Critical issues in undergraduate cartographic education: Analysis of final tests and oral examinations

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ABSTRACT

This article identifies critical issues in cartographic education based on analysis of more than 1,300 anonymized didactic tests and anonymized results of final oral examinations of university courses since 2010. To analyze the students' results, the tasks in the tests and questions in the oral examination were categorized in the cartographic and didactic aspects based on the revised Bloom's cognitive taxonomy. The quantitative analysis shows that students achieve better results in tasks that test their procedural knowledge compared to tasks in which they must demonstrate a conceptual knowledge dimension. Students achieve the worst results in tasks that test their factual knowledge, while poorer results are also associated with tasks that require mathematical calculations. In the cartographic curriculum categories, the form of their delivery (lectures vs. exercises and seminars) plays a more important role than the nature (e.g. difficulty) of the content. This will undoubtedly place greater demands on the planning of cartographic education in the future.

KEYWORDS

critical issues; cartographic education; students' results; final test; oral examination

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1. Introduction

The importance of cartographic knowledge and skills for effective work with cartographic products has been demonstrated by numerous studies in the didactics of geography and cartography (e.g. Čerba et al. 2012; Duffek et al. 2018; Frangeš, Frančula, and Lapaine 2001; Gartner 2022; 2023; Hanus et al. 2020). Therefore, it is essential to integrate work with maps and map-related representations into the curriculum at all levels of education, as well as other learning activities (Wiegand 1993; 2006), to foster the development of these competencies from primary education through secondary to eventual tertiary education.

The next step is the provision of *cartographic education* as part of various university undergraduate programs. The goal of these study programs is to produce experts capable of undertaking the creation, revision and adaptation of cartographic products within the fields of geodesy and civil engineering, geography and regional development, geoinformatics, strategic and spatial planning, military, and other related disciplines. The utilization of cartographic skills by educated experts can be observed in other sectors in which maps are employed, ranging from basic data analysis to advanced interpretation and synthesis of spatial information. The aforementioned areas of expertise include but are not limited to archaeology, agronomy, biology, ecology, geology, historical and social sciences, climatology and urban planning, as well as within the operational centers of the Integrated Rescue System. Finally, the preparation of university students in the field of cartographic skills is aimed at future teachers, with a particular focus on geographic education. The intention is to prepare them to utilize maps, among other things, as tools to develop geographical thought in their pupils (Hanus et al. 2020).

Each graduate should have developed specific cartographic skills. The aforementioned format of cartographic competencies should be integrated into the content of university lectures, exercises and seminars. Additionally, it should be reflected in both continuous testing (testing the results and outputs of students during the semester, i.e. formative assessment) and final testing (after the end of the semester during the examination period, i.e. summative assessment). In many cases, cartographic education is integrated into a comprehensive system of subjects, where objectives and resources are aligned with the specifics of the disciplines.

At this point, it is appropriate to explain what the authors in this study mean by the term critical issues of curriculum. *Critical issues of curriculum* can be understood as areas of the curriculum where students or their teachers are failing for various reasons. The term therefore refers not only to the learning individual, but also to the concept of teaching, content or competences that the teacher understands as essential and tries to pass them on to the students. In this context, it is of particular importance to provide *feedback on student testing results* to teachers (McCarthy 2017; Nicol and Macfarlane-Dick 2006). This type of reflection can uncover critical issues within the educational context, including both the general and specific challenges students encounter (Stacke et al. 2020) and the quality of testing. In particular, it is necessary to determine whether the specific subject matter is effectively assessed during the testing process, what the teachers aim to evaluate, and the reliability of the testing process (validity and reliability of testing; Lane and Bourke 2019). In the educational context, reflecting on the quality of teaching and student assessment is crucial, as it can lead to continuous improvement in the content and design of the educational process (Ottens 2013).

The aim of this paper is to present the findings of a study that examined the results of the end-of-term assessment of students enrolled in a basic cartography course. Through this reflection, the authors contribute to the identification of critical issues in undergraduate cartographic education within geography and geoinformatics–related curricula, similar to how critical issues in the geography curriculum have been identified by geography didacticians (see Duffek et al. 2018). Identifying critical issues can help improve related cartography courses and contribute to addressing these problems effectively.

2. Cartography in university education

Cartography is an integral part of university education in a wide range of disciplines and related study programs. It is most commonly found in technical (examples in Czechia include Brno University of Technology, Czech Technical University in Prague and VSB – Technical University of Ostrava), science and environmental (Charles University, Czech University of Life Sciences Prague, Jan Evangelista Purkyně University in Ústí nad Labem, Masaryk University, Palacký University Olomouc, Technical University of Liberec, University of Ostrava, University of South Bohemia in České Budějovice), socioeconomic (Czech University of Life Sciences Prague, University of Pardubice, University of West Bohemia), education (Masaryk University, Technical University of Liberec, University of South Bohemia in České Budějovice) and military (University of Defense) departments. The characteristics and focus of the study programs determine the profile of their graduates.

Cartography plays different roles in the curricula according to the thematic focus of the study program:

(i) as a key discipline throughout the entire period of study (i.e. from the first to the last year, with a structured progression of acquired knowledge and skills), often in conjunction with geoinformatics;
(ii) as a discipline that is only auxiliary or complementary.

In the latter case, the time allocated to cartography-related courses may be limited to one or two courses in the early phase of the study, or may take the form of elective courses in the later phase of study. When a single course is offered across degree programs at a university, each with diverse graduate profiles, determining the content and organization of teaching becomes inherently more challenging.

The temporal scale aligns with the scope of the transferred knowledge and skills. *Cartographic skills*, as well as map skills, represent a complex set of operations and activities in which map and space still play a central role. Map skills can be categorized in terms of their cognitive complexity, ranging from using maps (reading, analysis, interpretation) to their actual production (Havelková and Hanus 2019). Nevertheless, cartographic skills encompass a range of abilities that are not necessarily directly related to the use or production of maps. These include a variety of data collection techniques and methods, as well as the distribution of cartographic products (Hanus and Marada 2014).

Undergraduate education typically aims to strike a balance between cartographic theory – the necessary minimum of professional knowledge, principles and conventions – and practical cartographic skills, involving the creation of maps or other cartographic products through partial or complex assignments during exercises and seminars. This also aligns with the generally accepted definition of cartography as "art, science and technology of making and using maps" (see, e.g., the 2003–2011 strategic plan of the International Cartographic Association, cited in Kraak and Fabrikant 2017). Here *science* corresponds to the theoretical concepts, principles and rules, while technology encompasses procedures and the integration with information technologies, geographic information systems (GIS) and other innovations in cartographic production (ibid.). Unfortunately, the principle of *art* is often not given sufficient attention in educational practice, particularly in map design and other less technical and structured aspects of map making. These competencies, occasionally referred to as visual talent or the talent component of map making, are more likely to be expected from map makers and professionals, including students.

In today's mainstream map making environment, which includes many individuals lacking the necessary cartographic production background and, regrettably, without the necessary skills (Dodge, McDerby, and Turner 2008), there is a pressing need to prioritize the practical use and creation of maps (*map use* and *map making*) in undergraduate education (MacEachren 2013; Ormeling and Rystedt 2014). The goal of such an educational program should be to equip students with an understanding of the fundamental principles of map design, including its visual elements and compositional structure. Additionally, it should develop practical skills in applying different scales and mathematical parameters (Anderson and Leinhardt 2002; Ooms et al. 2016; Wiegand 2006, 94–98), understanding the planimetric and altimetric components of maps and map lettering, selecting appropriate means of map representation and methods for representing thematic content (Michaelidou, Filippakopoulou, and Nakos 2007), and converting spatial and attribute data into map visualizations. This comprehensive list demonstrates that cartography places significant demands on students due to the inherently complex nature of the discipline. Even when cartography is introduced early in study programs, the demands are heightened due to the unique cross-curricular links it requires. Unlike fields such as statistical methods or spatial data processing, which are relatively universal in content, cartography requires specific knowledge and skills not offered in other courses. In addition, students typically possess a markedly disparate foundation of knowledge and abilities when transitioning from upper secondary education to undergraduate studies. Another significant challenge is the reluctance among successive generations of students, who have grown up in the digital age, to initially develop these skills in the traditional (analogue) form – drawing maps by hand without the use of GIS or other software tools (comp. Solórzano, Comíns, and Sendra 2017; Trahorsch and Reich 2023).

The framework of cartographic education objectives presented above provides the foundation for the *categories of cartographic curriculum* in the university environment. Based on the authors' extensive experience in teaching cartography and subsequent analysis (comp. Bláha 2021; Kůtová 2014), the following categories have been identified:

i) thematic cartography, map and content;
ii) map scale;
iii) map composition and compositional elements;
iv) map lettering;
v) cartographic semiology and linguistics, means of expression;
vi) mathematical principles of maps;
vii) topographic cartography, map and content (planimetric components);
viii) hypsography components – the third dimension in a map;
ix) statistical data processing/statistics;
x) other topics in cartography (cartography as a discipline, map, institutions, generalization, map production, history, evaluation, etc.).

3. Cartographic skills in a university environment and their testing

The development and level of cartographic skills can be influenced by a number of factors, including *the user of the cartographic product*, in this case the student, *the cartographic product* itself and *external factors* (Hanus et al. 2020, 97–102). These factors undoubtedly also influence students' performance in cartographic skills testing. Factors include student characteristics, such as learning style, cognitive level, age and experience, as well as external factors such as the integration of cartography activities within the study plan, the time allocated for the course, the content and structure of the course syllabus, the teacher, and the teaching and testing methods employed (Havelková and Hanus 2019; Ooms et al. 2016).

In the context of university education, students enrolled in study programs that include cartography typically have an average to slightly above average level of cartographic user skills before they start the study (similarly see studies Havelková and Hanus 2018). However, the level of tested cartographic skill may be significantly influenced by *disciplinary specificities*. For instance, there can be a notable difference between single-discipline geography × geoinformatics students, as well as between teacher × non-teacher students. These variations stem from the prerequisites and motivation of applicants for specific study programs, as well as from the admission procedure. Often, the cartography educator has little influence over these aspects, particularly when cartography is regarded as a mere auxiliary discipline. The aforementioned disciplinary specifics also determine the methods used in teaching cartography (e.g. by incorporating more frequent field exercises in technical or natural science disciplines).

Cartographic products and their quality play a crucial role in university education, serving primarily as examples of good and bad practice. Above all, graduate students should be able to distinguish between these two categories of cartographic products to enhance their effective use in the practice of their respective disciplines (Trahorsch and Bláha 2022).

The testing of cartographic or map *skills* is typically conducted during the course through practical activities. Such activities may focus on either the application of the acquired knowledge within the partial activities (e.g. map scale calculation and compilation, generalization of map content) or creating complete map output of various types (e.g. creating a thematic map). The process of testing also encompasses the evaluation of general competencies (such as the ability to work with visuals), or competencies derived from other subjects (such as mathematical operations, analyzing and processing statistical data).

In particular, in the end-of-term examination, both *knowledge* acquired during the semester and skills are tested, either in written or oral form, depending on the educational policy environment's practices (predominantly summative function of assessment). In certain disciplines, it is common to test knowledge more frequently through continuous written tests, surveys or interviews (predominantly formative function of assessment) (Bijsterbosch, van der Schee, and Kuiper 2017; Weeden and Simmons 2017).

Assessing map skills through a final didactic test or exam can have several dimensions. Generally well-known cognitively demanding tasks (Downs, Liben, and Daggs 1988) range from basic knowledge remembering and understanding to the application of learned information in analysis, evaluation and creation. In the former scenario, students typically exhibit passive learning, passing on what they have learned without significant cognitive activity. In the latter, the student is required to engage in higher cognitive processes, such as actively applying learned knowledge to new contexts and relationships and drawing informed conclusions (Anderson and Krathwohl 2001). Another cognitive didactic level relates to the type of knowledge (according to the Revised Bloom's taxonomy; Anderson and Krathwohl 2001). On the one hand, the evaluation may emphasize factual knowledge, which is the initial prerequisite for effective work and creation with map products. However, this emphasis may result in a lack of attention to the application level.

The second dimension of evaluation is conceptual knowledge, which is of a more general nature; this dimension contextualizes factual knowledge, which includes knowledge and understanding of theories, models, patterns and generalizations. The procedural knowledge dimension includes familiarity with widely accepted procedures and conventional practices within the field of cartography, e.g., using the correct rules for creating a map legend (de Almeida 2012). The final dimension of knowledge is metacognitive knowledge, which encompasses the understanding of one's own learning practices and processes.

Apart from the student's attributes, *the nature of the final examination*, particularly its format – written in the form of a didactic test, oral in the form of an interview or a combination of the two – undoubtedly influences the results of the final examination (Aljazairi et al. 2022). If the testing is conducted over a longer period (2010–2023 in the presented case study), among others, the following factors should be considered:

a) variants of the didactic test (historical and contemporary);
b) characteristics of the didactic test – reliability, validity, sensitivity of tasks, etc.;
c) the nature and content of the tasks in terms of didactics, or in terms of the categories of the cartographic curriculum.

It can be assumed that synthesis and consideration of the aforementioned approaches and factors may provide insights into the following questions:

a) in the didactic aspect: To what extent are students' results influenced by the nature of the written test tasks (e.g. dimensions of knowledge, cognitive demand, presence of visuals)? To what extent are students' results influenced by the need to apply specific competencies (e.g. mathematical or linguistic operations)?
b) in the cartographic aspect: What mistakes do university students make? What are the critical issues in the cartographic curriculum? To what extent

does study discipline influence overall performance or results within the different categories of the cartographic curriculum?

4. A case study from a Czech regional university

The case study presented below comes from the Jan Evangelista Purkyně University in Ústí nad Labem, a typical example of a Czech regional university. Cartography is an auxiliary discipline within the study programs, and it is taught in the first semester of study for three diverse groups of students with different graduate profiles:

a) single-discipline students of geography;
b) double-discipline students of geography and other disciplines, many of whom expect to work in geography education in primary and secondary schools;
c) single-discipline students of geoinformatics, applied mainly to the environment.

The testing process during the semester is based on the fundamental principle of learning by doing and learning from mistakes. Students are guided through the sub-activities of map making, where their acquired knowledge and skills are demonstrated in their map outputs. These outputs are continuously corrected by the lecturer, with students revising their maps based on the teacher's feedback to improve their work. The number of map outputs has evolved over the study period (2010–2023), with the initial five outputs being replaced by the three outputs that are currently in use. The first of the retained map outputs focuses on thematic cartography, the second on topographic cartography. In the third, students demonstrate their own map productions, incorporating not only their interests but also all the cartographic skills they have acquired so far. In addition to the presentation of the third output, the seminar also includes a peer evaluation of another student's map output, followed by a discussion. The number of attempts and the results of the student's efforts are reflected in the final evaluation, which uses a nominal (output submitted in an acceptable × unacceptable form) and interval scale (scoring). If all outputs are submitted in an acceptable form, and the student also obtains a minimum of 24 out of 46 points (approximately 52%), the student may proceed to the end-of-term examination. Considering the difficulties in analyzing the results of a continuous assessment, including various external factors, the authors decided not to prioritize this aspect of testing, instead focusing solely on the analysis of the students' end-of-term testing, namely its written form. However, based on the teachers' experience, it is evident that the ongoing assessment and its formative role in these tasks is likely to be reflected in the results of didactic tests.

The final testing of students' cartographic skills is conducted through an exam in written (for double-discipline students) or combined form (i.e. written and oral form; for single-discipline students of geography and geoinformatics). The written exam consists of a didactic test comprising 12 tasks of varying types. Each task is scored based on its significance, ranging from 1 to 3 points, for a maximum total of 20 points. Scoring is to the nearest 0.25 points, which allows for the recognition of differences, particularly in the responses to open-ended questions. A score of at least 11 points is required to pass the test. Grades are then derived from the scores obtained according to the system used at certain Czech universities: 1–3 are passing grades, grade 4 is a failing grade (0–10 points corresponds to grade *4*, 11–13 points correspond to grade *3,* 14–16 points correspond to grade *2* and 17–20 points correspond to grade *1*). For borderline scores of 10.5, 13.5 or 16.5, additional questions are provided for the failed tasks in the test. In light of the longer time horizon (2010–2023), the didactic test has a total of four historical variants (A–D). Each historical variant contains different contemporary sub-variants: 1–8 for the first three variants and 1–6 for the last variant.

5. Methodology

The presented research is semi-longitudinal and is based on the collection of the results of final tests and oral examinations in a basic cartography course. The study employs a quantitative approach, utilizing statistical procedures to identify the critical points of the curriculum and the factors that the student in the given example navigates with no difficulty. The results are interpreted using classical test theory (CTT), which has the potential to identify the level of ability and skills of the respondents.

5.1 Structure of didactic tests used

Tab. 1 and 2 illustrate the test structure and the various tasks that were expertly analyzed by the members of the research team, (a) the didactics aspects (Tab. 1), and (b) the categories of the cartographic curriculum (Tab. 2). The coding of the tasks was carried out by two members of authors' collective, independently of each other and then they compared and discussed their results. As an example, we present two tasks that were conceptually quite different in the tests (comp. with Tab. 1 and 2):

a) U1 – "Circle the appropriate thematic mapping techniques for the map topic below (there may be one or more correct answers): *Religious denominations* in Asia: (a) cartogram, (b) area-class map, (c) choropleth map, (d) dasymetric map, (e) diagram map;"
b) U9 – "Briefly but clearly explain in your own words the terms below from the field of cartography. Please provide examples if appropriate. Terms: (i) reference surface, (ii) UTM, (iii) isochrones."

Tab. 1 Structure of the test with tasks assessed from the didactic perspective.

Didactic aspects	U1	U2	U3	U4	U5	U6	U7	U8	U9	U10	U11	U12
Cognitive Process Dim.	App.	App.	App.	Anal.	App.	App.	Anal.	App.	Und.	App.	Rem.	Crea.
Knowledge Dimension	Proc.	Proc.	Proc.	Conc.	Proc.	Proc.	Proc.	Proc.	Fact.	Proc.	Fact.	Proc.
Type of Task	CMCA	OBRS	OBRS	OSSA	OBRS	OBRS	OBRD	OBRU	OBRU	OBRS	OSPA	OBRS
Working with Visuals	No	No	Yes	Yes	No	No	Yes	No	No	No	No	Yes
Mathematical Operations	No	Yes	No	No	No	No	No	Yes	No	Yes	No	No

Cognitive Process Dimension

Rem.	remember
Und.	understand
App.	apply
Anal.	analyze
Crea.	create

Knowledge Dimension

Fact.	factual
Conc.	conceptual
Proc.	procedural

Type of Task

OBRD	open-ended with broad response structure defined
OBRS	open-ended with broad response structure given by convention
OBRU	open-ended with broad response unstructured
CMCA	closed with multiple choice answers
OSPA	open-ended with brief response production
OSSA	open-ended with brief response completion

Notes for Tab. 1 and Tab. 2: U1–U12 are individual tasks, with task U4 having three sub-questions U41–U43 in the historical version of Test D, I–X are individual categories of the cartographic curriculum (see Part 2); for certain tasks, multiple categories are represented in varying proportions.

The oral part of the exam is conducted through an interview over two randomly selected topics and focuses mainly on the student's knowledge, or the analysis, interpretation and conceptual design of maps. Performance on the oral part of the examination is evaluated solely based on the aforementioned marking system, whereas the written test serves as the primary input parameter.

In the 2010–2023 period, the anonymized results of the scores and marks were stored in the database of written test results and the database of oral examination results. However, for a detailed analysis of the final assessment, only the database of written test results was used (monitored variables see Part 5.3). Due to incomplete records in the database, it is impossible to ascertain whether the first or second randomly selected topics influenced the outcome of the oral examination.

5.2 Methodological attributes of the tests used

From a methodological perspective, the authors examined the attributes of test tasks and historical test variants. Initially, it was necessary to unify the individual tasks according to their thematic focus into tasks under the U1–U14 label (Tab. 1). In each of these tasks, both the didactic and cartographic attributes, as well as the sensitivity and difficulty of each task, were monitored. *Task sensitivity* is defined as the extent to which a given task measures what the whole test measures and is calculated using the *ULI* and *RIT* coefficients. All the tasks fall within the range of <0.10–0.66>, indicating sufficient sensitivity for individual tasks (or at least tolerable, for those slightly above 0.10), specifically, the U4 and U9 tasks (Štuka and Vejražka 2021). *Task difficulty* measures how challenging a task is for students. The index used in this case ranges from 0 to 100, with higher values indicating easier tasks. All the tasks observed in each historical variant had values <25; 80>, indicating that none of the tasks were inappropriately easy or difficult (ibid.).

The reliability of the individual historical variants of the test, calculated using Cronbach's alpha, ranges from 0.57 (historical variant C) to 0.74 (historical variant A). It should be noted that variant C has the smallest number of records ($N = 119$), however, when converted to values per 250 (like the other historical variants), the reliability is close to 0.70. In general, the reliability of the individual tests can be considered sufficient, but slightly lower for historical variants B (0.62) and C (0.57). Based on methodological studies, the reliability can be described as acceptable, sufficient and satisfactory (Taber 2017).

These data show that the tests used are reliable and, in terms of their properties, applicable in practice (none of the questions deviates significantly from the testing objective). The presented tool (didactic test) can thus be used to answer research questions.

5.3 Structure of the results database

The total *number of monitored tests* (the number of processed written tests) is 1,315. Each submitted test corresponds to exactly one record in the database, which has the following structure:

a) information about the test (test ID, year and date of the test, historical variant and contemporary sub-variant of the test, total score, total test score marked with a grade);

Tab. 2 Structure of the test with tasks assessed from the perspective of the cartographic curriculum.

Historical variant	Sub-variant	U1	U2		U3			U41	U42	U43	U5		U6		U7		U8	U9			U10			U11	U12	
A	1	I	II	III	IV	V		VI			III	V	V	I	VII	VIII	II	V	X	I	IX	I	V	X		
	2	I	II	III	IV	V		VI			III	V	V	I	VII	VIII	II	VIII	X	X	IX	I		III		
	3	I	II	III	IV	V		VI			III	V	V	VII	VII	VIII	II	X	V	X	IX	I	V	X		
	4	I	II	III	IV	V		VI			III	V	V	VII	VII	VIII	II	V	VIII	VI	IX	I		III		
	5	I	II	III	IV	V	VIII	VI			III	V	V	I	VII	VIII	II	VI	X	X	IX	I		V		
	6	I	II	III	IV	V		VI			III	V	V	VII	VII	VIII	II	III	X	V	IX	I	V	V		
	7	I	II	III	IV	V		VI			III	V	V	I	VII	VIII	II	VI	VI	X	IX	I	V	X		
	8	I	II	III	IV	V		VI			III	V	V	I	VII	VIII	II	VI	X	V	IX	I		X		
B	1	I	II	III	IV	V		VI			III	V	V	I	VII	VIII	II	V	X	VI	IX	I	V	V		
	2	I	II	III	IV	V		VI			III	V	V	I	VII	VIII	II	V	I	X	IX	I		III		
	3	I	II	III	IV	V		VI			III	V	V	I	VII	VIII	II	VI	X	X	IX	I	V	X		
	4	I	II	III	IV	V		VI			III	V	V	I	VII	VIII	II	V	VIII	VI	IX	I		V		
	5	I	II	III	IV	V		VI			III	V	V	I	VII	VIII	II	VI	VI	I	IX	I	V	X		
	6	I	II	III	IV	V	VIII	VI			III	V	V	VII	VII	VIII	II	VI	X	V	IX	I		V		
	7	I	II	III	IV	V		VI			III	V	V	I	VII	VIII	II	X	X	VIII	IX	I	V	X		
	8	I	II	III	IV	V		VI			III	V	V	I	VII	VIII	II	III	VI	V	IX	I		X		
C	1	I	II	III	IV	V		VI			III	V	V	I	VII	VIII	II	V	X	VI	IX	I	V	V	III	V
	2	I	II	III	IV	V		VI			III	V	V	I	VII	VIII	II	V	I	X	IX	I		V	III	V
	3	I	II	III	IV	V		VI			III	V	V	I	VII	VIII	II	VI	X	X	IX	I	V	X	III	V
	4	I	II	III	IV	V		VI			III	V	V	I	VII	VIII	II	V	VIII	VI	IX	I		V	III	V
	5	I	II	III	IV	V	VIII	VI			III	V	V	I	VII	VIII	II	VI	VI	I	IX	I	V	X	III	V
	6	I	II	III	IV	V		VI			III	V	V	VII	VII	VIII	II	VI	X	V	IX	I		V	III	V
	7	I	II	III	IV	V		VI			III	V	V	I	VII	VIII	II	X	X	VIII	IX	I	V	X	III	V
	8	I	II	III	IV	V		VI			III	V	V	I	VII	VIII	II	III	VI	V	IX	I		X	III	V
D	1	I	II	III	IV	V		VI	VI	VI	III	V	V	I	VII	VIII	II	V	X	VI	IX	I	V	V	III	V
	2	I	II	III	IV	V		VI	VI	VI	III	V	V	I	VII	VIII	II	V	I	X	IX	I		V	III	V
	3	I	II	III	IV	V		VI	VI	VI	III	V	V	I	VII	VIII	II	VI	X	X	IX	I	V	X	III	V
	4	I	II	III	IV	V		VI	VI	VI	III	V	V	I	VII	VIII	II	V	VIII	VI	IX	I		V	III	V
	5	I	II	III	IV	V	VIII	VI	VI	VI	III	V	V	I	VII	VIII	II	VI	VI	I	IX	I	V	X	III	V
	6	I	II	III	IV	V		VI	VI	VI	III	V	V	VII	VII	VIII	II	VI	X	V	IX	I		V	III	V

Categories of cartographic curriculum

I	thematic cartography, map and content	VI	mathematical principles of maps
II	map scale	VII	topographic cartography, map and content (planimetric components)
III	map composition and compositional elements	VIII	hypsography components – the third dimension in a map
IV	map lettering	IX	statistical data processing/statistics
V	cartographic semiology and linguistics, means of expression	X	other topics in cartography (cartography as a discipline, map, institutions, generalization, map production, history, evaluation, etc.)

b) information about the student (student ID, specialization – discipline, number of testing attempts to date – maximum of six attempts during one study period);

c) information on the results in individual tasks (scores for individual tasks, which have been standardized for the purposes of subsequent statistical analysis and standardized on a scale of 0–100, corresponding to the percentage of successful solutions).

In cases where a student completes both the written and oral parts of an examination, a record is included detailing the topics selected for the oral interview and the final grade awarded. This enables comparisons between the results of the written and oral examinations.

5.4 Statistical analysis of the results

The results database is the primary input material for statistical analysis. To perform the statistical analysis, classical measures of central tendency (modus, median – *M*, mean), measures of variability (mainly standard deviation – *SD*) and inferential statistical procedures were utilized. The authors followed the recommendations of Rabušic, Soukup and Mareš (2019) in assessing the normal distribution of the data.

Normality tests (Shapiro–Wilk, Kolmogorov–Smirnov) indicated that the observed sample did not exhibit a normal distribution of data. However, the authors emphasize that these tests are unreliable in numerically large samples and that normality can be assessed by examining skewness and kurtosis values, assessing differences between mean and median values, or analyzing the shape of the histogram. In accordance with these criteria and recommended procedures, the authors subsequently applied parametric statistical tests. These included the comparison of two or more means, followed by a post hoc analysis (*t*-test for the comparison of two means; ANOVA test for the comparison of multiple means and Bonferroni's post hoc test) and calculating product–moment correlation coefficient. Subsequently, the assessment of statistical significance was enhanced by examining *effect size* indicators (η^2), which gauge the significance and practical importance of the results. The interpretation of these indicators is based on the recommendations of Cohen (1988) and Soukup, Trahorsch and Chytrý (2021).

6. Results

6.1 Testing results in overall terms

In the observed tests, students achieved an average score of 9.2 points (SD = 3.3), with a success rate of 46%. There is a minimal difference between the median and the mean (M = 9.25). The mode of the sample corresponds to a score of 10.75 points (students achieved this score 42 times), which is interesting considering that a score of 11.00 points (55%) is required to pass the written exam or proceed to the oral part of the exam. During the monitoring period (2010–2023), no student achieved the maximum score of 20.00 points.

All the primary measures of central tendency demonstrate that the students' scores fluctuate around the 50% success rate, which is near or just below the threshold for obtaining credits or being admitted to the oral exam. This fact is also illustrated by the histogram (Fig. 1). The observed mode (value of 10.75) and the apparent shift in the histogram around the values of 9.00–10.00 points can be attributed to the subsequent evaluation of the written tests by the lecturer. Despite the implementation of objective assessment criteria, the teacher tries to differentiate between the performance of those who failed the test and those who succeeded. This procedure leads to a reduction in the total number of tests with a score of 9.50–10.00. The rationale behind this scoring system is twofold. Firstly, it aims to eliminate debates about narrowly missed passing grades. Secondly, it ensures that students who only take the written exam achieve the lowest passing score, 10.75, which is rounded up to meet the minimum threshold.

The overall results demonstrated how the success rate of the test varied depending on *the students' attempts*. In this case, the analysis of variance revealed that there was no statistically significant difference (p = 0.182) in success rates between attempts. For the first through fifth attempts, the average success rate was just above 9.00 points, while the first attempt exhibited the lowest success rate. Considering the aforementioned result, it is not surprising that the effect size of the sequence of attempts on the overall test score is minimal (η^2 = 0.006). Unfortunately, this indicates a minimal practical impact on improving student performance with repeated attempts. Consequently, the number of attempts explains only 0.6% of the overall test score. This may be due to a lower degree of student motivation in studying the field (in the case of this study geography) or very low study prerequisites of students who may not yet have been assessed and selected in other courses (students are still at the beginning of their studies).

As previously stated, students from different study groups may exhibit disparate outcomes due to their varying profiles and the *targeted focus of their respective study programs*. It was not confirmed that there

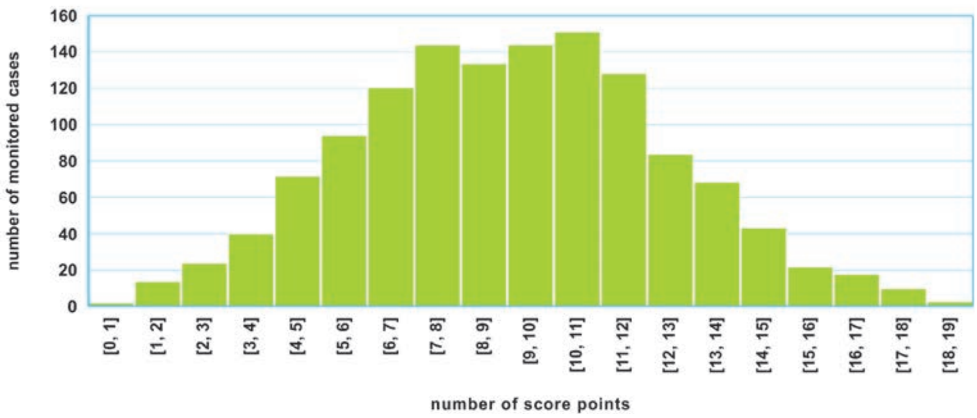

Fig. 1 Histogram of scores of the didactic test.

was a statistically significant difference (p = 0.08) among the various disciplines of study (i.e. applied geoinformatics, single-discipline specialized geography, double-discipline with geography, geography teaching). Additionally, the effect size indicates that the influence of the discipline of study on the results is minimal, practically zero ($\eta^2 = 0.04$). In the next phase of the analysis, the authors proceeded to a more in-depth examination of the results by discipline, dividing them into groups with similar skills and fields (disciplinary grouping). These groups included applied geoinformatics, single-discipline geography, geography combined with physical education, geography combined with social sciences, geography combined with science (excluding biology), and geography combined with biology. Even using this division of disciplines, a statistically significant difference between them was not confirmed (p = 0.08). The only additional information available is that the highest mean scores were achieved by students in applied geoinformatics, which may be due to the smaller sample size (see e.g. Soukup, Trahorsch, and Chytrý 2021) and different characteristics of the historical version of the test (see Methodology).

6.2 Student results in the didactic aspects of the tasks

In tasks involving *visuals*, the results were found to be slightly worse (47%) than in tasks lacking visual elements (48%). Two-sample t-test showed a statistically insignificant difference between the two types of tasks (p = 0.08; d = 0.21; r = 0.05), indicating that the inclusion of visuals had a minimal effect on task achievement – according to r, only 5%. This may be because students have already developed the requisite skills to work with different types of visuals, leading to an insignificant difference in the success rate of solving problems with and without visuals. The students' own production of maps during the semester may also be a factor.

In tasks requiring *complex mathematical operations*, students achieve worse results than in tasks without such operations (45% vs. 49%). The difference between the results of these two types of tasks is statistically significant (two-sample t-test; $p < 0.01$; d = 0.23; r = 0.10). Although the result is statistically significant, the effect of mathematical skills on solving tasks is only about 10%, indicating a small effect. Students achieve higher success rates in tasks that do not require more complex mathematical operations. However, there was no association between success rates in tasks requiring mathematical operations and the discipline of study (p = 0.45; $\eta^2 = 0.001$). This may be related to students' lack of mathematical skills, as mathematics is often not an elective subject for graduating from high school. On the contrary, geography is frequently selected as an "escape" from disciplines in which mathematical skills are applied more frequently.

An analysis of student results in terms of *Bloom's taxonomy of cognitive goals* (Fig. 2) reveals some interesting patterns. Students achieve the highest success rate in tasks requiring application (53%), while showing the same success rate (40%) in tasks with both low and high cognitive demands. The difference in success rate across different cognitively demanding tasks is statistically significant (analysis of variance; $p < 0.01$; $\eta^2 = 0.06$). In terms of substantive significance, the result can be assessed as moderately important. Bonferroni's post hoc test showed a statistically significant difference between the lower cognitive level tasks (knowledge, understanding) and the application ($p < 0.01$) as well as between the application and the higher cognitive level tasks (analysis, evaluation, creation; $p < 0.01$); a statistically significant difference between the lowest and highest cognitive operations was not identified by a post hoc test (p = 1). In contrast, no statistically significant difference was found between the lower and higher cognitive level tasks. One potential explanation for these results may lie in the teaching approach, which prioritizes the practical application of cartographic skills over the mere rote memorization of definitions. The difficulty of the higher cognitive functions, and therefore the low success rate, correlates with the overall proficiency level of geography students (as seen in other studies), potentially influenced by the rigorous testing and assessment of these cognitive abilities.

In the context of higher success rates in application tasks, and in consideration of the nature of cartography, the authors conducted further research into the extent to which students are successful in *understanding and applying the of conventions*. In tasks where students are required to demonstrate understanding of conventions and their application, they achieve a higher success rate (56% vs. 42%) than in other tasks. The observed difference in success rates

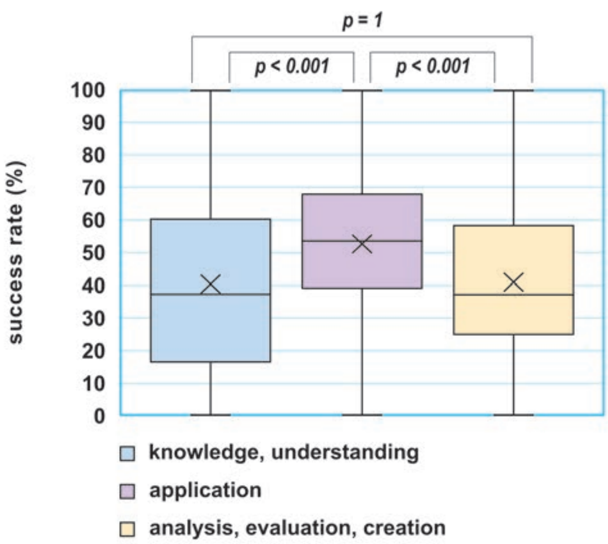

Fig. 2 Comparison of success rates between the different cognitive dimensions of the didactic test.

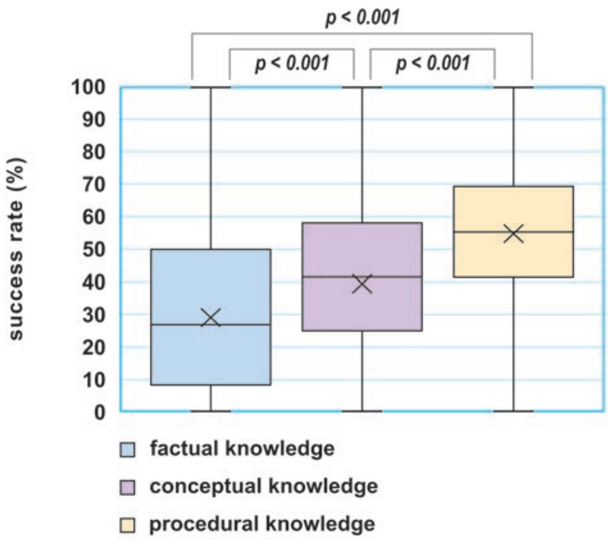

Fig. 3 Comparison of success rates between different types of knowledge in the didactic test.

between the two types of tasks is statistically significant (two-sample t-test; $p < 0.01$; $d = 0.73$). This may be beneficial for future studies, as the results show that students have demonstrated an understanding of fundamental cartographic procedures and conventions. The result is of medium significance and has the highest impact on task success compared to the other factors.

In terms of the *knowledge dimension* (Fig. 3), students achieve the highest success rate in procedural knowledge (55%), and the lowest success rate in factual knowledge (29%). The differences in success rates for tasks requiring different types of knowledge are statistically significant (analysis of variance; $p < 0.01$; $\eta = 0.189$). The effect size indicates that the knowledge dimension of the task has a considerable impact on the success rate, affecting the result by almost 20%. Bonferroni's post hoc test showed a statistically significant difference between all dimensions (in all cases $p < 0.01$). This may be due to the prevailing teaching methods, which place a significant emphasis on procedural knowledge (i.e., the procedures for creating maps and their component parts). This is evidenced by the fact that students are able to infer conceptual knowledge during the tests. In contrast, students demonstrate low levels of factual knowledge, struggling to derive independently, with effective memorization and repetition of learning required for its reproduction.

6.3 Students' results in the cartographic aspects of the tasks and the oral examination

The results of the descriptive statistics (Fig. 4) show that students achieve the highest success in map composition (Category III) and the lowest success in Category X (other topics of cartography – see Part 2) and to a lesser extent in statistics (Category IX), which is a specific category and has a higher degree of variability (see below). This is consistent to a certain extent with the results of the previous analysis, in which the problematic tasks were those in which students were required to solve mathematical operations. A greater variability in the results was evident in the categories focusing on map lettering (Category IV) and topographic cartography (Category VII). Conversely, a low variability of results was observed for cartographic semiology and linguistics (Category V) and thematic cartography (Category I). These findings may be caused by the form in which the information is presented; much of the information that students find difficult is presented in lectures (frontally, without practical application), while much of the knowledge and skills students find easier are discussed in seminars with practical applications (e.g., creating the maps, among others).

The differences in success rates observed between the various cartographic aspects are statistically significant (analysis of variance; $p < 0.01$), indicating that students achieve significantly different results in the different categories. Bonferroni's post hoc showed that there is a statistically significant difference ($p < 0.05$) between the success of most cartographic aspects.

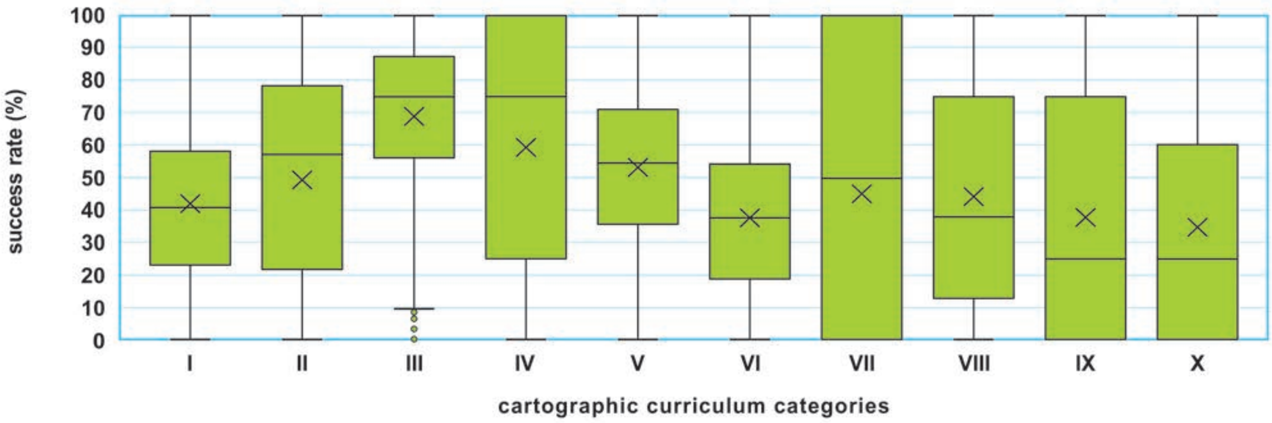

Fig. 4 Success rate by individual cartographic aspects of the tasks.

Tab. 3 Pearson correlation coefficients between individual cartographic aspects of the tasks.

	I	II	III	IV	V	VI	VII	VIII	IX	X
I	×	0.22	0.08	0.05	0.25	0.15	0.05	0.08	0.36	0.12
II		×	0.14	0.09	0.21	0.15	0.00	0.05	0.24	0.12
III			×	0.29	0.42	0.15	0.07	0.11	0.11	0.16
IV				×	0.30	0.06	0.09	0.16	0.03	0.18
V					×	0.26	0.21	0.25	0.23	0.35
VI						×	0.13	0.16	0.11	0.34
VII							×	0.92	−0.04	0.19
VIII								×	−0.02	0.24
IX									×	0.11
X										×

Notes: $p < 0.05$ shown in red.

If we select exemplary examples of cartographic aspects between which no statistically significant difference was identified, it is Category I – thematic cartography aspect with Category VII – topographic cartography aspect ($p = 1$) and Category VIII – hypsography aspect ($p = 1$). Furthermore, there are thematically and competently similar thematic categories, namely Category IX – statistical data processing and Category VI – mathematical foundations of maps ($p = 1$) or Categories VII–VIII – topographic cartography and hypsography ($p = 1$), in which it is necessary to demonstrate logical reasoning and more complex mathematical calculations. There was also no statistically significant difference between Category II – map scale and Category V – cartographic semiology ($p = 0.1$).

Tab. 3 demonstrates this association between the different cartographic aspects of the tasks. Categories VII (topographic cartography aspect) and VIII (hypsography aspect) demonstrate a highly significant correlation, indicating their close interconnection. Moreover, higher correlations are evident in those aspects that are practiced in the seminars, specifically Categories III, IV and V (map composition and compositional elements, map lettering, and cartographic semiology and linguistics, respectively). In general, the statistical data processing aspect (Category IX) shows a comparatively weaker correlation with other aspects, likely due to its specific knowledge and skill requirements.

A statistical analysis of the average success rate of students divided according to the individual disciplines (see Part 6.1) reveals relatively minor differences in the cartographic aspects of the tasks. Students of biology and science have a higher success rate than those studying physical education. In Categories VII and VIII (topographic cartography including planimetric and hypsography components), biology students have the highest success rates, while students of other science disciplines have the greatest difficulties with these categories. In contrast, science students have the highest success rates in Categories II and III (map scale calculation and map composition including compositional elements). Applied geoinformatics students have the highest success rates in Category VI (mathematical principles of maps). Category V (cartographic semiology and linguistics) exhibits minimal variability in success rates across disciplines. This may be because the subject matter is largely specific and novel to the majority of students.

The results of the oral and written parts of the exam in the records containing information from the oral examination (over 330 records) are correlated, and the correlation is statistically significant (rank correlation coefficient; $r = -0.55$, $p = < 0.01$). In the context of the oral examination, the procedure for selecting thematic areas for students is structured so that they must choose three topics guaranteed by random selection of numbers. They are permitted to answer only two of their own choice. Although a detailed analysis of the results is not possible due to the aforementioned reasons (see Part 4), it is at least possible to observe the frequency of popular or unpopular topics in cartography. It can be hypothesized that preference or dislike is primarily influenced by the subjective perception of difficulty, specifically in identifying critical aspects within the cartography curriculum.

The frequency analysis revealed the most commonly answered and eliminated topics. This analysis demonstrates that the aforementioned categories of cartographic curriculum do not, in themselves, play a significant role in the formation of positive or negative attitudes. Rather, it is the forms of transfer of the individual content that are of greater importance. While the topics practiced in the seminars and individual exercises (e.g. map symbols, thematic maps and thematic mapping techniques, placement of lettering) were favored by the students, the fact-based topics (history of cartography, state and military maps) were not as popular. Students tend to favor relatively simple definitions (cartography, cartographic product, plan, etc.), yet their explanations often lead to numerous errors.

In certain categories of cartographic curricula (e.g. mathematical cartography), contradictions can be identified (cf. relatively popular reference surfaces vs. unpopular coordinate system conversions). This may be due to the presence of different forms of spatial imagination and visualization possibilities. In general, topics in which the student can apply certain easier forms of visualization (e.g. cartographic generalization methods, placement of lettering, map symbols) are preferred.

Finally, students tend to avoid topics with a greater degree of uncertainty resulting from the on-site assignment (selection of the method of thematic cartography according to the given topic, choice of cartographic projection for the given territory) or the need to follow current trends (private production, work on the map including data acquisition and distribution of cartographic products). An exception to this is the evaluation of the cartographic product given during the oral exam, which appears to reflect the experience of the activity that students attempt during the seminars.

7. Discussion

The analysis of the students' scores on both the didactic and cartographic aspects of the written test tasks indicates that their performance is significantly influenced by the curriculum content covered in seminars, practical activities and through frontal teaching – lecture or open discussions during lectures. The analysis of the most/least favorite topics during the oral examination showed similar results. Therefore, the overall results cannot be solely attributed to specific categories of the cartographic curriculum. Identifying critical issues is more complex and likely depends significantly on the teaching approach, including the distribution and content of lectures and seminars.

In terms of the didactic aspects, the statistical analysis revealed a *hierarchy of influences on student performance*. The incorporation of visuals in the test tasks has a relatively low impact on students' success, but simple visualization techniques can motivate students in oral examinations to select a particular topic over others that are more challenging to visualize. As the long-term experience of the examiner shows, students prefer during the oral examination precisely those questions where it is possible to apply visualization or where visuals are present.

The presence of more complex mathematical operations has a slightly greater impact on students' success rate. Finally, varying levels of cognitive complexity and different dimensions of knowledge (factual vs. procedural) have the greatest impact on success rates. From the analysis, it can be concluded that students are prepared for the application of knowledge and procedural knowledge, meaning that they have developed adequate cartographic skills. Conversely, students often lack sufficient development in fact-based information, leading to gaps in their performance on the final test. University curricula are heavily fact-based, and mastering this information requires time, ongoing repetition, and consistent effort. When procedural knowledge involves mathematical competence, students are more likely to fail compared to tasks that do not require the application of more complex mathematical operations.

In considering the role of cartography in the curricula of the Jan Evangelista Purkyně University in Ústí nad Labem as an auxiliary or complementary discipline, the results of this study can be viewed positively. It is crucial for students to master the fundamental practical procedures of map creation and understand the associated concepts and conventions, such as creating diagram scales within diagram maps, determining intervals for dataset values, and designing a graphical scale. Graduates can acquire this factual knowledge, including terminology, through the repetitive process of map production and further professional communication practice.

7.1 Limitations of the study

The present study has a number of limitations that could have affected its results. Limits can be divided from the point of view of the actors of the educational process into limits on the side of students (e.g. the predominant type of study, anxiety about a written test or, conversely, of exams, dropping out of studies and entering another field) and limits on the side of teachers (staffing of exercises, representation of teaching methods, changes in the assignment and scoring of tasks). Furthermore, limits related to changes in the organization of the course can be reflected in the results (changes in the content concept of the test – Tab. 2, partial changes to the curriculum in response to changes in study plans and current trends in the field). Nevertheless, we believe that the presented study tried to present maximally comparable data and results based on them.

8. Conclusion

The summative evaluation of student achievement in cartographic education represents a key feedback tool not only for cartography educators but also for all cartographers in general. As shown in this study, such evaluations have the long-term potential to identify a number of critical issues within the curriculum of a given subject (discipline). Addressing these issues can lead to enhanced teaching quality, with the aim of eliminating these weaknesses over time. The case study revealed that students encounter difficulties with tasks requiring factual knowledge, complex mathematical operations, statistics, or other topics in cartography, such as the history of the discipline.

Conversely, students had fewer difficulties with aspects of the curriculum that were covered extensively during the seminars, due to the course design and the summative assessment. This is valuable information to a certain extent, as it shows that content taught more practically can eliminate critical issues in the cartography curriculum. However, it is interesting to note that the variations between study programs (in terms of students' disciplinary differences) are not significant, underscoring that the teaching approach is likely a key factor in the final testing.

Nevertheless, the following suggestions or modifications are proposed regarding the teaching of cartography at this institution:

a) place even more emphasis on the mathematical background of operations. Reinforce the practice of mathematical operations when a separate course is not available and encourage more collaboration between teachers of courses in which these competencies are promoted (e.g. applying statistical methods to real data, which are then used in GIS teaching);
b) incorporate fact-based tests into the exercises during the semester to help students learn factual knowledge gradually and continuously;
c) consider including a glossary of key terms or linking seminar activities more closely to existing didactic tools, such as textbooks, which frequently emphasize these terms.

However, within diversely designed study plans featuring distinct graduate profiles, expectations and needs may vary, necessitating a detailed analysis specific to each university.

This paper contributes to the ongoing discussion among cartography educators regarding how teaching strategies can be applied across various study programs and graduate profiles. Future research should explore similar analyses of summative assessments at other universities to compare whether critical issues vary significantly across different disciplines and universities.

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