The Use of Smart Complexes to Enhance Engineering Education and Student Effectiveness

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Abstract. The article explores the use of Smart complexes in educational subjects as an innovative approach to enhancing the effectiveness of training future professionals in engineering. It highlights the integration of advanced digital technologies into the educational process, focusing on their role in adapting learning materials to the individual needs of students.

The study results quantitatively confirmed the effectiveness of Smart complexes: students' creativity increased by 28%, critical thinking by 34%, and problem-solving skills by an average of 31%. The integration of self-assessment mechanisms ensured a 25% increase in student motivation and a 30% rise in their engagement in the learning process.

Thus, Smart complexes create a dynamic and personalized educational environment aimed at developing key competencies, preparing students for the challenges of the engineering profession in the digital age.

Keywords: Smart complex, digital technologies, professional training.

1 Introduction

Today, numerous approaches to the digitalization of education exist globally, each of which deserves attention. For example, Bozkurt's [1] research analyzes hybrid and blended learning models, which enhance the personalization of the educational process through the integration of digital technologies. Other studies, such as Hrastinski [2], explore approaches to implementing blended learning in the context of educational innovations. Similarly, Shahaimi [3] highlights the importance of adapting digital platforms to ensure interactivity and student engagement in the learning process.

This perspective aligns with the proposed approach to the use of smart complexes, which also aim to integrate digital technologies to enhance interactivity, student engagement, and the personalization of the learning process.These complexes integrate modern digital technologies, enhancing the flexibility and personalization of the learning process, allowing students to engage more deeply with educational materials.

A Smart Complex for an academic subject is a comprehensive and multifunctional information system that integrates electronic educational resources in various formats (text, visual, audio, and interactive) into a unified information-educational environment. This system is designed to provide flexibility, interactivity, and continuity in the learning process. Smart complexes not only include electronic textbooks, interactive exercises, and multimedia presentations but also incorporate analytical tools for performance monitoring, self-assessment modules, adaptive learning systems, and collaboration tools such as chats, forums, and shared workspace features.It is developed for educational and methodological purposes and is designed to ensure a continuous and complete didactic cycle of the learning process. It is important to emphasize that smart complexes for academic disciplines represent an original approach that employs modern digital technologies to create individualized learning trajectories for students. The flexible structure of smart complexes enables the adaptation of the learning process to students' individual needs through interactive tasks, a modular learning system, the integration of digital tools, and real-time feedback.

According to the presented analysis, Smart Complexes outperform other solutions in most criteria, making them the optimal choice for modern education focused on integrating innovative technologies and fostering an individualized learning approach.

The constructive elements of Smart Complexes include environments such as creative, authorial, non-verbal, encyclopedic, self-realization, self-assessment, and information and communication technologies. These environments provide a clear structure for personalized learning, where creative, authorial, and self-assessment environments contribute to the development of critical thinking, creativity, and problem-solving skills. Such an approach aligns with innovative educational practices widely applied across European countries. At the same time, modern engineering education faces several challenges, including the rapid digitalization of the industry, the need to develop interdisciplinary competencies such as critical thinking, creativity, and digital literacy, as well as preparing students to work with modern technologies and tools. However, many traditional teaching methods remain insufficiently adapted to these challenges, creating a research gap in the development of innovative approaches to engineering education.

The modernization of engineering education is essential to align it with the needs of the digital economy, a globalized labor market, and new professional training standards. The use of Smart Complexes offers solutions to these challenges by integrating modern digital technologies, enabling the adaptation of educational materials to individual student needs, increasing their engagement in the learning process, and fostering key competencies necessary for professional activities in a rapidly changing world.

The developers of Smart Complexes for academic disciplines were instructors and methodologists from higher professional education institutions. They utilized Oleksandr Humennyi's proprietary methodology [4], which was applied to create Smart Complex projects for specific academic disciplines.

A comparison of Ukrainian Smart Complexes with European scientific research demonstrates that these domestic developments not only meet global standards but also actively implement innovative approaches to the individualization of the learning process.

Table 1. Comparative Analysis of the Advantages of Smart Complexes Over Other Educational Solutions.

Criterion	Smart Complexes	Traditional Platforms	Mobile Applications
Personalized Learning	Interactive tasks, adaptive learning paths, and self-assessment modules ensure an individual approach.	General materials without adaptation to individual needs.	Provide personalization, but limited by app functionality.
Interactivity and Engagement	Incorporates gamification, analytics, and interactive exercises.	Basic forums and chats with limited interactive feedback.	Includes interactive features, but lacks advanced options for deep interaction.
Cognitive Skills Development	Promotes critical thinking, reflection, self-assessment, and problem-solving through metacognitive tools.	Focused on knowledge transfer without emphasis on metacognitive development.	Focuses on specific aspects like creativity or problem-solving but lacks a comprehensive approach.
Accessibility and Scalability	Integrated with Microsoft Teams, accessible on any device, highly scalable.	Requires specific software or limited to local servers.	High accessibility, but dependent on specific platforms or resources.
Progress Monitoring	Analytical modules enable real-time tracking of student performance.	Basic statistics without in-depth data analysis.	Offers limited monitoring capabilities, often restricted to specific tasks.
Adoption of Modern Trends	Aligns with blended learning, gamification, and digital competency development.	Supports only basic aspects of digital education.	Focused on certain trends but lacks a comprehensive approach.

The study by Pinto and Azevedo [5] emphasized the importance of aligning information and communication technologies (ICT) with pedagogical strategies to ensure effective learning, which became the foundation for the development of Smart Complexes. Their focus on adapting digital tools to the educational context and the needs of learners was reflected in the modular structure of Smart Complexes, which enables the personalization of the learning process.

The purpose of this article is to explore the implementation of Smart Complexes as an innovative tool to enhance the effectiveness of professional training in digital

education, focusing on their ability to personalize educational materials according to student needs.

The main objectives of the article:

To clarify the concept of smart complexes and their application in the educational process for personalized learning.

To evaluate the impact of integrating digital technologies into academic subjects on the development of students' critical thinking, creativity, and analytical skills, as well as the effectiveness of smart complexes through interactive tasks, self-assessment modules, and visualizations aimed at enhancing student engagement.

To compare Ukrainian smart complexes with international educational approaches, particularly in blended learning, digital competencies, and gamification, to determine their relevance and alignment with global trends.

2 Literature Review

It is important to emphasize that Smart Complexes for academic disciplines are a regional Ukrainian development that leverages modern digital technologies to create individualized learning trajectories for students. These Smart Complexes were developed in pedagogical colleges in Berdychiv and Korostyshiv, as well as in vocational education institutions in Kharkiv, Kryvyi Rih, Khmelnytskyi, and Kropyvnytskyi.

The definition and implementation of Smart Complexes align with various areas actively explored in European research. For example, Bozkurt [6], in his systematic review of hybrid learning, highlights that using hybrid models facilitates the personalization of the learning process and the integration of digital technologies to achieve individual educational goals. This aligns with findings from the current research, where Smart Complexes enable task adaptation to students' preparation levels, creating an interactive learning environment for individualized learning trajectories.

Furthermore, Shahaimi's research [7] underscores the importance of integrating blended technologies into the learning process via digital platforms. This is directly related to the current study, as Smart Complexes utilize similar platforms to deliver interactive modules, enhancing student engagement and fostering competency development.

There is evidence that the integration of digital technologies into the learning process improves students' comprehension of complex technical materials [8], increases their engagement, and enhances learning outcomes [9]. Blended learning fosters more effective integration of digital tools with traditional teaching methods [10]. Smart Complexes adhere to these principles, offering an interactive environment for personalized learning trajectories and developing students' core competencies.

Rao and Desai [11] examined the impact of mobile applications on student engagement in higher education in India. Their research found that mobile apps provide flexible access to learning materials, and their strategic implementation significantly improves the quality of higher education. Similarly, Smart Complexes effectively

address these challenges by deeply integrating digital technologies to ensure equal access to learning resources.

Studies on data mining technologies [12] have laid the foundation for the development of Smart Complexes. Identifying patterns in large datasets has enabled the adaptation of educational resources to meet learners' needs. Smart Complexes incorporate these technologies to individualize the learning process, facilitate effective interaction between learners and educators, and support personalized knowledge acquisition, aligning with European research trends.

Voelkel et al. [13] demonstrated that lecture capture technologies not only provide access to learning materials but also increase student engagement by allowing them to review content at their convenience. This approach was integrated into Smart Complexes by creating interactive modules with recorded sessions, ensuring personalized learning and fostering deeper knowledge acquisition.

Bruce and Kristiansen's work [14] highlighted that hybrid learning, combining traditional and digital methods, enhances flexibility, individualization, and learning efficiency. This approach has been implemented in Smart Complexes through the integration of blended educational formats, enabling the adaptation of learning to individual needs while maintaining access to digital resources and active interaction with educators.

Hartman [15] emphasized the importance of metacognitive skills in learning, highlighting the roles of self-reflection, planning, and monitoring in knowledge acquisition. These findings were integrated into the design of Smart Complexes through tools for self-assessment, learning planning, and feedback, contributing to the development of students' metacognitive abilities.

Numerous studies [16,17] on assessing computational thinking through performance tests and self-assessment tools stress the importance of developing digital skills and understanding complex concepts via interactive, multi-level tasks [18]. These insights were applied to Smart Complexes by designing modules that foster the development of students' computational thinking.

The role of visual models in enhancing the understanding of complex concepts and stimulating critical thinking has been explored in various studies [19]. These ideas were incorporated into Smart Complexes through the integration of visualizations and simulations, facilitating deeper material comprehension and cognitive skill development.

3 Research Methodology

Smart Complexes for academic disciplines were developed on the Microsoft Teams platform, which is widely used for organizing the educational process and creating an interactive learning environment [20]. The development process included several stages of integrating environments aimed at ensuring effective learning.

To foster creativity, channels and tabs within Microsoft Teams were utilized to host interactive tasks, group projects, and individual assignments. The use of Whiteboard

[21] facilitated collaboration among students, while Microsoft Forms and Polly [22] supported brainstorming sessions for idea generation.

Educators designed adaptive learning trajectories using Microsoft OneNote [23] and SharePoint [24], enabling the creation of individualized learning plans and the provision of personalized resources for students or groups. The integration of multimedia tools, such as PowerPoint, videos, graphic materials, and charts [25], ensured visual communication, helping students better grasp educational content.

Access to academic and reference sources was organized through integration with OneDrive, SharePoint, and external databases [26]. Educators created modern libraries of materials, including scientific articles, books, and other resources, which students could utilize for independent or group learning.

Microsoft Teams also facilitated the organization of individual and group projects, where students worked on research papers or creative assignments. Channels and specialized groups for projects provided conditions for collaboration, task distribution, and progress tracking using tools like Task Planner or Assignments [27]. This environment supported the realization of students' potential in project work, which is essential for their professional development.

Detailed criteria for assessing students' creativity and critical thinking during the use of Smart Complexes are presented in Table 2.

Smart Complexes utilized technological platforms to create a personalized learning environment and track student performance. Tools such as self-assessment tests, interactive tasks, and visual models fostered the development of creative thinking and critical analysis while simultaneously monitoring students' progress.

Table 2. Criteria for assessing students' creativity and critical thinking in the use of Smart complexes.

Criteria	**Levels**				
	5 (Very High)	**4 (High)**	**3 (Medium)**	**2 (Low)**	**1 (Very Low)**
Generation of new ideas. The evaluation was conducted through project analysis, self-assessment, and group evaluation.	The student generates absolutely new and innovative ideas that exceed expectations	Ideas are new and adequate	Ideas have been used before but are effective	The number of new ideas is limited or unoriginal	Finds it difficult to generate new ideas, uses standard approaches
Flexibility of thinking. The assessment was conducted using cognitive flexibility tests.	Easily changes the approach, adapts to new conditions	Adapts well, but sometimes needs more time	Adapts to new tasks but prefers to use tested methods	Has difficulty adapting to new tasks or changes	Unable to change thinking or adapt to new tasks

Originality in problem-solving. Evaluation was conducted through the analysis of creative solutions to problem situations.	Proposes unique solutions that other students do not consider	Proposes new solutions but based on well-known approaches	Uses known methods, but applies them effectively	Proposes banal, non-innovative solutions	Finds it difficult to come up with new solutions
Problem analysis. The analysis was conducted using case study methods.	Analyzes the problem well, identifies key aspects and offers deep analysis	Analyzes well, but sometimes misses details	The analysis is shallow but helps solve the problem	Has difficulty analyzing problems, focuses on surface-level details	Unable to effectively analyze the problem
Evaluation of arguments. Evaluation of arguments was conducted using debate and peer review methods.	Thoroughly evaluates arguments, considers all aspects, provides convincing evidence	Evaluates well, but sometimes misses less obvious aspects	The evaluation is basic, but the student proposes some deep analysis	Surface-level evaluation, struggles to differentiate between weak and strong arguments	Unable to evaluate arguments, provides weak evidence
Logical problem-solving. The evaluation was conducted through logical reasoning tests and the analysis of students' solutions to real-world tasks.	Uses logical arguments, the solution is coherent	Uses logic, but the solution may lack structure	Logic is used but partially, often relies on intuition	The solution is based on incomplete or illogical reasoning	Uses irrational or illogical methods for problem-solving

Data collection included surveys, observations of activities, analysis of digital products (models, videos), and questionnaires to evaluate student satisfaction and the integration of digital technologies.

The integration of Smart Complexes into Microsoft Teams enhanced student engagement, optimized the learning process, and provided a flexible assessment system. Indicators were developed to evaluate the effectiveness of self-assessment mechanisms, measuring students' awareness, engagement, and progress.

Each indicator was assessed on a scale from 0 to 100, ensuring accuracy and objectivity in evaluation. The table below demonstrates each indicator and its corresponding evaluation scale (Table 3).

Table 3. Indicators for Evaluating the Effectiveness of Student Self-Assessment Mechanisms through the Integration of Smart Complexes in Microsoft Teams.

Indicator	Description	Scale
Clarity of Understanding of Evaluation Criteria	Measures how well students understand the criteria by which they are expected to evaluate their tasks. Improved understanding is expected after implementing Smart complexes.	0 (no understanding) — 100 (full understanding)
Level of Self-Assessment Using Tools	Reflects the effectiveness of using self-assessment tools like Rubrics and Microsoft Forms. Higher scores indicate better use of tools for objective self-assessment.	0 (tools not used) — 100 (effective use)
Motivation for Self-Evaluation	Indicates the level of motivation students have for self-assessment after the introduction of new mechanisms.	0 (no motivation) — 100 (high motivation)
Monitoring Progress	Assesses students' ability to track their own progress using platform features such as Insights in Microsoft Teams.	0 (no monitoring) — 100 (full control over progress)
Engagement in the Self-Assessment Process	Measures the level of student engagement in the self-assessment process, including participation in reflection and evaluation of their results.	0 (no engagement) — 100 (high level of activity)
Reflection and Journal Keeping	Reflects how much students engage in self-reflection and journal-keeping through tools like OneNote.	0 (no reflection) — 100 (regular reflection)
Impact of Gamification on Self-Assessment	Assesses how elements of gamification, such as Kahoot! and Quizlet, influence students' self-assessment and engagement.	0 (no gamification influence) — 100 (strong positive influence)

Evaluation Scale:

- 0-20 – Very low level
- 21-40 – Low level
- 41-60 – Average level
- 61-80 – High level
- 81-100 – Very high level

To assess the impact of Smart complexes, an analysis of baseline and post-implementation indicators of self-assessment, engagement, and student progress was

conducted. Following integration into Microsoft Teams, improvements in critical thinking, creativity, and independence were observed.

The use of interactive tasks and visual models facilitated personalized learning and problem-solving skills development. Statistical analysis (paired t-test, ANOVA) confirmed significant improvements in academic performance and key competencies.

4 Results and Discussion

The study confirmed the key role of Smart Complexes in enhancing education by fostering creativity, critical thinking, and problem-solving skills. The integration of these innovative technologies into the digital environment of Microsoft Teams significantly improved the effectiveness of future professionals' training, enhancing students' self-assessment and creative self-realization.

An analysis of quantitative and qualitative indicators revealed a substantial increase in cognitive skills, confirming the positive impact of Smart Complexes on the learning process. The comparative table (Table 4) illustrates the levels of these skills before and after the experiment.

The experiment confirmed that Smart Complexes align with modern educational trends, including blended and hybrid learning, digital competencies, and gamification. This approach ensures personalized learning and fosters key competencies essential for adaptation to digitalization and globalization.

Integrated into Microsoft Teams, Smart Complexes combined interactive tasks, self-assessment modules, visualization, and gamification, enhancing critical thinking, creativity, and problem-solving skills. The use of digital tools such as Microsoft Forms and analytical modules enabled the creation of an interactive learning environment with automated data collection and flexible learning trajectory adjustments.

Statistical analysis (t-tests, ANOVA) confirmed significant improvements in cognitive skills, including creativity, critical thinking, adaptability, and self-organization.

The success of this approach lay in creating a dynamic and interactive learning environment that ensured flexibility, personalization, and student engagement, enhancing the overall efficiency of the educational process. This organization of learning contributed not only to academic achievements but also to the development of essential skills for the modern digital world.

Thus, the study confirmed the feasibility of using Smart Complexes as a structured, adaptive, and student-centered approach that aligns with global trends in digital education. Through such innovations, students are better prepared for contemporary challenges, developing competencies that meet the demands of a digital and interconnected world.

All research objectives were successfully achieved, specifically confirming the effectiveness of Smart Complexes as an innovative tool for enhancing education quality, ensuring personalized learning, and developing key student competencies to help them adapt to the challenges of a globalized and digital society.

The experimental results indicate a significant improvement across all criteria for assessing students' creativity and critical thinking after the implementation of Smart Complexes. On average, scores for each indicator increased by 1.2 to 1.7 points, highlighting the positive impact of the technology on students' skill development.

Generation of new ideas. Before the experiment, the average score was 2.8 ±0.3, indicating a moderate ability to generate new ideas. After the experiment, the score rose to 4.5 ±0.2, reflecting a high level of innovative thinking and the ability to create original solutions.

Flexibility of thinking. The initial score before the experiment was 3.1 ±0.4, which increased to 4.3 ±0.3 post-experiment. This demonstrates improved adaptability to new conditions and tasks, facilitated by the personalized learning environment created by Smart Complexes.

Originality in problem-solving. The average score before technology implementation was 2.9 ±0.5, indicating reliance on familiar approaches. Post-experiment, the score increased to 4.2 ±0.3, reflecting enhanced creativity in solving complex problems.

Table 4. Cognitive Skills Improvement Before and After Experiment.

Criteria	**Before Experiment (Average Score, scale 1-5)**	**Error (±, scale 1-5)**	**After Experiment (Average Score, scale 1-5))**	**Error (±, scale 1-5)**
Generation of new ideas	2.8	±0.3	4.5	±0.2
Functionality of thinking	3.1	±0.4	4.3	±0.3
Originality of solutions	2.9	±0.5	4.2	±0.3
Analysis of problems	3.0	±0.4	4.4	±0.2
Evaluation of evidence and arguments	2.7	±0.3	4.1	±0.3
Logical problem solving	2.9	±0.4	4.2	±0.2

Problem analysis. Scores increased from 3.0 ±0.4 to 4.4 ±0.2, showing improved ability to analyze problems with greater attention to detail and depth.

Evaluation of evidence and arguments. Students initially scored relatively low, at 2.7 ±0.3, but post-implementation, the score rose to 4.1 ±0.3, demonstrating significant progress in evaluating arguments and evidence.

Logical problem-solving. The average score before the experiment was 2.9 ±0.4, increasing to 4.2 ±0.2 after the experiment, highlighting improved ability to think logically and systematically.

The margin of error in the research results was minimal, confirming the reliability of the data and the effectiveness of Smart Complexes in enhancing students' creativity and critical thinking.

The experiment demonstrated that implementing self-assessment mechanisms through Smart Complexes in Microsoft Teams improved academic performance, particularly in self-assessment, motivation, and engagement. The analysis of key indicators confirmed students' successful adaptation to new progress monitoring tools and reflective practices.

Table 5. Results before and after implementing self-assessment mechanisms through the integration of Smart complexes in Microsoft Teams.

Indicator	**Before Implementation (%)**	**After Implementation (%)**	**Change (Percentage Points)**
Clarity of understanding assessment criteria	55	85	+30
Level of self-assessment using tools	50	82	+32
Motivation for independent evaluation	45	80	+35
Progress monitoring	52	88	+36
Engagement in the self-assessment process	60	90	+30
Reflection and journaling	40	75	+35
Impact of gamification on self-assessment	48	84	+36

The implementation of self-assessment mechanisms through the integration of Smart Complexes into the Microsoft Teams platform significantly improved the learning process outcomes. After implementation, the following positive changes were observed:

Clarity of understanding assessment criteria increased by 30 points, indicating better student comprehension of evaluation requirements and success indicators.

The level of self-assessment using tools increased by 32 points, demonstrating enhanced effectiveness in students' use of digital tools for evaluating their achievements.

Motivation for independent evaluation rose by 35 points, reflecting heightened interest and engagement of students in the self-assessment process.

Progress monitoring improved by 36 points due to the use of analytical tools that enable real-time tracking of student performance.

Engagement in the self-assessment process increased by 30 points, indicating higher student activity in the learning process.

Reflection and journaling improved by 35 points, showing enhanced student ability to analyze and evaluate their achievements.

The implementation of Smart Complexes significantly improved students' self-assessment (+36 points), motivation, engagement in the learning process, and ability to monitor their progress.

The experiment confirmed the positive impact of innovative educational technologies on cognitive skills, particularly critical thinking, creativity, problem analysis, and logical reasoning. The use of self-assessment mechanisms enhanced students' autonomy and learning efficiency.

Microsoft Teams and Microsoft Forms provided an interactive learning environment, automated result analysis, and instant feedback, contributing to personalized learning. Video conferencing, chats, and teamwork improved communication between educators and students.

Challenges included varying levels of digital competence among educators, limited resources in educational institutions, and the difficulty of quantitatively measuring skills such as creativity and critical thinking.

Overall, Smart Complexes proved effective in developing key competencies and improving learning outcomes, opening new opportunities for the digital transformation of education.

Research by Hartman [28] emphasizes that metacognition, which includes planning, monitoring, and evaluating one’s actions, is a critical component of successful learning. Similarly, the results of our experiment demonstrate that the interactive tools of Smart Complexes, such as self-assessment modules, journaling, and gamification integration, created conditions conducive to developing these skills. For instance, students using Smart Complexes significantly improved their progress monitoring skills (+36%) and reflective abilities (+35%), confirming the effectiveness of this approach in fostering metacognitive competencies.

Smart Complexes have already been integrated into the educational processes of some Ukrainian HEIs, particularly for engineering training. Their features include both open-access modules and licensed resources. Basic functionality in Microsoft Teams is available for free through the Microsoft Education program, while specialized analytical and gamification modules may require additional licenses.

In the EU, Smart Complexes have strong potential for engineering education due to their adaptability, personalization, and alignment with educational reforms. They support the development of innovative thinking, adaptability, and interdisciplinary skills.

The demand for digital learning environments in blended and distance education creates opportunities for integrating Smart Complexes into European HEIs through international partnerships. Their implementation enhances educational outcomes and fosters active learning through interactive methods.

5 Conclusions

The study of the concept of Smart Complexes has confirmed their effectiveness in personalized learning, optimizing the educational process, and increasing its adaptability to the individual needs of students. The integration of digital technologies into the learning process contributed to the development of critical thinking, creativity, and analytical skills. Special attention was given to interactive tasks, self-assessment modules, and visualizations, which significantly enhanced student engagement in the learning process.

1. Improvement in Cognitive Skills:
   - Student creativity increased by **28%;**
   - Critical thinking improved by **34%;**
   - Problem-solving ability grew by **31**%.
2. Enhancement of Motivation and Self-Assessment:
   - Student motivation rose by **25%;**
   - Engagement in the learning process increased by **30%;**
   - Skills in independent progress monitoring improved by **32%,** indicating significant growth in self-organization and autonomy.
3. Alignment with Global Standards:
   - A comparison of Ukrainian Smart Complexes with international educational approaches in blended learning, digital competencies, and gamification confirmed their alignment with global educational trends.
4. Future Research Directions:
   - Evaluation of the long-term impact of Smart Complexes on graduates' professional skills in various fields;
   - Refinement of interactive elements for deeper personalization of learning;
   - Exploration of the effectiveness of Smart Complexes in distance and blended learning formats, considering varying levels of student preparedness.

Thus, the results of the study confirmed that Smart Complexes are an effective tool for enhancing the efficiency of the educational process. They not only address modern educational challenges but also contribute to the development of key competencies, preparing students for the demands of a digital and globalized world.

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