3.2. COLLABORATIVE AND COMMUNICATION COMPETENCE OF PRE-SERVICE STEM TEACHERS AS A RESOURCE FOR RESILIENT AND INNOVATIVE EDUCATION IN WARTIME

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Abstract. *The chapter examines the development of collaborative and communication competence of pre-service STEM teachers as a resource for resilience and innovation in education during the war in Ukraine. It demonstrates that the soft skills of cooperation and communication for a science and mathematics teacher are not a secondary add-on to professional training, but a prerequisite for organizing joint activities of learners, supporting their psychological resilience, and ensuring continuity of the educational process under conditions of danger and uncertainty. The aim of this study is to provide a theoretical justification and empirical verification of a model that combines the potential of non-formal STEM education (team-based intellectual competitions) with formal training of prospective teachers at a higher education institution, targeting the development of collaborative and communication competence. The empirical base consists of two components. The first covers an analysis of the dynamics of five groups of soft skills of participants in FEMMI competitions, with particular attention to the "Communication" and "Teamwork" indicators. The second is represented by a pedagogical experiment with prospective teachers of mathematics, physics, and computer science, in which a traditional model of training was compared with the STEM-oriented model focused on group projects, the use of digital tools, and reflective practices. The results showed a statistically significant increase in the levels of communication and teamwork among competition participants, as well as growth in the motivational, cognitive, praxeological, and reflective components of readiness to implement STEM education among learners in the experimental group. It is demonstrated that collaborative and communication competence are formed most effectively when team-based formats of activity are embedded in the goals, content, and assessment of educational programs, and when every episode of joint work is accompanied by reflection. An integrated model for developing soft skills of prospective STEM teachers is substantiated, which strengthens the resilience of educational communities under wartime conditions and can be used to modernize teacher education and in-service training programs.*

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Introduction

The full-scale war against Ukraine has radically changed the conditions under which the education system operates, especially in those regions where educational institutions function under constant threat of shelling, forced relocation, and the destabilization of everyday life. For institutions that train prospective science and mathematics teachers, these challenges have a dual nature. On the one hand, they are concerned with ensuring the continuity of the educational process amid permanent danger and recurring shifts between face-to-face, distance, and blended formats. On the other hand, there is an urgent need to cultivate in prospective teachers those qualities that enable them to act as agents of resilience, agency, and innovation for their future learners. Under these conditions, the issue of developing soft skills becomes not an additional, but a foundational dimension of the professional preparation of a STEM teacher (Succi & Canovi, 2020).

International studies emphasize that the ability to collaborate effectively, communicate, think critically, and creatively solve problems is a cornerstone of a teacher's professional competence in a digitally rich STEM environment (OECD, 2018; Voogt et al., 2015). In the context of wartime Ukraine, these qualities assume additional significance, including psychological resilience, readiness to act in uncertain situations, empathy, and the ability to foster supportive interactions within the learning community. The collaborative and communicative competence of prospective STEM teachers becomes a resource that enables them to transform unstable and traumatic circumstances into a space for mutual support, joint problem-solving, and the sustainable development of the educational environment.

Collaborative competence encompasses the readiness and ability to work effectively in a team, distribute roles, take responsibility for shared outcomes, resolve conflicts, and maintain productive interactions (Johnson & Johnson, 2017). Communication competence presupposes the ability to express ideas clearly and intelligibly, listen actively, provide constructive feedback, and use different channels and formats of communication, including digital ones (Hattie & Clarke, 2019). Taken together, these competences form an important component of soft skills, without which effective interaction in learner groups, organizing STEM projects, and cooperation with parents, colleagues, and local communities cannot be achieved.

Research on the transformation of STEM education indicates that contemporary models of teacher preparation must extend beyond subject specialization and traditional teaching methods, integrating elements such as project-based work, interdisciplinary tasks, the use of digital simulators and laboratories, and participation in contests and competitions (English, 2016; Marginson et al., 2013). Participation of learners in team-based intellectual competitions, Olympiads, hackathons, and tournaments in mathematics, computer science, and other STEM subjects is viewed as an effective tool for developing not only subject-related, but also social and communication skills (Yurchenko et al., 2019). Team-based activity formats with clearly defined deadlines, open-ended problem situations, and the need for rapid interaction create natural conditions for the development of collaboration, leadership, and responsibility for shared outcomes.

Importantly, under wartime conditions, such competitions are increasingly held in distance or blended formats, relying on digital platforms for communication and collaborative work. This, on the one hand, broadens opportunities for learners from different regions, including those who have been forced to relocate or change their place of study. On the other hand, this generates a need to reconsider the roles of organizers, coaches, and mentors, who simultaneously perform the functions of facilitators, tutors, and moderators of digital interactions (Bozkurt et al., 2020). For prospective STEM teachers, participating in such activities as competitors or coordinators becomes a unique experience in which they test their own ability to sustain team dynamics, manage communication, and maintain productivity despite stress factors in practice.

Formal preparation at a higher education institution should therefore not only acknowledge the potential of non-formal education and team competitions, but also integrate their logic into the content of educational components. This may be reflected in the inclusion of STEM-oriented modules in the curriculum, where learners work in small groups on complex tasks, develop mini-projects, conduct experiments, and present their results using digital visualization and communication tools (Semenikhina et al., 2021). Such integration makes it possible to determine whether the development of collaborative and communication competence is indeed not a side-effect or accidental outcome of the educational process, but a consciously planned result.

The monograph in which this chapter appears focuses on the phenomenon of education at the edge, where resilience, adaptation, and innovation are closely intertwined with the experience of war. Within this field, prospective STEM teachers hold a special place, as they are expected to serve as guides in a high-tech, scientifically oriented, yet humane and supportive educational environment. The capacity of schools to ensure continuity of learning, develop twenty-first-century skills in learners, and support their psychological resilience depends on how successfully the preparation of such professionals combines subject-matter depth with the development of soft skills.

Within this logic, the main research question of this chapter concerns how the combination of learners' participation in team-based intellectual competitions and the targeted formal preparation of prospective teachers of science and mathematics influences the development of their collaborative and communication competence as components of soft skills. Accordingly, the analysis focuses on both theoretical models of soft skills and the professional competence of STEM teachers, as well as on empirical data obtained through the implementation of relevant educational programs and experimental studies. The purpose of the chapter is to describe and substantiate, on the basis of an analysis of scholarly publications and empirical findings, a model for developing collaborative and communication competence of prospective STEM teachers as a resource for resilient and innovative education during the war in Ukraine, to identify effective pedagogical conditions for such development, and to outline prospects for further research and practical solutions for higher education institutions.

Analysis of recent publications

Soft skills in teacher preparation and STEM education

In scholarly discourse, soft skills are described as a group of cross-cutting competencies that ensure effective interaction between a person and others, as well as with a rapidly changing social environment. They typically encompass communication, collaboration, critical thinking, creativity, leadership, self-organization, and readiness for lifelong learning (Mailool et al., 2020). Unlike “hard” professional knowledge, these skills are manifested in the ways a learner acts and interacts with others, rather than in the mastery of a specific set of algorithms or formulas.

In the preparation of prospective teachers, including those in STEM specializations, soft skills are regarded as the foundation of professional competence that makes it possible to combine subject-matter depth with the organization of productive teamwork in the classroom, the creation of a safe atmosphere of mutual support, and the building of dialogue with parents and the local community. Studies conducted in different countries show that employers and educational institutions expect teachers to be able to adapt quickly to change, take responsibility for decisions in uncertain situations, and coordinate interaction in heterogeneous groups that bring together different levels of preparation and life experience (Mailool et al., 2020; Zhukova et al., 2021).

In the STEM field, which develops at the intersection of science, technology, engineering, and mathematics, the importance of soft skills becomes even more pronounced. A teacher who works with project-based tasks, inquiry-based cases, digital simulations, and blended learning formats constantly moderates group interaction, organizes the distribution of roles, and helps learners negotiate ways to solve problems. This requires not only a well-developed methodological culture, but also robust collaborative and communication skills as the basis of professional behavior.

Collaborative and communication competence of prospective STEM teachers

In contemporary research, the collaborative competence of a teacher is described as an integrated capacity to organize and sustain joint activity, define and align goals, distribute functions, establish horizontal interaction, and prevent destructive conflicts. It includes the ability to plan the work of a team, build mutual trust, encourage the involvement of those inclined towards passive participation, and support productive reflection after a task has been completed jointly (Zhukova et al., 2021).

The communication competence of a prospective STEM teacher entails the ability to formulate tasks in ways that are understandable to different age groups, use verbal and non-verbal means of interaction, listen to and clarify the positions of interlocutors, provide constructive feedback, and effectively employ digital tools for both synchronous and asynchronous communication. In hybrid or fully distance work modes, such abilities become crucial for maintaining a sense of "presence" in an online group, coordinating joint activities, and responding in a timely manner to learners' difficulties.

In the preparation of prospective STEM teachers, these two competencies are rarely developed in isolation. They are embedded in project-based work formats, laboratory classes, teaching practicums, participation in research clubs, and intellectual competitions. For this reason, the literature emphasizes the need for a holistic view of soft skills: collaboration and communication mutually reinforce each other and rely on the learner's reflective capacity to analyze their own actions, mistakes, and interaction strategies (Mailool et al., 2020; Zhukova et al., 2021).

Team-based intellectual competitions as a space for developing soft skills

One line of research represented in the sources used concerns the impact of team-based intellectual competitions on the development of soft skills in young people. In the article by A. Yurchenko and co-authors, it is demonstrated that participation in team contests in informatics and computer graphics results in a significant increase in indicators of collaboration, communication, responsibility for shared results, and readiness to work under time pressure and with incomplete information (Yurchenko et al., 2024).

The researchers emphasize that the very structure of such competitions naturally fosters the development of soft skills. Team participation requires rapid distribution of roles (analyst, programmer, presenter, coordinator), joint discussion of problem-solving strategies, and negotiation of decisions when team members' views diverge. Time constraints underscore the importance of clear communication, the avoidance of redundant information, and the prompt coordination of actions.

The findings obtained in the study indicate that systematic participation in such activities makes it possible not only to develop subject-related skills associated with programming or data analysis, but also to foster a conscious attitude to joint work and one's own role in the team. Young people report improvements in their ability to listen to others, defend their position with arguments, search for compromise solutions, and overcome fear of mistakes, since responsibility for the outcome is shared among all participants. This is particularly important for prospective higher education learners in STEM fields, who will later work in interdisciplinary project teams.

Additionally, during the full-scale war, a significant proportion of competitions were moved to distance or blended formats. This required active use of platforms for online communication, collaborative editing of files, and visualization of solutions, which in turn strengthened the digital dimension of communication competence. Such formats create "model" situations that closely resemble the realities of the educational process during the war, when a teacher must rapidly switch between offline, online, and asynchronous modes of interaction with the class.

Developing soft skills in prospective teachers: international experience and Ukrainian studies

In the study by J. Mailool et al. (2020), which examines lecturers' experience of teaching soft skills in a teacher education program in Indonesia, it is shown that soft skills are developed more effectively not through separate "additional" courses, but through integration into the content of professional disciplines, practicum, and mentoring formats of interaction. The lecturers describe how elements of presentations, group projects, mentoring, and reflective tasks are integrated into courses, serving as tools for fostering responsibility, ethics, communication skills, and teamwork (Mailool et al., 2020).

In the work by O. Zhukova and co-authors (2021), devoted to the development of soft skills in prospective teachers during teaching practice in the pandemic period, the authors emphasize the role of real pedagogical situations in which a prospective teacher has to perform professional tasks and, at the same time, adapt to the constraints of blended or distance formats. They argue that it is precisely the combination of classroom-based preparation with learning "on the job" (in a school, lyceum, or college) that creates conditions for developing reflexivity, flexibility of communication, the ability to regulate emotions, and the capacity to sustain learners' motivation under unstable conditions (Zhukova et al., 2021).

The Ukrainian studies presented in the files, which focus on developing the readiness of prospective science and mathematics teachers to use STEM technologies, reveal a similar tendency. The models being developed aim not only to master the content of STEM but also to form motivational, cognitive, praxeological, and reflective components of readiness. Collaborative and communication skills permeate all four components: a learner needs to be intrinsically motivated to work in a team, possess knowledge about ways of organizing group activity, have practical experience of participating in joint projects, and be able to reflect on their own interaction strategies.

The pedagogical experiment, fragments of which are presented in the second file, demonstrates that the purposeful design of educational modules that incorporate STEM projects, group work formats, and systems for diagnosing motivation and reflection enables statistically significant improvements in indicators of readiness to implement STEM technologies. Although the main focus of analysis is readiness for STEM, the methods used (motivation questionnaires, tools for assessing the capacity for reflection, and analysis of group tasks) directly relate to soft skills, primarily communication, teamwork, and responsibility for shared results.

Thus, international and Ukrainian studies converge on several important conclusions. First, it is advisable to develop soft skills not as a separate "add-on" to professional preparation, but through integrated models that combine project-based, research, practical, and competitive activities with reflection. Second, real or near-real interaction experience plays a decisive role: teaching practice during a pandemic, participation in team-based intellectual competitions, and working with a class under wartime threats. Third, the development of teachers' soft skills is closely linked to the transformation of the educational environment and professional requirements, and cannot occur in isolation from broader societal changes.

Synthesis of the analysis and formulation of the research problem

The review of publications shows that both international and Ukrainian pedagogical scholarship have already accumulated a substantial theoretical and empirical body of work on soft skills of teachers and learners. Studies devoted to the structure of soft skills enable the determination of the place of collaborative and communication competence within the system of a teacher's professional qualities. Research conducted in teacher education programs demonstrates the effectiveness of integrated models in which soft skills are treated as an integral part of the content and methods of preparation (Mailool et al., 2020). Works focusing on the period of teaching practice emphasize the role of real educational situations as a catalyst for developing reflection, flexible communication, and the ability to act in non-standard conditions (Zhukova et al., 2021). The experience of organizing team-based intellectual competitions reveals that such formats provide a powerful space for fostering collaboration, communication, leadership, and responsibility in young people (Yurchenko et al., 2024).

Nevertheless, several aspects remain underexplored. First, in studies that analyze team competitions, the focus is most often on school students or learners in non-academic programs, whereas prospective STEM teachers are rarely considered, and their participation in competitions is described only fragmentarily. Second, most research on soft skills in teacher preparation was conducted before the start of the full-scale war in Ukraine or in other crisis conditions (such as the COVID-19 pandemic), but without accounting for the systematic impact of wartime threats on the organization of the educational process. Third, in existing models of preparing teachers of science and mathematics, collaborative and communication competence are usually mentioned briefly, as elements of motivational or reflective components, without a detailed theoretical and empirical analysis of their dynamics.

This gives rise to a research problem: it is necessary to describe and substantiate a model for developing collaborative and communication competence of prospective STEM teachers that combines the potential of formal education in a higher education institution with the opportunities offered by non-formal formats, in particular team-based intellectual competitions, and that takes into account the realities of war as a long-term source of instability. Such a model should clarify which specific elements of content, forms of organizing activity, digital tools, and diagnostic procedures ensure the sustainable growth of soft skills, which in turn serve as a resource for resilient and innovative education in wartime.

This defines the focus of further analysis in this chapter: combining theoretical approaches to understanding soft skills with empirical findings from studies of team competitions and from a pedagogical experiment on preparing prospective teachers of science and mathematics, and identifying those pedagogical conditions under which collaborative and communication competence become a real rather than merely declarative resource for educational resilience.

Methods and materials

This subsection describes the empirical base of a study that combines two complementary strands. The first concerns an analysis of the impact of FEMMI team-based intellectual competitions on the development of participants' soft skills, primarily collaboration and communication (Yurchenko et al., 2019; Yurchenko et al., 2024). The second is related to a pedagogical experiment on developing the readiness of prospective science and mathematics teachers to apply STEM technologies, in which collaborative and communication competence are treated as cross-cutting components of this readiness (Yurchenko, 2025). Both studies share a common logic: they are based on quantitative methods, repeated measurements (before and after the intervention), and the use of statistical tests to confirm the significance of the observed changes.

Overall research design

The research design consisted of two empirical steps. At the first stage, a quantitative analysis was conducted of the dynamics of five groups of soft skills (communication, problem-solving, teamwork, lifelong learning, and leadership) in upper secondary school students who participated in FEMMI team-based intellectual competitions. This made it possible to describe how team-based work formats, problem-focused tasks, and digital support for competitions influence the development of soft skills in young people who are potential future learners in STEM fields at higher education institutions.

At the second stage, a pedagogical experiment was conducted with prospective teachers of mathematics, physics, and computer science. Two trajectories of professional preparation were modelled: a traditional one (control group) and an author's trajectory oriented towards the integration of STEM technologies, group projects, and reflective practices (experimental group). In this experiment, readiness to apply STEM was conceptualized as an integrative characteristic that includes motivational, cognitive, praxeological, and reflective components, while collaborative and communication competence were captured through a set of indicators within each of these components.

Both empirical strands were united by a pre- and post-test logic. Participants completed questionnaires before the start of the competitions or the implementation of the author's preparation model, and again after the respective activities had been completed. This made it possible to assess not only the static level of soft skills, but also their dynamics under the influence of clearly defined educational conditions.

Participants and materials in the FEMMI competition study

The FEMMI team-based intellectual competitions were organized at Sumy State Pedagogical University, named after A. S. Makarenko, and aimed to engage learners in Grades 8–11 of general secondary education institutions in the Sumy region in solving complex tasks in informatics, mathematics, and related fields. The analysis drew on data from 350 participants who participated in the competitions as team members and completed a questionnaire assessing their level of soft skills development.

The competition tasks were predominantly problem-oriented and inquiry-based, requiring participants not only to prepare subject matter but also to negotiate, distribute roles, and explain their own ideas. At certain stages, digital tools were employed – systems for demonstrating solutions, online platforms for submitting answers, and shared digital workspaces. This created an additional arena for demonstrating communication skills in a digital environment.

The materials for analysis included participants' responses to a standardized questionnaire measuring five groups of soft skills, the results of team task performance, and basic socio-demographic information about participants (grade level, place of residence, and previous experience with similar events). In this chapter, particular attention is paid to the "Communication" and "Teamwork" groups, which directly reflect collaborative and communication competence.

Participants and materials in the pedagogical experiment with prospective STEM teachers

The pedagogical experiment was conducted among learners enrolled in "Mathematics", "Physics", and "Computer Science" programs at several Ukrainian higher education institutions. The participants were learners in the final years of their studies who had already completed basic pedagogical disciplines and were undertaking or preparing to undertake teaching practice.

Within the study, two groups were formed: an experimental group and a control group. The experimental group was studied according to an author's preparation model, which provided for the purposeful inclusion of STEM-oriented modules, group projects, the use of digital laboratories and simulators, as well as the organization of reflective sessions in which learners analyzed their own interaction in teams and communication difficulties. The control group studied the content of educational components within a traditional model in which group and project-based formats of work were not systematic, and learners' reflection on their soft skills was largely situational.

The size of the groups was comparable, allowing for statistical comparability of the results. Participants in both groups studied in closely related educational programs, which allowed the impact of the author's model itself to be compared rather than differences in curricula.

The materials for analysis comprised the results of questionnaires, test tasks, and reflective surveys aimed at measuring the four components of prospective teachers' readiness to apply STEM technologies in teaching science and mathematics: motivational, cognitive, praxeological, and reflective. Items concerning group interaction, the effectiveness of communication, the ability to organize collective problem-solving, and the capacity to establish feedback made it possible to indirectly assess the level of collaborative and communication competence.

Diagnostic instruments

In the FEMMI competition study, a modified questionnaire was used, based on previous work by the authors' team

(Yurchenko et al., 2019). The instrument covered five groups of soft skills. For each group, several statements were formulated, with which participants had to agree or disagree. For the "Communication" group, the items concerned readiness to listen to others, enjoyment of questions about one's own explanations, willingness to clarify what was not understood, and a tendency to seek agreed team decisions. Responses were recorded on a scale that allowed for the analysis of both the distribution of levels for each indicator and changes after the competitions had ended.

In the pedagogical experiment, a comprehensive diagnostic toolkit was applied, which included:

- a questionnaire on motivation for success and for using STEM technologies in professional activity;
- test tasks to assess complex interdisciplinary knowledge and understanding of the nature of STEM education;
- specially designed situational tasks that modelled the organization of learners' group work, in which a prospective teacher had to choose a team-working strategy, a mode of communication, and approaches to conflict resolution;
- reflective surveys in which learners assessed their own contribution to teamwork, the difficulties of interaction, and changes in their understanding of the role of communication and collaboration in a STEM lesson.

Each component of readiness was assessed using a set of indicators with quantitative expression. For the motivational component, these included, for example, interest in STEM, willingness to engage in additional educational activities, and orientation towards teamwork. For the praxeological component, they included the ability to plan and implement STEM projects, distribute roles within a group, and use digital tools to coordinate joint activity. The reflective component encompassed the ability to critically evaluate one's own actions, acknowledge mistakes, and adjust communication strategies.

Procedure and statistical analysis

The data collection procedure in the FEMMI study involved two measurements. At the beginning of the competition, participants completed a questionnaire, which enabled the recording of the initial level of development for each group of soft skills. After the final stage of the competitions, the survey was repeated in the same format. The responses obtained were coded, grouped by indicators, and compared. Before applying statistical tests to assess the significance of changes, the normality of the data distribution was checked using Pearson's chi-square test. To identify statistically significant differences between the indicators at the beginning and at the end of the competitions, Student's t-test for dependent samples was used. This made it possible to determine in which groups of skills reliable positive shifts had occurred and whether they were linked to participation in team-based intellectual competitions.

In the pedagogical experiment, the procedure also included three successive stages: baseline (diagnostic), formative, and control. At the baseline stage, an initial diagnosis was conducted to assess the level of readiness of prospective science and mathematics teachers to apply STEM technologies in both the control and experimental groups. This made it possible to verify the absence of statistically significant differences between the groups on key indicators before the implementation of the author's model.

At the formative stage, a set of pedagogical conditions was implemented in the experimental group: integration of STEM components into course content, organization of group projects using digital tools for modelling and visualization, and targeted work on developing collaborative and communication competence (distribution of roles in teams, facilitation of discussions, reflective conversations about interaction difficulties). In the control group, teaching followed the existing curriculum without a systematic emphasis on these aspects.

At the control stage, diagnostics were repeated using the same instruments as at the beginning of the experiment. To analyze changes within each group and to compare the control and experimental groups, a Student's t-test was applied, as well as a Pearson's chi-square (χ^2) test to assess differences in the distribution of levels of readiness components. The level of statistical significance was set at $p < 0.05$.

This combination of baseline and formative procedures, standardized questionnaires, and statistical methods of analysis made it possible not only to describe specific aspects of the development of collaborative and communication competence but also to provide empirical evidence for the effectiveness of the pedagogical conditions embedded in the preparation model for prospective STEM teachers and in the organization of team-based intellectual competitions. It thus provides a robust foundation for interpreting the results presented in the next subsection.

Results

Baseline level of participants' soft skills and prospective STEM teachers' readiness

The baseline stage of the study made it possible to outline the initial "profile" of participants in both empirical strands. For the school students who took part in the team-based intellectual competitions, mean values were recorded for the five groups of soft skills on a five-point Likert scale. In the "Communication" and "Problem-solving" groups, the mean values fell within the moderate range (approximately 2.6–2.8 points), indicating the presence of basic interaction and problem-solving skills, but without a clear expression of confidence in these abilities. The "Teamwork" indicator was somewhat higher (above 3 points), which suggests that some participants already had experience working in a team and rated their ability to collaborate positively. The "Lifelong learning" and "Leadership" groups showed mean values of approximately 2.7–3.1 points, reflecting a potential for further development rather than fully formed strategies of self-directed learning or leadership behavior.

Overall, this means that before the competitions, most participants relied on intuitive notions of teamwork and communication. They already had experience of participating in joint learning or extracurricular activities, but did not always fully understand their own strengths and weaknesses as team members. This created favorable conditions for tracking change, as there was a clear “margin” for growth, with no extremely low or maximally high scores observed.

In the pedagogical experiment aimed at developing prospective teachers’ readiness to apply STEM technologies in teaching science and mathematics, the baseline data in the control and experimental groups likewise indicated predominantly average levels across all four readiness components. The motivational component was characterized by a combination of general interest in educational innovation and uncertainty about one’s own ability to implement STEM in future professional activity. The cognitive component manifested itself in fragmentary ideas about the nature of the STEM approach, isolated examples of interdisciplinary links, and familiarity with basic concepts without a coherent system.

At the start of the experiment, the praxeological component had a limited character: learners could name certain techniques of interactive or project-based teaching, but had not yet gained their own experience of completing a full STEM project cycle, from problem formulation to the presentation of results. The reflective component was also at an average level. Most learners were able to describe their strengths, but rarely analyzed their own behavior in a team, the causes of communication difficulties, or the role of feedback.

Statistical analysis of the baseline data revealed no substantial differences between the control and experimental groups; that is, the groups were comparable prior to the implementation of the author’s model. This is important, as it provides grounds for attributing subsequent differences primarily to the influence of the pedagogical conditions embedded in the experiment, rather than to initial inequality between the groups.

Dynamics of soft skills among participants in team-based competitions

After the cycle of competitions had been completed, participants were surveyed again using the same questionnaire. Comparison of the mean values before and after participation showed a clear positive dynamic for three of the five groups of soft skills.

In the "Communication" group, the mean score increased from approximately 2.78 to 3.46. The difference proved to be statistically significant: Student's t-test exceeded the critical value for $p < 0.05$. This increase reflects shifts in participants' self-assessments of their ability to formulate ideas, ask clarifying questions, participate in collective decision-making, and express their position openly within the team. Qualitative comments recorded during the competitions support this conclusion: participants noted that over time it became easier to "come to an agreement", to hear others' arguments, to avoid everyone speaking at once, and to move towards a more structured exchange of views.

For the "Problem-solving" group, the mean score also increased (from about 2.62 to 3.18), and the t-test revealed a statistically significant difference between the baseline and final measurements. This indicates that participants began to rate their ability to analyze problem conditions, search for non-standard approaches, and combine different solution strategies with greater confidence. Under competition conditions, where the tasks were open-ended and did not always have an "obvious" algorithm, learners were trained to accept uncertainty and to see it as an invitation to creative exploration rather than as a threat.

The "Teamwork" group showed the most pronounced dynamic, with the mean score rising from approximately 3.06 to 3.84 points, and the t-value again exceeded the critical threshold. This result supports the conclusion that there was a strengthening of participants' sense of belonging to the team, their ability to distribute roles, maintain an even level of engagement among all members, and take responsibility for particular functions. In their feedback, participants stressed that the repeated format of the competition stages helped them "adjust to one another", practice strategies of "coordinating rather than dominating", and recognize the value of different types of contribution to the team result.

By contrast, the "Lifelong learning" and "Leadership" groups demonstrated positive but not statistically significant changes. The mean score for "Lifelong learning" increased from about 2.7 to

3.02, and for “Leadership” from 3.14 to 3.42, but the corresponding t-values were below the critical level. This can be explained by several factors. First, the duration of the competitions and the task format were oriented primarily towards team interaction and joint problem-solving, rather than long-term planning of one’s educational trajectory or the formation of stable leadership roles. Second, the participants themselves may have perceived leadership as a character trait that does not change rapidly, and therefore adjusted their self-assessment for this indicator more cautiously.

Taken together, the results of this strand show that team-based intellectual competitions are an effective environment for developing, above all, the collaborative and communication dimensions of soft skills. They create situations of intensive interaction in which each participant is required simultaneously to listen to others, propose their own ideas, and coordinate actions under time pressure. These conditions closely align with the realities of a future STEM teacher’s work, where they must coordinate group activities among learners engaged in projects or inquiry-based tasks.

Changes in indicators of readiness to use STEM technologies and indirect dynamics of collaborative and communication competence

In the pedagogical experiment, it was important to compare the dynamics of indicators in the control and experimental groups. The aggregated results presented in the corresponding tables and charts show substantially more intensive growth in the experimental group across all four components of readiness.

For the motivational component, the experimental group showed a significant increase in the proportion of learners with high and sufficient motivation to incorporate STEM into their future professional activities. Respondents more frequently reported interest in working with interdisciplinary tasks, willingness to participate in additional STEM projects, and confidence that the use of STEM technologies makes it possible to combine subject-matter knowledge with a creative approach. In the control group, the changes were moderate and mainly concerned a shift of some respondents from a low to an average level. Statistical analysis revealed that the differences between the groups in the final data were significant and could not be attributed to random fluctuations.

The indicator "Awareness in the field of STEM" was most strongly influenced by the systematic study of the theoretical foundations of STEM education, analysis of models for integrating science, technology, engineering, and mathematics, and discussion of international and Ukrainian practices. Learners in the experimental group demonstrated the ability to clearly articulate the essence of the STEM approach, distinguish between interdisciplinary integration and the simple juxtaposition of materials, and explain the advantages of STEM in developing critical thinking and soft skills in learners. In the control group, these ideas remained more fragmentary.

The indicator "Complex interdisciplinary knowledge" in the experimental group showed a pronounced increase due to systematic work on tasks that required combining mathematical tools, scientific laws, and technological solutions. Learners gradually transitioned from isolated pieces of knowledge to an ability to see the overall structure of a task – for example, connecting analysis of a physical phenomenon with its computer modeling and mathematical description. This created conditions for the natural emergence of teamwork: each person took responsibility for part of the task, but successful completion required integrating all parts into a single solution.

The indicator "Ability to implement STEM" showed the greatest increase precisely in the experimental group. The main contribution to this growth came from forms of work that required active collaboration, including project-based learning, the use of computer simulations, organizing small-group inquiry projects, and public presentations of results followed by discussion. Learners not only practiced designing a STEM lesson, but also constantly interacted with one another while planning, distributing roles, and discussing interim results. This fostered the development of collaborative competence at the level of practical actions rather than mere declarations.

The dynamics of the indicator “Capacity for reflection” are of particular interest. In the experimental group, a clear shift was observed from episodic, situational reflection to a more stable practice of self-analysis. The strongest impact was observed in reflective journals, discussions of difficulties in teamwork, and analyses of specific situations where communication or collaboration had proven ineffective. Learners began not only to note that “it was hard to come to an agreement”, but also to search for reasons related to role distribution, communication style, or vague formulation of a shared goal. This is directly linked to the development of communication competence.

In the control group, some positive changes were also observed, which were associated with the natural accumulation of experience and the completion of teaching practice. However, statistical analysis (Student’s t-test and Pearson’s chi-square test for the distribution of levels) showed that the gains in the experimental group were substantially higher across all components. Thus, the author’s model, which systematically combined STEM-oriented modules, project-based activities, and reflective practices, proved effective not only for enhancing indicators of readiness for STEM but also for developing collaborative and communication competence as cross-cutting characteristics.

Collaboration and communication as a resource for educational resilience in wartime

Combining the findings from the FEMMI team-based competitions and the pedagogical experiment suggests that collaborative and communication skills become a genuine resource for the resilience of educational communities under crisis conditions. Participants in the competitions, who had practiced acting as a team in uncertain and time-pressured situations, showed a greater readiness to navigate new forms of interaction, including online environments. Later, as higher education learners, such participants are more likely to engage actively in clubs, projects, and conferences, which support their educational and professional trajectories despite external threats.

For prospective STEM teachers, the ability to organize teamwork and build productive communication proved to be critically important, precisely in wartime conditions. During transitions to blended or fully online formats, interruptions of classes due to air raid alerts, and situations where part of the class is offline and part online, it is collaborative and communication skills that enable the maintenance of the educational process's integrity.

The experimental results show that learners who completed the author's preparation model spoke more confidently about their own ability to sustain group dynamics, adapt forms of work to changing conditions, and use digital tools to support interaction (shared documents, virtual whiteboards, chats for organizing project work). They adopted a more deliberate stance towards creating an environment of mutual support, in which every learner has a voice and space for initiative.

One important outcome concerns the reflective dimension. An increased capacity to analyze one's own behavior in a team, articulate mistakes, and adjust communication strategies indicates that prospective STEM teachers become less vulnerable to emotional burnout. They learn to see difficulties not as personal failure, but as a signal to reconsider how joint activities are organized. This directly supports resilience: under the harsh conditions of war, such an attitude helps maintain professional agency and find resources for continuing one's work.

Integrating findings and outlining a model for developing collaborative and communication competence

An integrated analysis of both empirical strands enables the development of a model for enhancing collaborative and communication competence in prospective STEM teachers, where formal and non-formal education complement each other.

The data obtained in the FEMMI framework show that even relatively short-term participation in a cycle of team-based competitions leads to statistically confirmed gains in the "Communication" and "Teamwork" groups. This supports the rationale for systematically incorporating such formats into the professional growth trajectory of prospective teachers – both through participation in student team tournaments and through involving learners in organizing competitions for school students. In this way, a prospective teacher masters two roles simultaneously: that of a team member and that of a facilitator of others' teamwork.

The pedagogical experiment implementing the author's preparation model demonstrates that collaborative and communication competence are formed most effectively when they are not isolated in a stand-alone "soft skills course", but permeate the motivational, cognitive, praxeological, and reflective components of readiness for STEM. The motivational component is strengthened through the experience of successful team projects, the cognitive component through discussions of real examples of collective scientific and engineering work, the praxeological component through the systematic performance of group STEM tasks, and the reflective component through the analysis of specific situations involving communication difficulties.

Taken together, the results of the study provide grounds to argue that the collaborative and communication competence of prospective STEM teachers can be developed in a purposeful way under the following conditions:

1. Involving learners in diverse formats of team-based activity (competitions, projects, teaching practicum) with clearly defined shared goals.
2. Using digital tools that support transparent and regular communication, joint planning, and reflection.
3. Ensuring a constant transition from action to analysis, where each episode of collaboration becomes material for reflecting on how interaction is organized and what exactly helps or hinders the team from moving forward.

In wartime conditions, such a model not only enhances the professional readiness of prospective STEM teachers but also equips them to be carriers of resilience within their school communities. Learners who develop collaborative and communication competence alongside STEM-oriented content are able to shape the educational process as a space of mutual support, joint problem-solving, and responsible engagement with their own development. This directly aligns with the idea of education "at the edge", which not only withstands extreme circumstances but also gives rise to new forms of resilience, adaptation, and innovation.

Discussion

The findings make it possible to view the development of collaborative and communication competence in pre-service STEM teachers as a process in which the effects of formal and non-formal education, digital environments, and wartime challenges are intertwined. Participants in the competitions showed statistically significant increases in the "Communication" and "Teamwork" groups, while prospective science and mathematics teachers in the experimental group demonstrated gains in the motivational, cognitive, praxeological, and reflective components of readiness to implement STEM. This indicates that purposeful immersion of learners in team-oriented learning situations leads to qualitative changes not only in subject knowledge, but also in the ways they interact with others.

Comparison with international studies helps to outline more clearly the specificity of the Ukrainian results. In the work of B. Yildirim (2020), a model of professional development for STEM teachers is proposed in the format of "STEM Teacher Institutes", where the training course is designed as a long-term program with an emphasis on project work, interdisciplinary tasks, and collective lesson planning. The author demonstrates that joint problem-solving, group reflection, and collaboration among teachers of different subjects foster the development of communication and collaborative skills (Yildirim, 2020). Our results support this conclusion, but add a new dimension – the involvement not only of teachers, but also of school students and prospective teachers in team-based intellectual competitions, which in effect function as "mini-institutes" for developing soft skills among a broader group of participants.

In a recent study, B. Yildirim (2024) examines the impact of a "flipped TRIZ-STEM" model on teacher preparation, comparing face-to-face courses and online formats that incorporate elements of flipped learning and creative problem-solving based on TRIZ. The author demonstrates that an innovative format, in itself, does not automatically guarantee growth in creativity or other soft skills; the effect depends on how consistently tasks, feedback, and group interaction are designed (Yildirim, 2024). A similar pattern can be observed in our experiment: what proves decisive is not only the use of digital tools or project-based formats, but their integration into the logic of repeated collaboration, systematically accompanied by reflection.

The study by K. Tzafilkou, M. Perifanou, and A.A. Economides (2022) focuses on teachers' views on distance STEM teaching, the barriers they encounter, and their training needs. The authors document high levels of tension related to technical difficulties, time constraints, and psychological fatigue, as well as a strong demand for support in digital communication and online interactions (Tzafilkou et al., 2022). Our results partly resonate with these findings, but point to an even sharper dimension of the problem: for Ukrainian prospective teachers, the need for such competences is driven not only by the transition to distance formats, but also by the requirement to work under wartime threats, frequent interruptions of classes, and heterogeneous groups. Collaborative and communication skills, therefore, function not merely as a means of overcoming technical barriers, but as a mechanism for sustaining the community's viability.

In the work of D. Yabas and T. Abanoz (2024), which examines the innovative preparation of early childhood and primary school teachers for integrated STEM teaching, the authors emphasize the importance of specially organized training sessions where educators work in teams on projects, test didactic solutions, and receive mentoring support. They demonstrate that such conditions facilitate the development of a stable sense of self-efficacy, broaden the repertoire of communication strategies, and enhance the capacity to collaborate when planning and conducting STEM lessons (Yabas & Abanoz, 2024). Our experimental course for prospective science and mathematics teachers operates on a similar logic, but with several essential differences. First, it is explicitly oriented towards combining university-based learning with real school conditions under martial law. Second, it places stronger emphasis on the reflective component, which allows participants not only to acquire new collaboration practices but also to make sense of their own emotional reactions and behavioral strategies in crisis situations.

A series of studies on integrating engineering thinking, design, and digital technologies into the preparation of prospective STEM teachers underscores the importance of deliberately “nudging” learners towards cooperation. B. Wu, Y. Hu, and M. Wang (2019) demonstrate how design thinking in online courses for prospective teachers fosters joint problem exploration, the exchange of ideas, and the collective refinement of solutions. Learners acquire not only the ability to generate options but also to propose changes with arguments, accept critique, and maintain the overall logic of product development (Wu et al., 2019). Our findings – in particular the increase in “Problem-solving” and “Teamwork” indicators in the FEMMI competitions and the growth of the praxeological component in the experimental group – align with these conclusions: collaboration proves most effective when tasks involve multistep collective construction of solutions rather than a set of separate individual actions.

Similar emphases can be traced in studies on educational robotics and immersive technologies in teacher education programs. In the research by A. Rodrigues and colleagues, the impact of an interdisciplinary course in educational robotics on the ability to plan and implement STEM lessons is examined, with part of the solutions being developed by learners in teams (Rodrigues et al., 2024). In the work of F. Díaz and co-authors, the attitudes of prospective teachers towards immersive technologies and their readiness to integrate these into STEM courses are analyzed. The authors note that positive attitudes are stronger when there is experience with joint practicums and labs, rather than only theoretical familiarization. In these studies, deep integration of technologies occurs through shared activity, rather than individual testing of tools. In our model, interactive environments, simulators, and digital platforms are likewise used not as an “add-on” to lectures, but as the core of group projects, strengthening not only technical but also communication skills.

A separate international line of research concerns digital support tools, including artificial intelligence. In the work of Y. Ji and colleagues (2023), the impact of ChatGPT on achievement and cognitive load among prospective STEM teachers is analyzed. The authors demonstrate that utilizing ChatGPT as a tool for supporting explanations and generating tasks can enhance understanding and alleviate perceived load, provided that the teacher establishes clear boundaries and employs the tool to facilitate discussion rather than replace interaction (Ji et al., 2023). Our study does not focus specifically on AI, but it highlights the importance of the prospective teacher's pedagogical stance as a moderator of digital communication, capable of organizing discussion, critical analysis of solutions, and collaboration on online platforms. This is close to Ji and colleagues' conclusion that the effectiveness of digital tools depends on the extent to which they are embedded in a living process of shared thinking.

International studies on the professional preparation of STEM teachers within university "ecosystems" also confirm the central role of soft skills. Educational ecosystems that combine formal courses, research clubs, innovation centers, digital laboratories, and partnerships with external schools are viewed as environments that naturally foster demand for collaboration, communication, and cognitive flexibility. Ukrainian studies on the professional preparation of STEM teachers through digital technologies in the university environment emphasize that it is precisely interdisciplinary tools, joint projects, and digital platforms for interaction that shape a new "norm" of professional behavior for the future teacher, not as an isolated specialist, but as a member of a community. Our results align with this logic, but highlight that under wartime conditions, the university ecosystem's responsibility for developing collaborative and communication skills becomes particularly significant, as these skills underpin graduates' ability to support school communities in crisis situations.

Another strand of international publications focuses on the link between teacher preparation and sustainable development. A. Scheunpflug and J. Costa (2025) describe education for sustainable development as a space where the leading role belongs not so much to transmitting knowledge about the Sustainable Development Goals as to developing the capacity to act together, participate in collective decision-making, and recognize the long-term consequences of local actions. In the study by S. Baena-Morales and colleagues (2024), the views of teachers on the Sustainable Development Goals and education for sustainability are analyzed; the authors demonstrate that the integration of sustainability topics into education remains superficial without well-developed soft skills in cooperation, communication, and ethical reflection. Our findings fit this line of reasoning: the collaborative and communication competence of prospective STEM teachers emerges not only as a resource for organizing learning during the war, but also as a precondition for school communities to engage collectively with questions of reconstruction and ecological and social responsibility.

In addition, research on infrastructural innovations, such as blockchain technologies in education (Savelyeva & Park, 2022), underscores the importance of transparency, decentralization, and trust as the foundations of sustainable educational systems. Although our study does not involve blockchain or similar technologies, it shows that these principles can be implemented "at the human level" – through building horizontal ties, mutual support, and shared decision-making in learner groups and among prospective teachers.

In summary, the results of our study are consistent with international trends in STEM teacher preparation, where collaboration and communication are seen as integral components of professional competence. At the same time, the Ukrainian experience adds an important layer to this picture: collaborative and communication competence appears not only as an instrument for improving the quality of teaching, but as a condition for the resilience of education under conditions of protracted war. Participation in team-based intellectual competitions, engagement in STEM projects, and reflective practices within the author's preparation model transform soft skills into a real resource for overcoming crises, supporting educational communities, and moving towards sustainable development. This underscores the need for further research aimed at long-term tracking of graduates' professional trajectories and at disseminating similar models across different regions and countries.

Conclusions

The study was designed to substantiate and empirically test a model for developing the collaborative and communication competence of prospective STEM teachers as a resource for resilient and innovative education during the war in Ukraine. The research question concerned how the combination of learners' participation in team-based intellectual competitions and targeted formal preparation at a higher education institution influences the development of soft skills, such as collaboration and communication, that are necessary to sustain the viability of educational communities under conditions of prolonged uncertainty and danger.

Theoretical analysis of works on soft skills in teacher preparation made it possible to conceptualize collaborative and communication competence as interrelated components of the professional readiness of a STEM teacher. In the scholarly literature, they are described not as auxiliary abilities but as fundamental principles of professional behavior for a teacher who organizes joint activities, facilitates classroom interactions, works with diverse stakeholders in the educational environment, and coordinates blended and distance formats. Reflection on international research and Ukrainian work in the field of STEM education and soft skills development revealed that project-based, inquiry-based, competitive, and reflective formats of work create a natural environment for the development of collaboration and communication. At the same time, the role of the university increasingly consists not only in transmitting knowledge, but also in creating educational ecosystems in which learners tackle real tasks in interaction with others, utilize digital tools, and learn to analyze their own behavior and the roles they assume.

The analysis of FEMMI team-based intellectual competitions showed that such formats are an effective means of developing soft skills in upper secondary school learners and potential applicants to STEM programs. The baseline measurements indicated predominantly average levels in the "Communication", "Teamwork", "Problem-solving", "Lifelong learning", and "Leadership" groups. Following participation in the competition cycle, statistically significant increases were observed in the "Communication" and "Teamwork" groups, as well as a noticeable, albeit not always statistically significant, improvement in the "Problem-solving" indicator. This suggests that participation in team competitions changes not only the level of confidence in solving problems, but also attitudes towards joint activity: it teaches participants to coordinate actions, listen to others, and take responsibility for shared results. The less pronounced dynamic in the "Lifelong learning" and "Leadership" groups indicates that orientations towards long-term self-development and stable leadership roles require a longer period of formation and a broader range of educational influences.

The second empirical strand, related to the pedagogical experiment on preparing prospective teachers of science and mathematics to use STEM technologies, demonstrated that the author's model, oriented towards the integration of STEM modules, group projects, digital tools, and reflective practices, brings about substantial changes in the structure of learners' professional readiness. In the experimental group, there was a marked increase in the motivational component, as evidenced by a growth in interest in STEM, an increase in the desire to use integrated tasks, and a willingness to participate in additional projects. The cognitive component ceased to be fragmentary: learners defined the essence of STEM more precisely, distinguished between interdisciplinary integration and simple juxtaposition of material, and became aware of the potential of STEM for developing critical thinking and soft skills in school learners.

The praxeological component also undergoes a qualitative change: prospective teachers master not only individual methodological techniques but also the complete cycle of a STEM lesson, including problem formulation, organization of group work, use of digital simulations, and presentation of results. In this dimension, collaborative and communication competence are manifested in the ability to plan and implement joint tasks, distribute roles, and create an environment of trust and mutual support. Growth in the reflective component is expressed in a shift from episodic reflections to a stable practice of analyzing one's own activity: learners learn to identify the causes of communication difficulties, assess the effectiveness of chosen collaboration strategies, and formulate alternative approaches.

A comparison of the control and experimental groups revealed that the observed changes cannot be attributed solely to the natural accumulation of experience or completion of teaching practice. In the control group, positive dynamics were limited and were not accompanied by a systematic reconsideration of learners' views on the role of collaboration and communication in the STEM lesson. This allows us to conclude that it is the deliberately designed preparation model – in which collaboration and communication are embedded in the aims, content, formats, and assessment procedures – that creates conditions for the sustainable development of these competences.

Combining the FEMMI competition data with the findings from the pedagogical experiment enables the development of an integrated model for fostering collaborative and communication competence in prospective STEM teachers. Non-formal education, in the form of team-based intellectual competitions, provides learners with an intensive experience of teamwork, where they feel a genuine sense of responsibility for shared results. They learn to negotiate, act under time pressure, and utilize digital tools to coordinate their work. Formal university-based preparation ensures the duration and systematic character of this experience, making it possible to interpret it, connect it to theoretical models of STEM education and education for sustainable development, and transform separate episodes of collaboration into stable professional practices.

Wartime conditions impose additional demands on this model. The collaborative and communication competence of a prospective STEM teacher becomes not only a condition for effective teaching but also a resource for supporting the resilience of educational communities. A teacher who can build horizontal interaction, maintain continuous contact with the group in blended and distance formats, and effectively organize mutual support among learners serves as an "anchor point" for a class experiencing chronic danger, loss, and migration. The results of this study show that such abilities do not emerge by chance, but can be formed through a carefully designed combination of team-based activities, digital tools, and reflective practices.

Comparative analysis with international studies suggests that the Ukrainian experience is broadly consistent with global trends in STEM teacher preparation, while adding a specific dimension of wartime challenges. In many countries, emphasis is placed on the fact that developing collaboration and communication is necessary for implementing integrated STEM courses, supporting innovation, and cooperating with various partners. Under Ukrainian conditions, these same competences serve an additional function: they help education withstand the impact of war, maintain continuity of learning, and create a space for learners to share meaning, offer mutual support, and engage responsibly with the future.

At the same time, this study has certain limitations. The sample is restricted to specific regions and higher education institutions that already implement STEM-oriented programs and competitions. A substantial part of the indicators is based on participants' self-assessment. Further longitudinal research is needed to trace how the competences formed manifest themselves in graduates' actual teaching practice, as well as comparative studies in different regions of Ukraine and in other countries experiencing war or other crisis situations.

In summary, the findings allow us to argue that collaborative and communication competence constitute the core of the soft skills of a prospective STEM teacher, without which it is impossible to ensure the resilience, adaptability, and innovativeness of education during war. The combination of non-formal (team-based competitions) and formal (STEM modules, projects, reflective practices) educational formats creates an effective trajectory for developing these competences. The proposed model can serve as a basis for modernizing teacher education programs, designing in-service training schemes, and building partnerships between universities, schools, and organizers of STEM initiatives aimed at supporting the sustainable development of educational communities under challenging historical conditions.

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