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EXPLORING THE DEVELOPMENT PATH OF A SYSTEMS ENGINEER'S MINDSET: FROM ABSTRACT IDEAS TO SPECIFIC TASKS

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ABSTRACT
This article delves into the development path of a systems engineer's thinking, focusing on the transition from abstract ideas to concrete tasks and actions through the structured application of Systems Engineering (SE). It underscores that cultivating a systems engineering mindset is a long and demanding process, requiring substantial investments of time, resources, and commitment from both individuals and institutions. The journey to becoming a proficient systems engineer extends far beyond completing a few courses; it necessitates comprehensive education and sustained practice to develop the advanced thinking and technical skills essential for success in the engineering field. The article emphasises the importance of systems thinking and the integration of Model-Based Systems Engineering (MBSE) into contemporary project lifecycles. It identifies the critical educational challenges of SE, particularly in bridging the gap between theoretical knowledge and practical application in schools and universities. A detailed analysis of the systems engineer's learning path highlights the vital interplay between theoretical understanding, hands-on experience, and collaborative problem-solving. Practical examples, including university programmes, illustrate the significant resources and interdisciplinary strategies required to shape capable professionals. Student feedback further reinforces the need for adaptive, practice-focused learning methods to address real-world challenges effectively. Building systems engineering expertise requires long-term investment and collaborative efforts among governments, private companies, educational institutions, and individuals. Such collective action is necessary to address the growing complexity of global industry requirements and to equip young professionals with the robust mindset needed to succeed. By facilitating such collaboration, new opportunities may emerge to address pressing challenges in systems engineering education and practice.

Keywords: Engineering education, systems engineer mindset, system vision

1 INTRODUCTION
The motivation for studying the development of systems engineering thinking is related to the need to train specialists capable of solving complex engineering problems. This path involves the transition from theoretical ideas to practical solutions, which requires not only technical knowledge but also special systems thinking. Engineers must see systems holistically, understand their interrelations and dynamics, which allows them to effectively solve problems that are inaccessible with a traditional approach [1]. Model-Based Systems Engineering (MBSE) plays a key role in developing such thinking [16]. Using models instead of traditional documents helps analyse, visualise, and test systems at different levels of abstraction [17]. This helps align theory with practice, improves development, increases design quality, and facilitates interdisciplinary interaction [2]. MBSE training requires a combination of theoretical knowledge and practical skills. University programmes use simulations, project-based learning, and teamwork to develop students' ability to critically analyse systems, assess their limitations, and find optimal solutions. It is important to develop not only technical skills, but also the ability to work in a team, adapt to changing conditions, and consider the broad context of engineering solutions [3]. MBSE is widely used in the development of complex projects in aerospace, medical and other industries. This approach helps improve communication, minimise risks and ensure that all system components meet specified requirements. Its implementation in educational processes helps eliminate the gap between theory and practice, ensuring the training of engineers who are able to adapt to the growing complexity of modern technologies [2].

2 THE PATH OF DEVELOPMENT OF THE ENGINEER'S THINKING

The development of a systems engineer's thinking begins in school, where pupils first encounter tasks requiring logical analysis, structured problem-solving, and teamwork (figure 1). STEM courses, research projects, and competitions help build analytical skills, the ability to identify cause-and-effect relationships, and effective collaboration. These early experiences lay the foundation for systems thinking. At the university level, this thinking becomes more structured and technical. Students study MBSE, modelling languages like SysML, and tools for analysing complex systems. Coursework in mathematical modelling, systems lifecycle management, and systems analysis helps formalise problem-solving approaches. Interdisciplinary projects and industry-linked activities, such as hackathons and internships, provide practical exposure, fostering adaptability and decision-making in complex scenarios [4]. In professional settings, systems thinking reaches full maturity. Engineers must balance cost, reliability, security, scalability, and customer requirements. MBSE becomes essential for modelling, testing, and optimising solutions, allowing early issue detection. Beyond technical expertise, modern industry demands soft skills—teamwork, negotiation, and adaptability. Engineers with strong systems thinking not only solve problems but anticipate challenges, devise mitigation strategies, and drive innovation [5]. Thus, systems thinking evolves from foundational skills in school to structured expertise in university and practical mastery in industry. Continuous learning, hands-on experience, and adaptability are essential, making systems engineers key players in modern engineering.

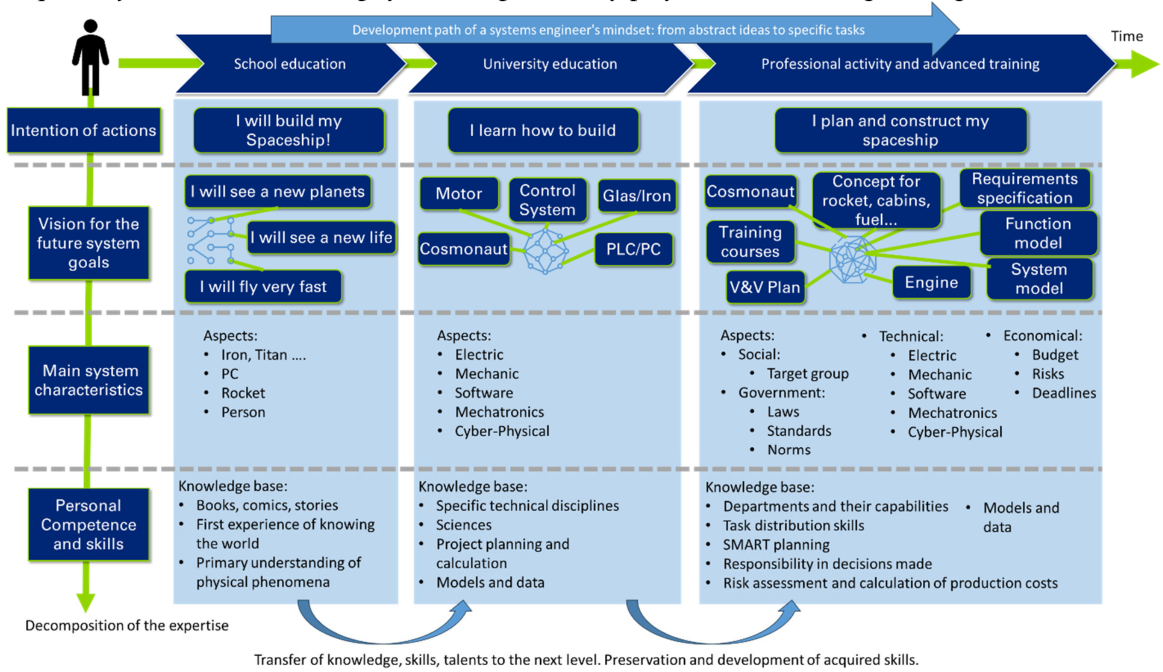

Figure 1. Development of a comprehensive view of the problem from an engineer's point of view

2.1 Challenges in studying MBSE/SE

SE and MBSE education face challenges at all levels, hindering the development of essential systems thinking skills [7, 8]. Figure 1 shows the development path of an engineer from school to professional activity. In schools, early exposure to systems thinking is unconnected. STEM education remains fragmented, focusing on basic projects without a holistic methodology. A shortage of qualified educators further limits students' understanding of complex systems before university [8]. At the university level, a gap exists between theoretical knowledge and industry needs. Many curricula lack sufficient hands-on training, leaving graduates unprepared for real-world projects. Limited interdisciplinary programmes prevent students from gaining practical experience in cross-functional teams [9]. In industry, these gaps become evident. Even graduates from top universities often lack MBSE expertise, struggle with evolving requirements, and face challenges in cross-department collaboration. Companies must invest heavily in additional training, slowing workforce integration. Furthermore, universities often teach outdated or overly theoretical MBSE concepts, misaligned with industry standards [10]. To bridge these gaps, educational programmes must integrate practical training, foster university-industry collaboration, and emphasise interdisciplinary learning. Only through such reforms can MBSE/SE education effectively prepare engineers for modern engineering challenges.

2.2 Collaboration in the study of MBSE/SE

Universities, students, and industry have unique approaches to learning model-based systems engineering (MBSE) and systems engineering (SE), and their learning paths often intersect through collaboration, displayed on figure 2 based on research [11, 12, 18]:

Academic Pathway: Universities focus on providing structured education through degree programmes, specialised courses, and research initiatives. MBSE/SE is taught through lectures, case studies, and laboratory hands-on activities using industry-standard modelling tools such as SysML, MagicDraw, and Cameo Systems Modeler. Universities also conduct research projects, often in partnership with industry, to explore new methodologies and advances in systems engineering. In addition, faculty integrate real-world applications into the curriculum by engaging students in collaborative projects and competitions.

Student Pathway: Students are engaged in MBSE/SE through formal education, hands-on assignments, and participation in workshops, hackathons, and industry challenges. Many students also complete online certificates, internships, and independent projects to gain additional insight into MBSE tools and real-world applications. Student-led engineering teams working on projects such as robotics, aerospace systems, and smart technologies further strengthen learning by applying systems engineering principles in a practical setting.

Industrial Pathway: Industry advances MBSE/SE through professional training, continuous skill development, and collaboration with universities. Companies offer on-the-job training, certifications, and ongoing education to keep engineers updated on the latest modelling techniques and system methodologies. Many industries engage in research initiatives, share case studies, and contribute to MBSE tool development. Engineering firms also leverage conferences, workshops, and professional organisations like INCOSE to enhance MBSE/SE expertise.

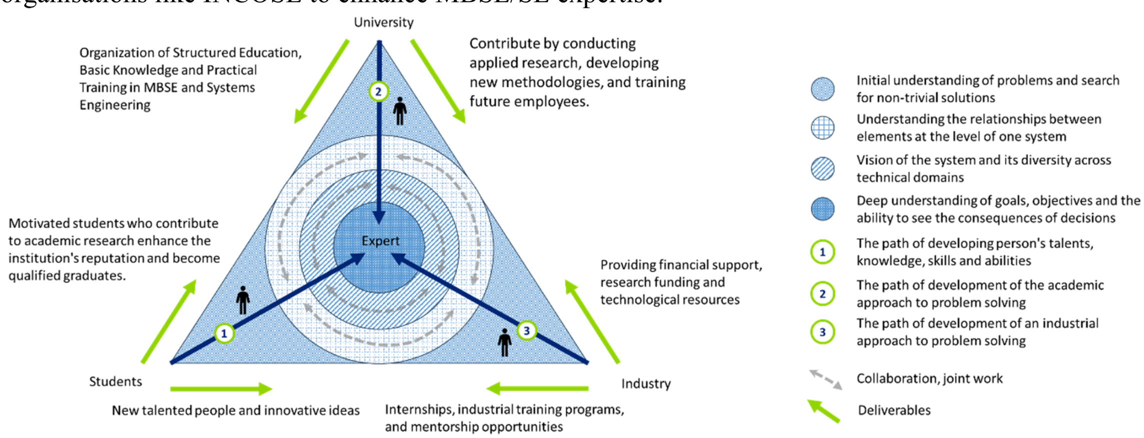

Figure 2. Paths to becoming an expert in your field

The relationship between universities, students and industry in MBSE and systems engineering education is, therefore, an interdependent system, with each party having specific expectations and contributions [13]. Industry relies on universities to produce highly skilled professionals who are ready to enter the workforce with theoretical knowledge and practical skills. Companies are looking for graduates who can apply MBSE methodologies, work collaboratively and adapt to complex engineering challenges [14]. To meet this demand, universities must ensure that their programmes meet industry needs by integrating real-world applications, advanced modelling tools and problem-solving experience into the curriculum [15]. Universities, in turn, expect industries to support education by sponsoring research, providing access to advanced engineering tools and offering real-world practical research. Many universities partner with companies to develop industry assignments, fund student projects and offer internship opportunities, ensuring that students receive practical training that bridges the gap between academic learning and professional practice. Students, as the primary beneficiaries of this relationship, are keen to acquire relevant skills that will make them competitive in the job market. They expect universities to provide them with practical, high-quality education that will prepare them for industry roles, and they also look to industry for exposure to real-world engineering projects, internships, and career opportunities. Interacting with companies during their studies allows students to apply their knowledge in real-world scenarios, making them more confident and competent upon graduation. This three-way collaboration ensures that students gain the knowledge that industry requires, universities remain relevant through industry support, and companies gain well-trained engineers who can contribute effectively from day one.

3 PROJECT-BASED LEARNING TO QUALIFY STUDENTS' CAPABILITIES

Teaching the fundamentals of MBSE/SE requires an educational framework that mirrors real-world engineering scenarios and emphasises practical applications. This approach engages students in problem-solving, fosters teamwork, and enhances their understanding of complex systems by analysing their individual components. At the Chair of Industrial Information Technology (IIT) at TU Berlin, a structured learning pathway integrates collaboration between universities, industry, and students into a semester-long course. Students start working with a given task and, from an abstract idea, approach a concrete solution and successful completion of the project in small steps. Such tasks are developed in close cooperation between university representatives and industry representatives, such as BMW, Volkswagen or Mercedes-Benz. In this case, industry experts bring real-life problems of the day, describing their limitations and the desired outcome. In turn, students develop their independent creative solutions within a strict, defined framework of the project. The scope of the project tasks corresponds to the semester time, and the implementation of the tasks implies the joint work of several team members. Students begin by analysing the problem and specifying the tasks. Concepts are then built and compared, and then actual modelling and simulations are carried out. Additionally, they test intermediate models and refine them using CAx-tools, considering design and production aspects. At the end of the project, all models are assembled, and final tests are carried out, both virtually and in conjunction with physical prototypes (Figure 3).

In addition to the project work, teachers introduce students to the theoretical foundations of MBSE through lectures and seminars, introducing them to key concepts such as systems thinking, requirements analysis, systems modelling and architecture development. Lectures on MBSE are also supplemented by specialised lectures on the topics studied, such as factory planning, logistics route development and others. During the exercises, students learn to use industry-standard modelling tools such as SysML/Capella/Simulink etc. to create visual representations of the system. These models help them conceptualise the interactions of the various components, ensuring clarity and consistency in the team's work. At the start of the project, students are divided into multidisciplinary teams, combining a variety of personal knowledge and skills needed in real-world industrial projects. Each team is assigned both general and individual project tasks that reflect a real-world problem, such as designing an engine assembly station or a robotic machine parts welding station. Throughout the project, teams hold regular design reviews to assess system behaviour, evaluate design concepts, and refine their solutions based on feedback from IIT chair and industry experts. This collaborative environment fosters active discussion and problem-solving, enabling team members to learn from diverse perspectives and improve their designs. Communication and leadership skills are developed as student teams present their models, concepts, solutions, and progress to faculty and external stakeholders during design reviews. This not only improves students' ability to formulate technical concepts but also prepares them for real-world collaboration across departments or organisations. Faculty and industry experts act as mentors, providing guidance when students encounter challenges while encouraging independent critical thinking.

The entire semester can be roughly divided into three phases, where each phase will last approximately 4 to 6 weeks [11]. Each phase ends with a Review; all the main stages and the student's path are presented in Figure 3. Design reviews are an overview of the current status of the work, as well as discussions with industry experts. Experts help to adjust the developed concepts and models within the framework of the set tasks and current needs. Also, approximately before the first review, industry experts invite student teams directly to their production facilities to personally show the product lines, working aspects and difficulties they face. Based on this, student teams develop a more comprehensive understanding of the project tasks and associated constraints. After two reviews, students prepare for the final presentation and demonstration of their research. The final presentation is a presentation of the final solution and assessment from both the academy and the industry. After this, students close the study of the module by writing a final working report on the project and writing an exam on the theoretical part of the module studied. Certainly, such partnerships between university chairs and industry, where companies provide project briefs and mentoring, have a positive impact on the learning process itself and the development of individual skills of students. It introduces students to current market challenges and industry expectations. By the time the project is completed, students will have practical experience with MBSE principles and tools, the theoretical foundations of the subject, developed problem-solving and collaboration skills, and will have a solid foundation for applying these concepts in a professional environment.

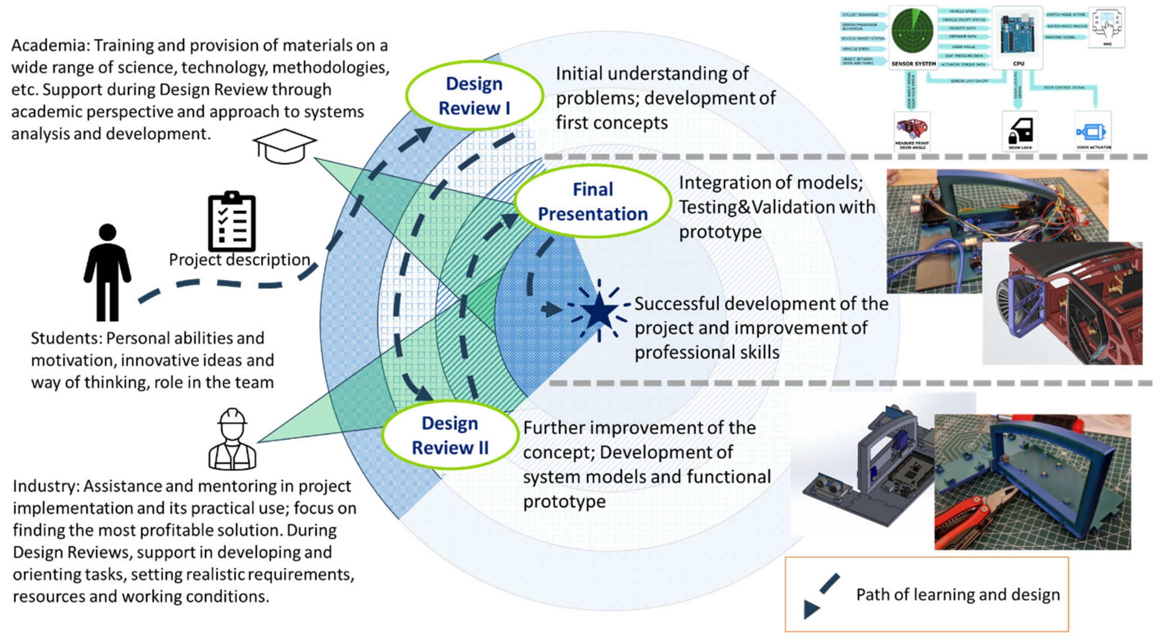

Figure 3. Collaboration in studying between academia, industry and students

4 CONCLUSION AND OUTLOOK IN A FUTURE

Modern MBSE/SE programmes are evolving to bridge the gap between theory and practice. Universities incorporate project-based learning, digital twins, and model-based simulation, while online platforms and professional certifications offer flexible learning pathways. Industry-led initiatives such as collaborative research projects, hackathons, and specialised MBSE training complement traditional education by providing direct exposure to real-world engineering challenges. However, gaps remain in integrating advanced technologies, fostering interdisciplinary collaboration, and incorporating real-time systems modelling into academic training. To improve MBSE/SE education, curricula must evolve with AI-based modelling, cloud MBSE tools, and agile methodologies. Stronger industry involvement ensures students gain practical skills before entering the workforce. Universities should also expand interdisciplinary training, balancing workload and quality education to address broader engineering, business, and sustainability challenges. Ultimately, success in MBSE/SE belongs to those who can rapidly adapt to technological advancements and evolving product requirements. Engineers, universities, and industries that embrace continuous learning, agile thinking, and modern tools will lead in solving complex systems challenges. The ability to integrate emerging technologies into engineering practices and navigate an ever-changing global landscape will define the future leaders in this dynamic field. Finally, an engineer with an inquisitive mind is constantly evolving, studying new technologies, analysing market trends, and adapting to shifting requirements. A commitment to continuous learning becomes a competitive advantage, enabling professionals to master new tools quickly and develop effective solutions. Flexibility, critical thinking, and the ability to collaborate across disciplines make such professionals invaluable. Beyond executing tasks, they anticipate future challenges and propose innovative approaches. Developing an inquisitive mindset is not just about accumulating knowledge but applying it effectively, recognising connections, devising unconventional solutions, and swiftly adapting to change. Those who cultivate these qualities do not merely follow technological trends, they shape them, driving the future of engineering and science.

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