Optimizing Teacher Training: Challenges and Innovations in Germany's Vocational Education for Electrical Engineering

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***Abstract*—Debates surrounding teacher education frequently concentrate on the preparation of educators for the domain of general education. It is evident that the demand for teachers in this area is higher, and there are certain similarities in terms of the challenges involved. However, it must also be emphasized that the strong focus on the professional activities of trainees at vocational schools and the linking of degree programs for future teachers with engineering degree programs pose a particular challenge. This challenge is compounded because a "typical" student in this field differs from "ordinary" students. This paper outlines a typical student profile and analyzes the design of teacher training programs at three universities. The subsequent section of the text undertakes a detailed examination of the potential developments of these programs, encompassing both structural developments and individual courses as illustrative cases. Consequently, recommendations for the design of the programs are formulated, thereby answering the central research question of this paper.**

***Keywords*—curriculum development, curricular analysis, dropout rates, subject didactics integration**

I. Introduction

Teacher education is a major societal responsibility with long-term impact. This applies to both general and vocational education. In the field of vocational education and training, significant challenges have emerged in the recruitment of young individuals into certain occupational sectors. The estimated difference between the supply of university graduates and the demand for teachers in German vocational schools is approximately 13,300 for the year 2035 [1]. This situation can be explained by two factors: the relatively low number of first-year students and the high dropout rate.

The first component of the problem, which pertains to the low number of first-year students, is evident in the statistics. Over the past decade, Leibniz University Hannover has consistently maintained a low enrollment in the electrical engineering program, with a typical number of first-year students remaining in the single digits. On average, eight students have started the bachelor's program, although this number is not stable. For instance, only two students started the bachelor's program during the previous winter semester. A similar pattern is observed at other universities in Germany. While this is not the primary focus of the present paper, it is essential to briefly address two factors. The economic situation and the demand for engineers are significant factors that influence young people's decisions. The bachelor's degree programs in pure electrical engineering and teaching-related electrical engineering exhibit numerous similarities, thereby permitting students to pursue their enthusiasm for electrical engineering in both programs. Concurrently, a significant proportion of students place a higher value on the career prospects and potential future earnings associated with engineering employment. Furthermore, the duration of the training period is not conducive to the implementation of teacher training, as after graduating from university (a minimum of five years), an additional preparatory service period of 18 months must be completed. A secondary facet of the teacher training program pertains to the aforementioned subject. In Germany, students must study a second subject—for example, mathematics, physics, politics, or German—and pedagogy in addition to their professional field of electrical engineering. This necessitates that students cultivate familiarity with various academic disciplines and develop competencies to effectively navigate diverse teaching methodologies. A significant challenge in this regard pertains to the delicate equilibrium between the working and thinking styles characteristic of engineering and the humanities.

The high dropout rates, which are the focal point of this discourse, constitute a salient challenge. At present, approximately 36% of engineering students abandon their engineering programs during their undergraduate studies. In master's programs, approximately 11% of students withdraw prematurely. If all bachelor's degree graduates enroll in a master's program, this results in a dropout rate of approximately 43%. This assumption is consistently valid in the domain of teacher training, as a bachelor's degree does not automatically qualify graduates to serve as certified teachers at vocational schools. Moreover, the rate of attrition in teacher training programs is often observed to exceed that of engineering programs. Consequently, it is imperative to enhance the program's

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design and provide assistance to students in this domain. This leads to the following research question: "How should teacher training in the vocational field of "electrical engineering" be designed to promote future-oriented education under the given conditions?"

To answer this question, an analysis of the existing framework conditions will be carried out. In addition to statistical data, the curricular specifications at three German universities where the author of this article has taught (Technical University of Berlin (TU), University of Kassel (UK)) or currently teaches (Leibniz University Hannover (LUH)) will be examined as examples. Furthermore, the author will delineate the experiences from the past decade that have been accumulated during the design of curricula at Leibniz University Hannover. The response to the aforementioned research question will consequently encompass recommendations for the curriculum's design, which are intended to serve as a starting point for discourse within both national and international contexts.

II. Starting Point

This chapter presents an overview of the statistical background and a characterization of a "typical" candidate for teacher training. It then proceeds to a presentation of the curricula of LUH, TUB, and UK. The objective of this exercise is to promote the development of ideas and recommendations. The proportion of students in teacher training programs decreased from 11% to 9% between 1993 and 2023, while the total number of students in Germany increased by 54% during this period. Consequently, there was a 25% increase in the number of students enrolled in teacher training programs [2]. This development is not evident in the professional field of electrical engineering. At LUH, the average number of students registered for the winter semester between 2014/15 and 2024/25 was approximately eight, with a maximum of four individuals beginning a bachelor's degree program in the previous two winter semesters. The number of students within the entire bachelor's program has fluctuated between 21 and 35 over the past decade, with the most recent peak observed in the winter semester of 2022/23. The maximum number of students enrolled in the master's program and in the SprintING Master's program over the past decade and eight years, respectively, was ten in each case [3]. The SprintING master's program is designed for students who have already obtained a bachelor's degree in electrical engineering and aspire to transition from engineering to a teaching career. Given the existence of analogous trends at disparate university locations, it is imperative to prioritize (very) small cohorts in the curriculum and course design to ensure the diversity of course offerings.

A particular challenge in choosing the program and during study is the different orientations of the engineering-oriented professional field, the pedagogical orientation of vocational education and subject didactics, and, depending on the subject, the scientific, linguistic, or social science orientation of the subject. On the one hand, a select few possess the broad spectrum of interests necessary to pursue such a course of study. On the other hand, these individuals also demonstrate the requisite skills to successfully complete such a study program. The necessity of practical experience in this field is a primary factor in the decision of most students to complete vocational training. Moreover, the students are male, originate from non-academic families, and possess a technical college entrance qualification [4]. In addition to the technical college entrance qualification, which 56% of successful students at the University of Kassel possess, the students have a master craftsman's certificate (5%) or a technician's degree (11%) [5]. In light of the aforementioned educational background and the interim between the most recent school attendance and the commencement of studies, students may encounter gaps in their knowledge, which can pose challenges, particularly in the context of the highly mathematics-intensive domain of electrical engineering. Consequently, there is a necessity for support in this area.

Müller and Kooij [4] articulate a secondary challenge, stating, "It is predominantly men who have already established themselves professionally and are pursuing a teaching degree as the subsequent phase in their career". In accordance with the aforementioned points and in consideration of the experience of LUH, the author of this article posits that the students in question frequently have familial obligations, including but not limited to a household with a partner or spouse, and in some cases, offspring. Furthermore, these individuals frequently engage in educational climbing, perceiving academic pursuits to enhance their professional prospects. Consequently, the teaching profession is regarded as a "way out" rather than a "way in". The initial facet entails challenges in terms of balancing family obligations with academic responsibilities. The subsequent facet has the potential to result in motivational difficulties. These issues may be compounded by the perception of the program, which Müller and Kooij [4] describe as "the image of a vocational training program" rather than an academic degree program. Consequently, the establishment of a connection to a prospective teaching position at a vocational school is of paramount importance within the scope of this degree program.

III. General Framework Conditions at Universities

Teacher training courses in Germany invariably encompass three fundamental domains. On the one hand, students pursue two distinct academic disciplines: a vocational subject and a teaching subject. On the other hand, they delve into educational content. In addition to subject-specific courses, the two disciplines also include courses on the didactics of the respective disciplines. In the following section, a comparative analysis of the curricula of the three universities is conducted, followed by an examination of their distinctive characteristics.

A. Curricula

The structure of the degree programs at the three

universities under consideration is summarized in Table I. The allocation of credit points across various domains at each institution is depicted, with the sum of credit points from both the bachelor's and master's programs expressed as a percentage of the total Credit Points (CP).

As demonstrated in Table I, there is a high degree of similarity in the overall patterns observed across the three universities. It is notable that TUB allocates a marginally higher proportion of resources to the second subject in comparison to other universities. Conversely, LUH and UK allocate a greater proportion of credit points to the professionalization area. Table II presents the distribution of credit points designated for subject-specific knowledge, including subject-specific didactics.

TABLE I. STRUCTURE OF THE DEGREE PROGRAM AT INDIVIDUAL UNIVERSITIES (INFORMATION IN CP)

Classification of Courses	LUH [6, 7]	TUB [8, 9]	UK [10, 11]
Subject-specific courses, including subject didactics	92+42 = 134 (45%)	87+37 = 124 (41%)	99+39 = 138 (46%)
Courses in the subject or secondary subject, including subject didactics	48+28 = 76 (25%)	67+42 = 109 (36%)	34+46 = 80 (27%)
Professional development (Pedagogy)	25+30 = 55 (18%)	16+26 = 42 (14%)	36+16 = 52 (17%)
Theses	15+20 = 35 (12%)	10+15 = 25 (8%)	11+19 = 30 (10%)

TABLE II. DISTRIBUTION OF CREDIT POINTS IN THE FIELD OF SUBJECT-SPECIFIC COURSES, INCLUDING SUBJECT DIDACTICS (INFORMATION IN CP)

Classification of Courses	LUH [6, 7]	TUB [8, 9]	UK [10, 11]
Subject-specific courses (compulsory component)	61+17 = 78 (58%)	62+0 = 62 (50%)	78+0 = 78 (57%)
Subject-specific courses (compulsory elective component)	15+15 = 30 (22%)	18+12 = 30 (24%)	12+18 = 30 (22%)
Subject didactics courses	16+10 = 26 (19%)	7+17 = 24 (19%)	9+21 = 30 (22%)
Subject didactics in combination with subject-specific courses	-	0+8 = 8 (6%)	-

With regard to the distribution of credit points within the subject-specific courses, all three universities have a similar structure. However, it is noteworthy that LUH is the only institution with compulsory modules in its master's program. At the other two universities, compulsory modules constitute only a part of the respective bachelor's programs. At TUB, a distinctive characteristic of the subject-specific didactics and research project (FFP) is the integration of collaboration between subject-specific didactics and subject-specific research into the curriculum. In this project, students are supervised by faculty members from both disciplines. While the integration of subject-specific and subject-specific domains is not an uncommon occurrence in teacher training programs, the implicit specification in this case is distinctive.

The integration of school practice into the degree program varies at the three universities. In the UK, practical school studies are carried out as part of two internships, which are supervised by academic staff. Students execute specific teaching sequences, which are subsequently monitored by both teachers and academic personnel. A congruent strategy is employed at TUB, wherein a practical semester is incorporated into the master's program. Students are required to attend vocational schools for a period of one semester, during which they are closely monitored by teaching staff. In addition, TUB lecturers undertake site visits to individual lessons and provide students with supplementary feedback. Due to the extended time commitment associated with their education, students become more deeply integrated into the school community. In the author's opinion, this increased engagement facilitates a more comprehensive learning experience that extends beyond the confines of the classroom, including participation in activities such as team meetings and class conferences. The practical school studies at LUH are implemented in the form of subject-specific didactic projects. These projects are planned at the university and carried out at vocational schools. The primary focus of these projects is on the process of lesson planning, which is evaluated based on its practicality and applicability in actual classroom settings. The author of this paper accompanies the students during the lessons.

B. Special Characteristics of Individual Universities

A notable characteristic of LUH (Fig. 1) is the distinction between research-oriented and teaching-oriented courses within bachelor's and master's programs. This does not imply that research-oriented courses lack a connection to teaching and school activities, nor does it suggest that teaching-oriented courses do not incorporate research components. Rather, it is a matter of focus.

As illustrated in Fig. 1 (left-hand side), students enrolled in teaching-oriented courses initially acquire foundational competencies in subject didactics. Subsequently, they progress to the more abstract aspects of teaching design, such as the interpretation of curricular guidelines, annual planning, and the utilization of media (e.g., simulation models) in the domain of electrical engineering. This theoretical foundation will then be applied in two subject-specific teaching projects, which will serve as an evaluation framework. In the scientifically oriented courses (Fig. 1, right-hand side), the introduction focuses on scientific reading and writing. These conceptual frameworks are introduced in the foundational course on professional sciences and subsequently applied through the medium of a seminar paper. Subsequently, a video and a scientific paper are produced in research seminars. These products are intended to facilitate the presentation of scientific results in both the scientific community and the general audience. The theses, which are not illustrated in Fig. 1, integrate the two domains and provide students with the opportunity to conduct their own preliminary research in a teaching-related context.

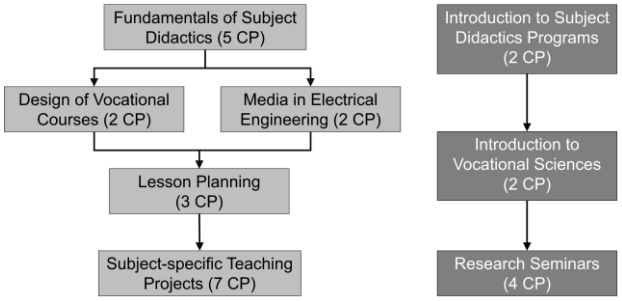

Fig. 1. Courses at LUH.

In addition to this cooperation between subject didactics and subject science, there is also very close cooperation between schools and teacher training centers at TUB. Teacher training centers (Studienseminare) are institutions that facilitate the second phase of teacher training (Vorbereitungsdienst, Referendariat) in Germany. This collaboration is formalized within the framework of a mentor qualification program, which is administered by the subject didactics department at TUB and subject supervisors (Fachleiterin/Fachleiter) at the study centers. The primary objective of this initiative is to equip educators from vocational schools with the skills necessary to function as mentors. These mentors are then charged with the responsibility of providing guidance to students during their practical semester. This guidance encompasses aspects such as lesson planning, implementation, and evaluation. Nevertheless, the collaborative endeavors undertaken by these three institutions serve to enhance their collaborative efforts. Furthermore, a "Last Wednesday of the Semester" event is organized at the conclusion of each semester. These events are open to alumni, representatives of the schools and teacher training centers, and students. In this setting, students present the results from the current semester and facilitate an exchange of ideas, thereby fostering personal and professional relationships among participants. The School of Education at TUB (SETUB) formally organizes a quality circle on a semesterly basis. This event is open to students and lecturers in the field of subject didactics, with the opportunity for subject specialists to participate upon invitation. The text discusses current challenges and developments in a non-exclusive manner, and requests for change are addressed in a manner that is not overly restrictive. This approach has been demonstrated to significantly reduce barriers to communication between students and instructors, thereby fostering an optimal learning and working atmosphere within degree programs.

In the UK, the promotion of cooperation with schools is facilitated by the deployment of teachers to the UK to serve as educational personnel. This initiative fosters personal connections in addition to the chair's interactions with individual school boards and teachers, thereby facilitating more intensive cooperation in the supervision of students. Furthermore, an educational staff member fulfills dual roles as both a teacher at a vocational school and a subject supervisor at a teacher training center. This dual role ensures close cooperation between the three training locations for prospective teachers. Despite the absence of formal institutionalization, the author of this article posits that this initiative exerts a favorable influence on present and future collaborative endeavors between the UK and the teacher training college.

IV. (Further) Development of Degree Programs

As previously stated, teacher training courses typically have a limited number of participants, ranging from two to three students in some cases. This necessitates the development of curricula that are tailored to the individual needs of the students while also considering the economic constraints. Sections A and B delineate the evolution of areas of specialization and two individual courses that have been previously implemented. The subsequent sections delineate the current state of relevant developments (Sections C and D).

A. Areas of Specialization

The budget of credit points limits the number of subject-specific courses, which allows students only a few opportunities for in-depth study. Notwithstanding, such an in-depth study is advantageous as it enables students to pursue their own interests. Consequently, from the author's perspective, the motivational aspect of students constitutes a pivotal element of such a specialization.

To establish a foundation for the development of specializations, a comprehensive analysis of the existing professional curricula in Germany was conducted.

Trainees in vocational training for these professions represent a future target group for the students' teaching activities. The analysis encompassed 44 recognized training occupations. Initially, these fields were primarily concentrated in the domains of energy technology, equipment technology, electrical installation, mechatronics and automation technology, as well as information and communication technology (Fig. 2).

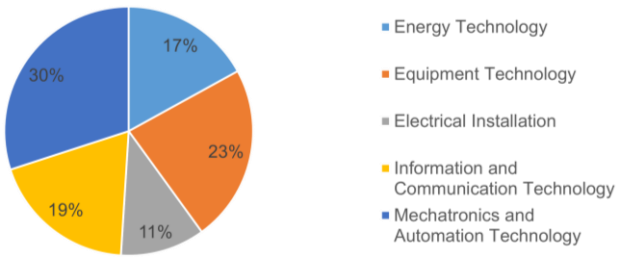

Fig. 2. Mapping of vocational occupations to domains.

The apprenticeship occupations were then assigned to university disciplines (automation technology, energy technology, microelectronics, communications engineering, and computer engineering) based on the areas of specialization identified in the respective framework curricula. The results of this assignment are illustrated in Fig. 3.

A close examination of the available data reveals that the fields of communications engineering and computer engineering are not prominent focuses in many different occupations. This apparent contradiction regarding the need for programming skills, which is postulated by

schools and teacher training centers (cf. next section), is resolved by an expanded classification of occupations (Fig. 4).

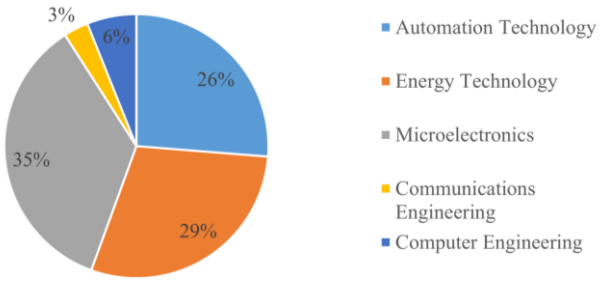

Fig. 3. Mapping of apprenticeship occupations to university disciplines.

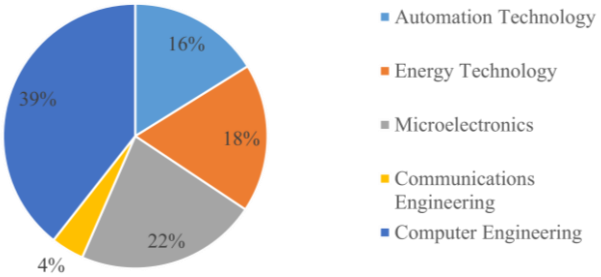

Fig. 4. Extended mapping of apprenticeship occupations to university disciplines.

In this analysis, each occupation is assigned a secondary specialization in addition to its primary specialization. In this regard, technical computer science is becoming increasingly important. For instance, the apprenticeship professions of "electronics technician specializing in automation technology" (ElektronikerIn mit der Fachrichtung Automatisierungstechnik) and "electronics technician specializing in information and telecommunications technology" (ElektronikerIn mit der Fachrichtung Informations- und Telekommunikations-technik) both have a significant focus on computer engineering, in addition to their respective specializations in automation technology and communications engineering. Consequently, the field of computer engineering has become the most predominant field, necessitating its deliberate incorporation into the curriculum.

In consequence of this analysis, specializations in microelectronics, automation technology, and energy technology were introduced. The degree program was expanded to include computer engineering as a compulsory component. Currently, microelectronics is set to be renamed electronics, as the term has a strong conceptual focus on engineering activities, and other universities use it.

B. Design of Individual Courses

A notable benefit of designing degree programs in the field of teaching is the relatively limited number of potential employers. Over the past decade, the majority of LUH graduates have successfully completed the second phase of their training in the Federal State of Lower Saxony, subsequently securing employment as teachers within schools situated within a 100-kilometer radius of LUH. Consequently, there is direct contact with the teacher training center and with most vocational schools.

A survey of these vocational schools and the Hanover teacher training center revealed a conspicuous deficiency in the students' competencies, particularly in the domains of programming languages and installation technology. Courses in the field of programming languages had been previously offered at LUH; however, these courses were designed for either engineering or computer science students. Consequently, the necessary prerequisites were not met by the teacher training students, or the course objectives were too specialized. Consequently, a specialized course was developed for students pursuing a major in electrical engineering. Subsequently, with the integration of computer science as a subject, the course was expanded to encompass the entire target group of teacher training students. This approach ensures that the subject-specific didactic aspects of future teachers are consistently taken into account. Consequently, the subject-specific objectives are not necessarily disregarded. However, it is imperative for student motivation that connections between academic instruction and practical applications in the field be firmly established.

A salient issue in the context of installation technology pertains to its absence from the curriculum of academic institutions. The field of installation technology is appropriately situated within the domains of vocational training and further education, as the fundamental principles of this discipline are not typically covered in university or college curricula. Consequently, a specialized course was initially developed in which the individual components of installation technology are taught. In addition to the technical aspects, subject-specific didactic aspects were integrated into the course. The integration of these aspects was intended to increase student motivation and to promote the direct use of learning outcomes in future employment at vocational schools. In recent years, this course has undergone significant development, resulting in a two-semester structure. The integration of distinct facets of energy technology, in conjunction with installation technology, has been a hallmark of this transformation. In the current version of the course, the first semester covers the fundamentals of systems upstream of the house connection (energy generation and distribution) and the second semester covers systems downstream of the house connection (house installation). Despite the courses being met with approval by students, the teacher training center, and schools, they are still undergoing development and adaptation to align with students' needs.

C. Current Developments

Following the experience of the previous academic year and in response to the feedback from students, a quality circle was initiated at LUH in the winter semester of 2024/25. All students specializing in electrical engineering who are enrolled in the teacher training program are invited to attend the meetings. In terms of academic instruction, the dean of studies from the Faculty of Electrical Engineering and Computer Science, the program coordinator, and the academic advisor are in

attendance. The Vice President for Teaching at LUH was in the audience at the initial meeting of the quality circle, facilitating a discourse between students, program coordinators, and faculty and university management. This exchange was carried out in subsequent semesters and has since become an integral component of the program development process. Students have expressed a strong positive opinion regarding the quality circles, citing the opportunity they provide to directly influence the design of degree programs as a significant benefit, without the need for bureaucratic processes.

The courses, "Introduction to Vocational Sciences", "Design of Vocational Courses", and "Media in Electrical Engineering" are the result of the author's experiences at TUB, discussions with students, and reaccreditation. The implementation of these changes was made possible by a comprehensive restructuring of the program, which entailed the replacement of existing courses with new ones. Furthermore, the curriculum was augmented with a tutorial for technical mechanics, a prerequisite for the compulsory course, "Control Engineering", which had been identified as a need by students. Given the persistent challenges that students encounter in the course "Control Engineering", a supplementary tutorial has been developed that focuses exclusively on the subject matter of control engineering. This tutorial is currently undergoing a trial phase. Although participation is not currently embedded in the curriculum and is therefore voluntary, the integration of this tutorial into the examination regulations is planned to follow a successful test phase. Preliminary feedback from individual students indicates a very positive rating for this offer, given its consideration of students' needs and its direct addressing of issues within the degree program.

D. Fields of Development

The development and adaptation of curricula at LUH can be summarized in the following categories:

(1) Selection of alternative courses from the subject area to better reflect students' interests and meet their requirements.
(2) Design of new courses that better reflect the requirements of teacher training.
(3) Supplementing the curriculum with courses that address students' issues and help them overcome these difficulties.
(4) Greater focus on students' future teaching careers through the creation of specializations.

The first and last categories emphasize a development that restructures the curriculum and attempts to utilize the development within the range of courses offered in engineering degree programs. This suggests that the courses are not explicitly designed for individuals aspiring to become teachers. Concurrently, economic factors have been taken into consideration, leading to the observation that enrollment rates in specialized courses for prospective educators are notably low. In categories B and C, this fact is taken into account, although the needs of future teachers are given higher priority in these categories.

V. Conclusion and Outlook

In summary, the three universities under consideration exhibit certain similarities in the design of their degree programs, although individual areas of focus are also apparent. The author posits that the areas of focus are determined by the personnel constellation of the responsible departments and their integration into the university and faculty structures. For instance, the close association with the field of electrical engineering is evident in the individual courses, attributable to the personal educational background of the author of this article. The author is responsible for subject-specific and 'teacher-oriented' courses, and for the integration of the subject area within the faculty. In contrast, a divergent trend is observed at TUB and UK, where the institutes are situated within Faculty I (Humanities and Educational Sciences) and Department 07 (Economics), respectively, and exhibit a propensity to be in closer proximity to other subject didactics. Additionally, it is imperative to address the primary focus of the main professorship. At TUB, for instance, this role is entrusted with the responsibility of representing subject didactics in electrical, automotive, information, media, and metal technology. This emphasis complicates the design and implementation of subject-specific courses for teacher training students.

It is therefore crucial to avoid defining subject didactics in overly broad terms, thereby ensuring the requisite focus on the specific professional domain. Additionally, it is imperative to ensure that the distinct requirements of students, which are profoundly influenced by their educational backgrounds, are given due consideration, despite the limited size of the cohorts. It is crucial to offer distinct courses for students to address both their qualifications and career aspirations, thereby fulfilling the responsibility for teacher training as a social duty. In addition to collaborating with schools and teacher training centers, it is not only conceivable, but also expedient and necessary, to collaborate with other universities and subject didactics. Furthermore, maintaining close communication with students is imperative. This encompasses both informal communication, which is readily facilitated due to the small cohort size, and a structured and systematic exchange process aimed at optimizing the degree programs.

The subsequent research activities in this domain will concentrate on a comparison of models (consecutive vs. non-consecutive degree programs, master's vs. state examination) as well as an international comparison. Furthermore, there are plans to expand the focus to a greater number of universities.

Conflict of Interest

The authors declare no conflict of interest.

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