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FOREIGN EXPERIENCE OF SOFTWARE TESTING ENGINEERS TRAINING: ANALYSIS OF EDUCATIONAL STANDARDS AND PROGRAMS OF EUROPEAN UNIVERSITIES

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The article explores the European educational system's approach to training software testing specialists. It contains an analysis of certain key standards for IT engineers training in Europe, such as the Standards and Guidelines for Quality Assurance in the European Higher Education Area (ESG), the European Association for Quality Assurance in Higher Education (ENQA) criteria, and national accreditation standards like the Polish Accreditation Committee (PKA), the German Accreditation Council (GAC), and the UK's Engineering Council (ECUK). The study emphasizes the place and teaching methods of software testing theory and practice within university curriculum guidelines, assessing both an availability of dedicated testing disciplines and the appearance of testing topics/modules in more general engineering disciplines. Despite similar interpretations of basic concepts and practices in software testing, opinions on teaching methodologies and the representation of both theoretical and practical aspects of it vary among the reviewed standards. Additionally, the research examines training programs at leading European universities to identify how software testing and quality assurance are reflected in their curricula. This analysis covers full-time training programs for students in computer science, software engineering, and related fields. The study explores programs in both general and basic disciplines within IT and those specific to certain technological or organizational areas, such as mobile device development or IT project management. The content of subjects, modules, lectures, and extracurricular work tasks available in open sources was also analyzed. Furthermore, the research investigates how these institutions incorporate practical training, such as internships and project-based learning, to ensure students gain hands-on experience in software testing and quality assurance

Keywords: *software engineering, software testing, educational standards, training program, European experience*

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1. Introduction

The Information Technology sector in Ukraine is experiencing substantial growth and development even considering the challenging economic conditions and ongoing resistance to russian aggression. The resilience of the Ukrainian IT industry is evident in its continued growth and the increasing number of professionals contributing to both local and international companies. This growth is occurring in a relatively young industry that relies heavily on external markets, with many Ukrainian companies and contractors working closely with partners in Europe. Furthermore, numerous international companies have established offices in Ukraine, bringing with them working styles, contexts, and requirements that align closely with European standards.

The dependence of Ukraine's IT industry on foreign markets has shaped its educational system to adapt quickly and efficiently. Ukrainian IT education strives to learn from its foreign counterparts, adopting best practices and methodologies from leading foreign institutions. This alignment ensures that Ukrainian IT professionals are well-equipped with the skills and knowledge, needed to meet international standards and expectations. Consequently, the curricula in Ukrainian universities are frequently updated to reflect the latest trends and demands of the global IT industry. Ukraine's movement towards integration into the European Union is a significant driving force behind these educational reforms. As Ukraine seeks closer ties with Europe, there is a clear intent to adopt European educational standards and integrate more deeply into the educational system. This transition aims to harmonize Ukrainian educational standards with those of the European Union, thereby facilitating the mobility of students and professionals and ensuring that Ukrainian qualifications are recognized and respected internationally.

Analyzing and adopting foreign experiences in teaching software testing is not merely an academic exercise but a strategic imperative for Ukraine. It ensures that the country's educational system remains competitive and relevant, producing graduates who can meet the highest international standards. This strategic alignment is vital for sustaining the growth of Ukraine's IT industry and for supporting the country's ongoing integration into the European and global economy.

2. Analysis of literature

The importance of integrating foreign, particularly European, educational experiences into Ukrainian IT education, especially in the context of software testing, cannot be overstated. Various studies emphasize this need by examining both the current state of educational programs and the potential improvements that can be drawn from international best practices.

Comprehensive reviews of software testing education across multiple European countries and identification of gaps in practical and advanced testing techniques within university curricula – a scientifical practice, which is popular in an international IT community. There's a variety of articles, which focus on identifying these gaps and suggesting ways to incorporate more hands-on and experience-based learning into software testing educational programs [1, 2]. The broader context of educational standards and their implementation, which plays a critical role in shaping effective IT education, is widely explored by modern scientists, finding an answer on how different regulatory frameworks and guideline models impact the quality of software engineering curricula. These works suggest that aligning educational programs with both national and international standards can significantly enhance the relevance and effectiveness of IT education [3, 4].

In the Ukrainian context, leveraging foreign experiences is particularly crucial. Ukrainian researchers have explored the value of incorporating international best practices into local educational frameworks. Avshenyuk, Dyachenko, and Kotun focus on the importance of international practices in teacher training, providing an analytical framework for enhancing Ukraine's pedagogical education system. This work highlights the foundational role of comparative studies in improving professional preparation [5]. Specific attention has also been directed to IT education as a whole. Seiko and Yershov analyze global IT education models, examining teaching strategies from countries, such as the USA, China, and South Korea, to identify lessons applicable to Ukraine [6]. Similarly, Bolotina investigates both domestic and international approaches to forming professional competencies among IT bachelor students, highlighting common practical strategies for improving educational outcomes [7]. There is also a growing interest in specialized fields and targeted disciplines. Matviychuk-Yudina specifically examines cybersecurity education, analyzing international curricula and offering recommendations for aligning Ukrainian programs with global standards [8]. However, despite these significant efforts, the area of software testing education remains largely unexplored in the Ukrainian research landscape, presenting an opportunity for further investigation

Understanding and integrating the methodologies of leading European institutions in training software testing specialists is important, as software testing is a fundamental aspect of the software development lifecycle, essential for ensuring that products meet quality standards and function correctly. By adopting proven methodologies, Ukrainian universities can enhance the quality of their IT education, providing students with both robust theoretical knowledge and practical skills. This improvement not only prepares students for the global job market but also elevates the standards of the Ukrainian IT industry as a whole.

3. The aim and objectives of the research

The purpose of the article is to study the experience of the educational system of European countries and United Kingdom in training software testing specialists and highlight its specific features.

To achieve this goal, the following tasks were identified:

1. Explore and study the key educational standards for training IT engineers in Poland, Germany and United Kingdom. Determine the place of software testing in the content of these standards.

2. Identify bright representatives of Polish, German and British higher education institutions in the field of information technology. Analyze training programs in the specialties "Computer Science"/"Software Engineering" for the inclusion of modules or even individual disciplines, devoted to the area of software testing and quality assurance.

4. Research results and discussion

Poland, Germany, and the UK were chosen as representatives of Eastern Europe, Western Europe, and England, respectively, due to their distinct social factors and national characteristics within the European Union. This selection highlights the diversity and adaptability of higher education systems across Europe, showcasing the range of accreditation programs and institutions. While analyzing only three universities does not provide comprehensive statistics, it offers a valuable snapshot of the educational landscape and the standards, adopted in different regions.

For each country, a prominent accreditation standard and a representative university were selected to illustrate local practices. In Poland, the Polish Accreditation Committee (PKA) accredits institutions, such as Wyższa Szkoła Bankowa (WSB) w Poznaniu. In Germany, the Accreditation Agency for Study Programs in Engineering, Informatics, Natural Sciences, and Mathematics (ASIIN) accredits universities like the Technical University of Munich (TUM). In the UK, the Engineering Council UK (ECUK) accredits programs at universities including Imperial College London. These examples provide insight into how various accreditation standards shape the quality and structure of higher education across different European regions.

4. 1. Standards and curriculum of Polish institutions

The Polish Accreditation Committee (PKA), known as "Polska Komisja Akredytacyjna", is the primary instance responsible for accrediting higher education institutions in Poland. Established in 2002, PKA's mission is to ensure the quality of education by evaluating and monitoring academic programs across various disciplines. The committee operates under the supervision of the Ministry of Science and Higher Education of Poland, and its accreditation is crucial for universities aiming to maintain high educational standards and gain recognition both nationally and internationally.

PKA evaluates computer science and software engineering programs based on several key criteria: cur-

riculum quality, faculty qualifications, infrastructure, and student support services. The standards are derived from national educational requirements and industry best practices, ensuring that the programs are relevant and aligned with current technological advancements. In the context of software engineering and software testing, PKA emphasizes a curriculum that balances theoretical foundations with practical applications. Core areas include programming, algorithms, data structures, software engineering, and databases. For software testing, the standards ensure that programs incorporate comprehensive modules covering various aspects, such as software quality assurance, testing methodologies, automated testing tools, and real-world project experiences [9].

Specific points, highlighted by PKA standards for software engineering programs, include:

– Curriculum Design: programs must include a mix of theoretical and practical courses, ensuring students gain a broad understanding of computer science fundamentals and specialized knowledge in software testing.

– Industry Relevance: courses should align with current industry practices, incorporating the latest technologies and methodologies, used in software development and testing.

– Faculty Expertise: instructors must have relevant academic qualifications and industry experience, enabling them to teach both the theoretical aspects and practical applications of the discipline.

– Infrastructure and Resources: universities should provide adequate resources, such as modern laboratories, access to current software tools, and facilities that support hands-on learning and experimentation.

Software testing is acknowledged as a critical component of computer science education, particularly within IT-related programs. PKA's evaluation criteria ensure that software testing is adequately covered in the curriculum. This includes theoretical knowledge, practical skills, and alignment with current industry practices. The curriculum typically involves modules on software quality assurance, testing methodologies, automated testing tools, and project-based learning experiences. However, it worth mentioning that there's no strict requirement to defining software testing as a separate discipline or even knowledge area: quality assurance is mostly covered as a supportive module or topic of software development disciplines.

Wyższa Szkoła Bankowa w Poznaniu (WSB) is one of Poland's leading private business schools, offering a range of programs in computer science and software development. The university emphasizes practical education, industry collaboration, and the integration of modern technologies into its curriculum.

The bachelor's program in Software Development at WSB offers specializations, such as Mobile Software Developer and Virtual Reality and Multimedia. The program spans three and a half years and awards an Engineer degree, with courses conducted in English. The curriculum is designed to provide a comprehensive education in software development, covering both fundamental concepts and advanced technologies. Moreover, the university's emphasis on practical skills ensures that students not only learn theoretical concepts but also apply them in real-world scenarios [10].

To accommodate diverse student needs, the program provides flexible education modes:

– Full-Time: This traditional on-campus education offers a structured schedule, ideal for students who can commit to daytime classes.

– Part-Time: Designed for working students, this option includes evening and weekend classes, allowing them to balance work and study.

– Dual Education: Combining academic learning with practical experience, this mode involves industry partnerships, giving students hands-on experience while they study.

Practical experience is integral to the program, ensuring that students gain hands-on skills through various opportunities:

– Internships and Industry Projects: These provide real-world exposure and practical experience in the field, helping students apply their theoretical knowledge.

– Laboratories and Workshops: Students have access to state-of-the-art labs, equipped with the latest tools and technologies, enhancing their learning experience through practical application.

The "Software development" curriculum at WSB includes a variety of courses that address different aspects of software engineering and testing:

– Mobile Technology Platforms and Application Design: Students learn about mobile operating systems, application development frameworks, and user interface design, with a focus on creating robust and user-friendly mobile applications.

– Programming in Objective C (Swift): This course covers the syntax and features of Objective C and Swift, two prominent programming languages, used in iOS development.

– Augmented and Virtual Reality Programming: Students explore the development of applications for AR and VR platforms, including the use of specialized hardware and software tools.

– Multimedia Application Development: This course focuses on the creation of multimedia applications, integrating audio, video, and interactive content.

– Big Data and Cloud Computing: Students gain insights into the principles of big data analytics and cloud computing, learning how to design and implement scalable and efficient data processing systems.

WSB's curriculum aligns well with PKA standards by integrating comprehensive modules on software quality assurance and testing methodologies. This trend is clearly visible in the public accreditation report, the analysis of which highlights both the content of the disciplines and their assessment by the accreditation committee. As part of the training program discussed above, testing competencies are formed in students during the study of such disciplines as "Inf_I_U04 - application programming", "Inf_I_U03 - modeling and programming of information systems" due to the inclusion in their program of separate thematic modules, devoted to the issues of covering functionality unit tests, writing test scripts and directly conducting testing. However, it is worth noting that individual disciplines, dedicated to the

testing context or its individual areas (performance testing, automation, etc.), are not included in the course program content [10].

4. 2. Standards and curriculum of German institutions

ASIIN, the «Akkreditierungsagentur für Studiengänge der Ingenieurwissenschaften und der Informatik», is a leading accreditation agency in Germany. Established to ensure the highest educational standards, ASIIN specializes in accrediting study programs in engineering, informatics, natural sciences, and mathematics. Recognized by the German Accreditation Council and listed as a quality assurance agency in the European Quality Assurance Register for Higher Education (EQAR), ASIIN plays a crucial role in maintaining and enhancing educational quality across Europe [11, 12].

ASIIN's accreditation standards are comprehensive and rigorous, focusing on various aspects of program quality, including curriculum design, learning outcomes, faculty qualifications, and resource availability. For software engineering and software testing, ASIIN emphasizes the following key areas:

– Curriculum Design: programs must provide a balanced mix of theoretical knowledge and practical skills, ensuring students are well-versed in fundamental and advanced concepts of software engineering and testing.

– Learning Outcomes: graduates should demonstrate proficiency in software development methodologies, quality assurance practices, and the use of automated testing tools. The standards ensure that students are prepared to address real-world software engineering challenges effectively.

– Industry Relevance: courses should be aligned with current industry standards and practices, incorporating the latest technological advancements and methodologies, used in software development and testing.

– Faculty Expertise: educators must have both academic credentials and industry experience, enabling them to teach the practical applications of software testing alongside theoretical concepts.

ASIIN's standards emphasize the importance of software testing within software engineering and computer science programs. These standards ensure that accredited programs include comprehensive coverage of testing methodologies, quality assurance, and the use of automated testing tools. Key aspects include the integration of testing techniques into the curriculum, hands-on projects, and practical applications to prepare students for real-world scenarios. Courses must teach unit testing, integration testing, system testing, and acceptance testing, ensuring students develop essential skills to maintain software reliability and performance. This approach aligns educational outcomes with industry demands, producing graduates proficient in contemporary testing practices.

The Technical University of Munich (TUM) is one of Germany's most prestigious universities, renowned for its strong engineering and computer science programs. The Bachelor of Science in Computer Science at TUM is a comprehensive 3-year program that equips students with both foundational and advanced knowledge in computer science. The program offers specializations in Artificial Intelligence and Machine Learning, Software Engineering, Computer Systems and Networks, and Data Science, allowing students to tailor their education to their career goals [13].

Practical experience is integral to the program, ensuring students gain hands-on skills through:

– Internships and Industry Projects: Offering real-world exposure and practical experience.

– Laboratories and Workshops: Access to state-of-the-art labs, equipped with the latest tools and technologies.

– Capstone Projects: Final year projects that integrate learning across different areas of computer science, often in collaboration with industry partners.

Students benefit from a structured full-time schedule, with some courses offered in English to accommodate international students. The program emphasizes hands-on learning, preparing graduates for successful careers in IT. TUM's strong industry connections ensure that the curriculum remains relevant and aligned with current technological trends.

TUM's computer science curriculum includes several courses that focus on software engineering and testing:

– Software Engineering I and II: These courses cover the software development lifecycle, design patterns, project management, and testing methodologies. Students learn about various testing techniques, including unit testing, integration testing, system testing, and acceptance testing.

– Quality Management in Software Engineering: This course delves into quality assurance practices, software metrics, and quality management systems. It emphasizes the importance of maintaining high software quality through rigorous testing and validation processes.

– Advanced Topics in Software Engineering: Students explore advanced topics, such as automated testing, software verification, and validation. The course includes hands-on projects where students apply automated testing tools to real-world software development projects.

4. 3. Standards and curriculum of English institutions

The Engineering Council UK (ECUK) is the regulatory body responsible for setting and maintaining standards in the engineering profession in the United Kingdom. Established to oversee the registration and professional development of engineers, ECUK works closely with various professional engineering institutions (PEIs) to ensure that educational programs meet the rigorous standards, required for professional registration. ECUK accreditation is a mark of excellence, indicating that a program meets high-quality standards and prepares students for successful engineering careers [14].

ECUK's accreditation standards for software engineering programs encompass several critical areas:

– Curriculum Design: accredited programs must offer a well-rounded curriculum that covers fundamental and advanced topics in software engineering, including software development methodologies, system design, and project management.

– Practical Experience: ECUK emphasizes the need for practical experience through internships, pro-

jects, and industry collaborations. This hands-on approach allows students to apply theoretical knowledge to real-world scenarios, enhancing their learning and professional readiness.

– Professional Skills: accredited programs must also focus on developing students' professional skills, such as teamwork, communication, and ethical considerations, which are essential for a successful engineering career.

The Engineering Council UK (ECUK) sets rigorous standards for engineering education, ensuring comprehensive coverage of software development and quality assurance. Accredited programs must integrate software testing methodologies, such as unit testing, integration testing, system testing, and acceptance testing, into their curriculum. Quality assurance practices, including both manual and automated testing, are emphasized to ensure software meets specified standards. ECUK standards also mandate practical experience through hands-on projects and industry collaboration, allowing students to apply their knowledge in real-world scenarios using industry-standard tools. Ethical and professional conduct in software testing is a crucial component, teaching students the importance of thorough and reliable testing and the ethical implications of software failures.

Imperial College London is one of the UK's leading institutions for engineering and technology education. The university is renowned for its strong focus on research, innovation, and practical application. The Department of Computing at Imperial offers a comprehensive range of programs in computer science and software engineering, designed to equip students with both foundational knowledge and advanced skills. The Bachelor of Science in Computer Science at Imperial College London is a prestigious 3-year program, designed to provide a solid foundation in computer science while offering opportunities for specialization. The curriculum includes core courses such as Programming, Algorithms, Data Structures, Software Engineering, and Databases, ensuring a comprehensive understanding of computer science principles. The program is primarily full-time, structured with lectures, laboratory sessions, and seminars. The courses are available in English, accommodating international students [15].

Imperial College's computer science and software engineering programs include several courses that address software testing and quality assurance:

– Software Engineering: This course covers the software development lifecycle, from requirements analysis and design to implementation and testing. Students learn about different testing strategies, including manual and automated testing, as well as techniques for ensuring software quality.

– Automated Software Testing: Focused on the principles and practices of automated testing, this course teaches students how to use various testing tools and frameworks to automate the testing process. Topics include test automation strategies, scripting, and the integration of automated tests into the development workflow.

– Quality Assurance and Testing: This course emphasizes the importance of quality assurance in software development. It covers various testing methodologies, defect management, and quality metrics. Students engage in hands-on projects to apply these concepts to real-world software systems.

Imperial College's adherence to ECUK standards is reflected in its well-rounded curriculum and strong emphasis on practical skills. The university's commitment to aligning its programs with industry standards and providing practical experience through projects and internships ensures that graduates are well-prepared for professional practice. By maintaining high educational standards and emphasizing practical skills, Imperial College London ensures that its graduates are equipped to contribute effectively to the field of software engineering and testing.

4. 4. Research limitations and prospects for further studies

The primary objective of the study was to analyze educational standards and university programs in the selected European countries. Due to limited time and resources, the analysis was restricted to three European countries, which does not provide a comprehensive view of the entire region. A similar limitation applies to universities: only the most prominent institutions, ranked among the top, were considered for each country, potentially overlooking valuable insights from other universities. Moreover, access to detailed course programs and internal interpretations of educational standards remains a challenge, as such information is not always available in open sources. This limitation extends to lecture content, its volume, practical assignments, and other critical factors, making it difficult to form precise conclusions about the unique structures of these programs.

Future research in this field holds significant promise. Expanding the analysis to include other countries, regions, and universities – whether private or public, specialized or general – would provide a more holistic view. Additionally, scientific collaboration with university representatives may offer a highly promising ground for deeper examination of educational programs and the nuances of their implementation, providing even more insights and value for Ukrainian educational sphere.

5. Conclusions

According to the objectives set and the analysis of the training of software engineers in European higher education institutions conducted, the following conclusions were made:

1. While the standards for accreditation, such as those from PKA, ASIIN, and ECUK, may differ slightly, they share a common emphasis on practical experience, industry relevance, and comprehensive curriculum design. These standards ensure that educational programs are aligned with industry needs and prepare students for professional roles effectively. It is also worth mentioning that although software testing is not typically recommended as a separate discipline, many relevant topics are covered within the scope of broader courses. This approach integrates testing methodologies, quality assurance practices, and automated testing tools into the curriculum, ensuring that students gain essential skills in software quality management.

2. Universities adhere to the standards above by emphasizing practical experience through partnerships

with industry. Internships, industry projects, and capstone projects are integral components of the curriculum, providing students with real-world exposure. Additionally, many programs are offered in English, which is beneficial for students' future careers in the global IT industry. The curriculum also places a strong emphasis on soft skills and practical application, and professional knowledge, ensuring that graduates are well-rounded and ready for the demands of the workforce.

In conclusion, the educational standards and programs across Poland, Germany, and the UK demonstrate a consistent focus on equipping students with both theoretical knowledge and practical experience. By integrating industry relevance and comprehensive training in their curricula, these programs ensure that graduates are proficient in modern software engineering practices, including software testing and quality assurance.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results, presented in this article.

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Use of artificial intelligence

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