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PRINCIPLES AND MODEL OF THE DIFFERENTIATED APPROACH IN ENGINEERING EDUCATION (USING THE EXAMPLE OF THE COURSE "ARTIFICIAL STRUCTURES ON HIGHWAYS")

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Abstract

This article examines both the theoretical foundations and practical implementation of a differentiated approach to training engineers – an approach that accommodates individual student characteristics (e.g., knowledge level, learning style, professional interests) while ensuring that all students acquire essential competencies. Drawing on various pedagogical theories and concepts (the theory of multiple intelligences, constructivism, social learning theory, personalized learning, and universal design for learning), the authors identify seven principles that demonstrate how to organize the educational process effectively in technical universities. Illustrative examples of differentiated assignments and project-based activities are presented, using the course "Artificial Structures on Highways" as a case study. The article also proposes a step-by-step model for developing professional skills. In the concluding section, the authors discuss limitations related to the need for additional resources, adaptation to specific university contexts, and cultural factors. The findings may be applied in designing curricula, developing assessment strategies, and enhancing the professional development of engineering faculty.

Keywords: *differentiation of instruction, engineering training, individualization, professional competencies, pedagogical theories*

Introduction

Under current conditions for the development of engineering education, the foremost challenge is to balance mandatory training standards with the need to accommodate the individual characteristics of students (Trilling & Fadel, 2004; Froyd et al., 2012; Aleksankov, 2017; Ivanov et al., 2013), a concern reflected in several decrees and regulations adopted in Uzbekistan (Presidential Decree of the Republic of Uzbekistan, 2021; Presidential Decree of the Republic of Uzbekistan, 2024). Numerous studies, including the works of Snigirev, Sukhovetskaya, and Khomyakov, as well as Boelt, Kolmos, Holgaard, Cabedo, Royo, Moliner, and Guraya (Snigirev et al., 2014; Boelt et al., 2022; Cabedo et al., 2018), emphasize that without considering factors such as learning style, initial knowledge level, motivation, and professional interests, it is difficult to ensure the full mastery of competencies required for future engineering activities.

The complexity of engineering tasks, the interdisciplinary nature of projects, and the constantly evolving demands of the labor market all require universities to create a flexible educational environment. In response, the scholarly and pedagogical community has been expanding on the idea of a differentiated approach that adapts the content and methods of instruction to the diverse characteristics of students. Building on contemporary pedagogical theories and concepts, this study systematizes various approaches to differentiation in engineering education and formulates seven principles aimed at aligning instructional processes with desired educational outcomes while accommodating individual learning trajectories.

The research proceeded in three stages:

1. **Literature Review:** This stage involved surveying and analyzing academic sources. Works by both Uzbek and international researchers on individualization and differentiation in higher education were examined, with an emphasis on literature addressing engineering training. Particular attention was paid to theories that focus on individual differences.

2. **Comparative Analysis of Concepts and Development of Principles:** Various definitions of "differentiation" and "differentiated approach" in engineering education were compared, and ideas from inclusive, personalized, and project-based learning were reviewed. Common and distinctive features were extracted and distilled into seven principles of the differentiated approach, along with a four-stage model for competency development.

3. **Application to "Artificial Structures on Highways":** Consultations were held with technical university instructors experienced in implementing differentiated methods (e.g., project-based assignments, hackathons, flexible assessment). The engineering course "Artificial Structures on Highways" was selected as an illustrative example, given the variety of constructions and solutions – bridges, overpasses, tunnels, etc. – that clearly demonstrate the possibilities of differentiation.

Results

The ideas behind the differentiated approach are rooted in multiple academic traditions. Gardner's theory of multiple intelligences underscores that students possess dominant types of intelligence (linguistic, logical-mathematical, spatial, etc.) which should be considered in selecting tasks and learning materials (Faiziyeva, 2020). Constructivist perspectives advanced by Piaget, Vygotsky, and Bruner emphasize that learners actively construct knowledge, with instructors serving as facilitators (Ulanovsky, 2009). Bandura's social learning theory highlights the importance of interaction and observation, particularly relevant in project-based learning formats (Bandura, 2000). Personalized learning (associated with researchers such as B. Bloom and S. Khan) calls for tailoring instruction to each student's individual goals (Artikova, 2019), while universal design for learning advocates for creating an accessible and effective educational environment for all, including students with special needs (Shutova, 2018).

Table 1. *Principles of the differentiated approach and their implementation in engineering education (illustrated by the course "Artificial Structures on Highways")*

Principle	Description	Example of Implementation
1. Multi-format and flexible	Employ various instructional formats (lectures, practicums, online modules, lab work, and project-based	In bridge-construction lectures, one group of students (already familiar with basic beam-structure calculations) receives advanced materials on dynamic load calculations for

Principle	Description	Example of Implementation
learning process	activities) that account for differences in knowledge level and interests.	bridge spans; another group receives in-depth guides with visual diagrams and video reviews for analyzing simplified calculation models.
2. Guaranteed attainment of professional skills	Ensure that each learner reaches at least the minimum required level of proficiency. Organize intermediate assessments to promptly identify skill gaps and provide additional resources to remedy them.	A "checklist" of key competencies is developed (e.g., basic skills for calculating loads on overpass supports, knowledge of common bridge-span designs, and the relevant calculation algorithms). After a midterm test, students with low scores are invited for extra consultations and receive additional exercises.
3. Differentiation by abilities and learning style	Consider students' preferred modes of perception (visual, auditory, kinesthetic, etc.), their cognitive styles (analytical or creative), and their level of independence.	At the beginning of "Artificial Structures on Highways," students complete a VARK questionnaire. Visual learners receive diagrams showing crack development in bridge structures, auditory learners are provided with audio lectures on overpass construction technologies, and kinesthetic learners use physical models of supports in lab sessions.
4. Active and proactive learning	Encourage students to engage in project-based and research tasks, shape individual learning trajectories, and take initiative in selecting topics and assignments.	A mini-conference on tunnel construction is organized. Students choose their own project (e.g., a tunnel in a mountainous region), form groups, and delegate roles: some handle geological surveys, others do arch calculations or schedule the construction phases. The instructor offers guidance and monitors progress.
5. Networked and collaborative learning	Form teams to tackle common problems, sometimes involving participants from other universities and related disciplines.	A joint project is established with the Materials Science Department: technology students develop a concrete mix for bridge structures, while civil engineering students in the "Artificial Structures" course calculate strength parameters and analyze the material's behavior under temperature fluctuations.
6. Progression and continuous personal growth	Each subsequent step or topic is more complex than the previous one, remaining within the learner's "zone of proximal development."	After mastering basic bridge-structure calculations, high-achieving students move on to designing reinforced concrete spans in seismically active areas. Those who need more practice continue working on standard calculations without seismic factors to solidify foundational knowledge.

Principle	Description	Example of Implementation
7. Optimization of learning effort	Allocate time and resources so that the most prepared students can engage in advanced learning while others receive extra practice to address any difficulties.	At the end of a test on "Methods for Calculating Bridge Spans," some students are assigned nonstandard, multi-span bridge designs, while others are asked to refine simpler models or perform additional load analyses for deeper understanding of standard calculations.

By synthesizing these core ideas and relating them to the specifics of engineering disciplines, we developed seven principles of a differentiated approach in engineering education, shown in Table 1. These principles articulate key guidelines for adapting the educational process to individual student characteristics while ensuring the formation of required professional competencies in engineering.

Collectively, these principles provide a way to blend solid foundational training – ensuring all students attain a baseline level of expertise – with individualized learning trajectories that reflect each student's preferences and potential. To facilitate this, we organized the application of differentiation into a four-stage model:

1. **Diagnostics.** At this stage, baseline knowledge (e.g., in mechanics, materials science, and strength of materials) and preferred learning styles are identified.

2. **Fundamental Mastery.** All students are introduced to basic structural concepts and calculations (for instance, beam bridges, standard span configurations).

3. **Deepening.** Some students choose more complex tasks (e.g., span calculations for nonstandard conditions such as tunnels in seismic zones), while others focus on reinforcing fundamental skills.

4. **Final Integration.** The capstone projects (a bridge, overpass, tunnel, etc.) are completed through collaborative efforts. Students with different skill levels assume tasks that match their competencies and interests.

This model offers a logical progression of increasingly complex tasks while providing opportunities to revisit foundational concepts and receive extra support as needed. For effective differentiation, a comprehensive approach to assessing students' initial data is recommended. This includes diagnostic tools such as the VARK questionnaire to identify primary learning channels, subject-specific tests, brief case studies to gauge cognitive styles (analytical or creative), and instructor observation during laboratory or practical sessions. The resulting data enable instructors to adjust the complexity and content of course materials, while students can choose learning trajectories that best align with their current needs and capabilities.

Discussion

The presented principles and the proposed model for competency development align with the classical theoretical underpinnings of differentiated instruction. In engineering education, these aspects are especially pertinent because engineering tasks are often multifaceted, requiring diverse forms of student engagement to accommodate varying levels of readiness and learning preferences. Examples from "Artificial Structures on Highways" clearly illustrate how to implement differentiation: from assigning specialized roles in a tunnel-construction project to customizing calculation tasks for bridge design.

For such strategies to be effective at the institutional level, systematic methodological support is needed, along with consistent assessment criteria and a flexible curriculum that facilitates multiple skill levels and adaptable learning trajectories. Questions remain regarding how best to quantitatively evaluate the effectiveness of the proposed differentiated approach and the four-stage model in actual engineering training. Further structured studies are required, including empirical experiments and statistical analyses, to examine how differentiation affects academic performance, engineering thinking, and graduate employability.

When piloting these ideas, one must also account for resource demands related to creating differentiated assignments and providing additional consultations, as well as for the professional development needed to prepare instructors for new teaching conditions. Consequently, the proposed principles of differentiated instruction may be implemented with varying degrees of success across different cultural and institutional contexts.

Conclusion

Overall, an analysis of pedagogical concepts and the practices of technical universities demonstrates the potential of a differentiated approach to enhance the effectiveness of engineering education. The principles presented here, derived from current learning theories, offer guidelines for flexibly designing instructional processes – ranging from multi-format lessons and attention to individual learning styles, to the step-by-step intensification of tasks and the creation of collaborative teams. Concrete examples tied to the course "Artificial Structures on Highways" underscore the applicability of these ideas in real teaching contexts. Future research and pilot programs are needed to collect statistical data on the outcomes of implementing a differentiated approach, to factor in the cultural and organizational nuances of universities, and ultimately to develop unified methodological recommendations.

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