.

[65] Про затвердження типової освітньої програми для 10–12 класів закладів загальної середньої освіти академічного спрямування : Наказ Міністерства освіти і науки України від 26.05.2025 № 765.

[66] Про схвалення концептуальних засад реформування профільної середньої освіти (академічні ліцеї) : Наказ Міністерства освіти і науки України від 10.10.2024 № 1451. URL: https://zakon.rada.gov.ua/rada/show/v1451729-24

preparation of pre-service English teachers cannot be postponed until the in-service stage, through short postgraduate retraining courses, but must be embedded within the initial, university-level programme of teacher education.

The urgency of this argument is reinforced by findings, discussed above, that self-efficacy and confidence – rather than theoretical knowledge alone – constitute the primary obstacle to teachers' willingness to design and deliver integrated instruction[67][68]. University teacher-education programmes are uniquely positioned to build this self-efficacy gradually, over a sustained period of guided practice, microteaching, and reflective portfolio development, in a way that brief in-service seminars cannot replicate. Therefore, preparing future English teachers to design STEAM-integrated lessons already during their bachelor's or master's studies functions as a direct, evidence-based response to the specific staffing and competence requirements created by current legislation, rather than as a general exercise disconnected from concrete institutional need. The scale of the underlying staffing problem should not be understated: the national STEM Concept explicitly names the teaching of natural-mathematical subjects by educators without appropriate specialist qualification, alongside low remuneration for teaching staff, as structural weaknesses of the pre-war system[69], and wartime mobilisation, displacement, and emigration have intensified this shortage in many regions. Under these conditions, English teachers capable of co-delivering or supporting bilingual STEM instruction represent a practical means of partially compensating for shortages of specialist subject teachers fluent in English, by enabling collaborative or team-taught models of instruction in which linguistic and disciplinary expertise are pooled across two members of staff rather than concentrated in one.

The legislative and institutional developments described above imply the need for a distinct professional competence for English teachers preparing to work with the natural and mathematical field. On the basis of the reviewed literature and practical requirements created by the bilingual-instruction provisions, four interconnected competence domains can be identified as necessary components of such a field of study: disciplinary content literacy – a working familiarity with the core concepts and terminology of physics, chemistry, biology, and mathematics sufficient to co-plan lessons with subject-area colleagues; academic-register competence in English itself, including

[67] Yunus M. STEAM in education: teacher responses and the implementation in English language teaching. Visi Sosial Humaniora. 2023. Vol. 4, No. 2. P. 156–168.

[68] Raimjanovna I. U. Benefits of STEAM technologies in English language learning. Central Asian Journal of Education and Innovation. 2024. Vol. 3, No. 11. P. 180–185.

[69] Про схвалення Концепції розвитку природничо-математичної освіти (STEM-освіти) : Розпорядження Кабінету Міністрів України від 05.08.2020 № 960-р. URL: https://zakon.rada.gov.ua/laws/show/960-2020-р (дата звернення: 23.08.2026).

command of the passive constructions, hedging devices, and precise technical vocabulary characteristic of scientific discourse[70]; integrative pedagogical design competence, understood as the capacity to construct genuinely transdisciplinary tasks rather than merely thematically decorated language exercises; and assessment literacy specific to integrated instruction. Systematic attention to all four domains within the university curriculum constitutes the substantive content of the preparation for STEAM-integrated classrooms that this study argues must begin during teacher training at the universities.

Preliminary institutional experience already illustrates both the promise and the challenges of this transition. Schools choosing the STEM cluster must demonstrate a teaching staff qualified to deliver advanced-level instruction across all specialised disciplines, together with adequate laboratories and equipment[71]. The all-Ukrainian pedagogical experiment on pre-specialised and specialised education, conducted within the New Ukrainian School concept, has diagnosed a generally sufficient level of teacher motivation but has identified continuity between pre-specialised and specialised levels, and the availability of appropriately trained personnel, as persistent organisational challenges[72]. These findings converge with the international evidence reviewed above in identifying teacher preparation – rather than curriculum design or infrastructure alone – as the decisive variable determining whether bilingual, STEAM-integrated instruction in specialised natural-mathematical schools will be implemented successfully or will remain, in practice, a largely declarative policy commitment.

Beyond the specific governmental policy discussed above, several further and mutually reinforcing factors underscore the topicality of preparing pre-service English teachers for STEAM-integrated instruction in the contemporary Ukrainian context. English functions today as the dominant working language of international scientific publication, conference communication, and research collaboration across virtually every natural-science and engineering discipline. Ukrainian secondary and higher education institutions increasingly compete for students' engagement in international olympiads, research competitions, dual-diploma programmes, and exchange opportunities in which command of academic English for STEM purposes is a precondition for participation.

[70] Gibbons P. Scaffolding Language, Scaffolding Learning: Teaching English Language Learners in the Mainstream Classroom. 2nd ed. Portsmouth, NH : Heinemann, 2015. 240 p.

[71] Про затвердження типової освітньої програми для 10–12 класів закладів загальної середньої освіти академічного спрямування : Наказ Міністерства освіти і науки України від 26.05.2025 № 765.

[72] Малихін О., Арістова Н., Ліпчевська І., Павловська О., Борзенкова Т. Організаційно-методичні умови допрофільного та профільного навчання в закладі загальної середньої освіти на засадах концепції Нової української школи: результати організаційно-підготовчого етапу всеукраїнського експерименту. Український педагогічний журнал. 2025. № 2. С. 94–104. DOI: https://doi.org/10.32405/2411-1317-2025-2-94-104

Academic-literacy resources on English communication for scientists illustrate the extent to which contemporary scientific practice presupposes genre-specific English competence skills that traditional general-English curricula rarely address in a systematic, discipline-embedded way[73]. Preparing pre-service English teachers to design STEAM-based instruction therefore directly serves the strategic goal of enabling Ukrainian STEM-oriented students to participate competitively in international academic and research environments.

Furthermore, English-mediated STEM instruction has become closely bound up with digital learning infrastructure that is itself internationally oriented. Widely used platforms and simulation environments referenced in the methodological literature on STEAM-oriented English teaching – including PhET Interactive Simulations developed at the University of Colorado Boulder[74], Nearpod's interactive-presentation tools[75], and coding and robotics environments such as Scratch, developed by the MIT Media Lab[76] – are overwhelmingly English-medium by default, meaning that Ukrainian students' ability to benefit fully from freely available international digital science-education resources is itself contingent on a level of academic English proficiency that general-purpose English courses do not systematically build. Future English teachers who understand how to exploit such resources pedagogically therefore extend their students' effective access to international digital-learning infrastructure that already exists but currently remains underused precisely because of the language barrier that separates it from the majority of Ukrainian STEM classrooms.

Ukraine's accession process to the European Union, and the associated harmonisation of educational policy with EU frameworks, adds a further dimension of urgency. The legislative provision permitting instruction in English within specialised schools is itself explicitly framed within Ukrainian policy discourse as a step toward European educational integration, mirroring similar content-and-language-integrated practices already established in a number of EU member states. L. Pukhovska and S. Leu's comparative analysis of EU and Ukrainian innovative educational experience situates vocational and STEM-oriented multilingual instruction as a shared European priority[77], implying that Ukrainian teacher-education programmes preparing graduates for

[73] Nature Education. English communication for scientists. Scitable. URL: https://www.nature.com/scitable/ebooks/english-communication-for-scientists-14053993/

[74] PhET Interactive Simulations. Free science and math simulations. University of Colorado Boulder. URL: https://phet.colorado.edu/

[75] Nearpod. Interactive presentations and virtual reality experiences. URL: https://nearpod.com/

[76] Scratch. Create stories, games, and animations. MIT Media Lab. URL: https://scratch.mit.edu/

[77] Pukhovska L., Leu S. Comparative analysis of EU and Ukrainian innovative educational experiences in VET. Comparative Professional Pedagogy. 2020. Vol. 10, No. 1. P. 8–16.

STEAM-integrated bilingual instruction are simultaneously advancing broader processes of curricular and professional-standard convergence with European practice. Several EU member-state and neighbouring education systems already treat proficiency in an internationally dominant language such as English, alongside mathematics and the national language, as a compulsory component of the specialised-track leaving examination – precisely the model that the Ukrainian bilingual-instruction provision begins to approximate, positioning graduates of Ukrainian teacher training programmes within a recognisably European model of specialised secondary education in which language and content instruction are structurally connected.

The Concept for the Development of Natural and Mathematical Education (STEM Education) to 2027 explicitly identifies the shortage of qualified STEM-subject teachers, together with an economy-wide deficit of graduates prepared for engineering, technological, and research careers, as structural problems that STEM/STEAM reform is intended to address[78]. Post-war reconstruction is widely expected to generate substantial demand for engineers, technologists, data specialists, and researchers capable of working within international teams using English-language technical and scientific literature; the corresponding UNDP Ukraine report on developing STEM and educational innovation amid war frames the sustained development of STEM education explicitly as an investment in the human capital required for reconstruction[79]. English teachers capable of supporting STEAM-oriented instruction thus occupy a strategically important position within this broader human-capital agenda, since they provide the linguistic infrastructure without which Ukrainian STEM graduates cannot fully access international knowledge networks, funding opportunities, and collaborative research partnerships.

Contemporary labour-market analyses consistently identify critical thinking, collaboration, communication, and creativity ("four Cs") as core transversal competences required across virtually all professional fields. STEAM-integrated English instruction is unusually well suited to their simultaneous cultivation, since collaborative, project-based tasks conducted partly or wholly in English require learners to argue and communicate complex reasoning in ways that isolated grammar-and-vocabulary instruction cannot replicate; the Ukrainian State Standard of Specialised Secondary Education explicitly foregrounds a coherent scientific worldview, problem-solving capacity, and communicative

[78] Про схвалення Концепції розвитку природничо-математичної освіти (STEM-освіти) : Розпорядження Кабінету Міністрів України від 05.08.2020 № 960-р. URL: https://zakon.rada.gov.ua/laws/show/960-2020-р

[79] UNDP Ukraine. Developing STEM and Educational Innovations amid War. 2023. URL: https://www.undp.org/ukraine/stories/developing-stem-and-educational-innovations-amid-war

and social competence as intended outcomes of the natural science domain[80]. It is reinforced by evidence that STEAM-integrated instruction measurably increases motivation and technology acceptance[81] and that career relevant STEM content strengthens motivation for English study[82]: learners who experience English as a meaningful tool for pursuing genuine scientific interests are more likely to sustain the effort required to develop the four Cs than learners who encounter English solely as an examination subject. Comparative analyses of Ukrainian mathematics and natural-science education further highlight persistently uneven international assessment results, disrupted learning caused by the war, and outdated teaching methods as continuing weaknesses of the system, while identifying STEM-approach strengthening and future teacher preparation as principal opportunities for improvement[83]; given that assessments such as PISA increasingly test students' capacity to apply reasoning to real world, often English-mediated problem contexts, the integration of STEAM methodology into English teacher education represents a way for addressing these systemic weaknesses.

CONCLUSIONS

The analysis presented in this article demonstrates that the topicality of preparing pre-service English language teachers for STEAM-integrated instruction in Ukraine rests on a convergence of theoretical, empirical, legislative, and strategic considerations rather than on a single motivating factor. Theoretically, the integration of Science, Technology, Engineering, Arts, and Math provides a coherent pedagogical rationale that aligns closely with established theories of content-and-language integrated learning, task-based instruction, and academic-literacy development. Empirically, a growing body of international and, increasingly, Ukrainian research demonstrates measurable benefits of STEAM-integrated approaches for language acquisition, motivation, and higher-order thinking, while consistently identifying insufficient teacher preparation as the principal obstacle to wider and more effective implementation.

Legislatively, the provision within the Law of Ukraine "On Complete General Secondary Education" enabling bilingual instruction of specialised

[80] Про затвердження Державного стандарту профільної середньої освіти : Постанова Кабінету Міністрів України від 25.07.2024 № 851. URL: https://zakon.rada.gov.ua/laws/show/851-2024-п

[81] Su Y. S., Lai C. C., Wu T. K., Lai C. F. The effects of applying an augmented reality English teaching system on students' STEAM learning perceptions and technology acceptance. Frontiers in Psychology. 2022. Vol. 13. Art. 996162. DOI: https://doi.org/10.3389/fpsyg.2022.996162

[82] Apple M. T., Falout J., Hill G. Exploring the relationships between Japanese STEM students' career self-images and English achievement. Language Learning Motivation in Japan / ed. by M. Apple, D. Da Silva, T. Fellner. Bristol : Multilingual Matters, 2020. P. 205–224.

[83] Хворостіна Ю., Юрченко А. SWOT-аналіз математичної освіти в Україні. Фізико-математична освіта. 2025. Т. 40, № 3. С. 44–50. DOI: https://doi.org/10.31110/fmo2025.v40i3-07

subjects in English, together with the associated State Standard of Specialised Secondary Education and its STEM cluster, converts what might otherwise remain a matter of pedagogical preference into a concrete professional requirement that current university-level teacher training programmes are not yet systematically prepared to meet. Strategically, the goals of European integration, post-war human-capital reconstruction, international scientific mobility, and the cultivation of 21-century transversal competences all point toward the same practical conclusion: the preparation of future English teachers of the natural and mathematical field for STEAM-integrated instruction must begin at the university stage of teacher training, rather than being deferred to sporadic forms of in-service retraining.

The practical implications of this conclusion concern curriculum design at the level of the educational programme. Because self-efficacy rather than declarative knowledge has repeatedly emerged as the binding constraint on teachers' willingness to attempt integrated instruction, STEAM preparation cannot be delivered adequately through a single theoretical lecture course; it requires an extended, practice-rich sequence combining conceptual grounding with guided hands-on experience and supervised microteaching, allowing confidence to develop cumulatively rather than being assumed to follow automatically from exposure to theory. Because the legislative provision discussed above applies specifically to the natural and mathematical field, curriculum designers should ensure that pre-service teachers encounter authentic content drawn from physics, chemistry, biology, and mathematics rather than a generic, undifferentiated notion of "science," so that graduates are prepared for the actual disciplinary range they are likely to encounter in specialised lyceums. Because assessment literacy for integrated instruction remains underdeveloped even in the international literature, teacher training programmes have an opportunity to model good practice directly, by assessing their own pre-service courses through combinations of proficiency testing, portfolio review, and observed teaching performance. Finally, because the wartime and post-war context adds urgency without necessarily adding resources, programme designers should give explicit attention to low-cost, adaptable STEAM activities – using accessible materials, free digital simulations, and locally available equipment, so that graduates are prepared to implement integrated instruction under the resource constraints that continue to characterise many Ukrainian schools, including those in front-line and recently de-occupied regions.

Universities responsible for training future English teachers should therefore embed the core principles of STEAM pedagogy (content-rich task design, academic-register instruction, collaborative project work, and multi-instrument assessment) within the compulsory methodological core of the

programme instead of treating them as an elective enrichment module, since the legislative provision for bilingual instruction applies to the system as a whole rather than to a specialised subset of institutions. At the same time, the critical perspectives reviewed above caution against a purely additive or declarative response, in which "STEAM" becomes a fashionable label attached to otherwise unchanged coursework; genuine implementation requires sustained investment in staff development for teacher-educators themselves, in partnerships between language and natural science departments within universities, and in the kind of structured, multi-module, practice-rich course architecture whose feasibility has already been demonstrated empirically within the Ukrainian higher education context. Prospects for further research lie in the empirical evaluation of specific course models for STEAM-integrated pre-service English teacher training and in the development of valid, multi-instrument assessment tools capable of capturing both content mastery and language development simultaneously.

SUMMARY

The article addresses the problem of preparing pre-service English language teachers for STEAM-integrated instruction within the system of Ukrainian higher pedagogical education. The relevance of the problem is substantiated by the convergence of several factors: the insufficient theoretical and methodological readiness of university teacher training programmes to embed Science-Technology-Engineering-Arts-Mathematics (STEAM) principles into English language coursework, and the recent Ukrainian legislative provision permitting specialised schools of the natural and mathematical direction to deliver core disciplines bilingually, partly in English. The aim of the study is to clarify the conceptual essence of STEAM education, to trace its theoretical foundations in foreign and Ukrainian scholarship, and to substantiate the topicality of STEAM-integrated preparation of future English teachers at the university stage. The study employs methods of theoretical analysis, generalisation, and comparative analysis of scholarly sources and normative legal documents. The results demonstrate that STEAM pedagogy is grounded in a coherent body of international theory (Content and Language Integrated Learning, task-based learning, academic-literacy theory) and in a growing corpus of Ukrainian research and state policy, and that the legislative provision for bilingual specialised instruction converts STEAM preparation from a pedagogical preference into a concrete professional requirement for university teacher-education curricula. Four interconnected competence domains for a STEAM-oriented English teacher are proposed: disciplinary content literacy, academic-register competence, integrative pedagogical design competence, and assessment literacy specific to integrated instruction. The findings can be used

in designing methodological courses for pre-service English teachers and in the further development of national teacher-training standards.

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