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The effectiveness of teaching methods for preparing teacher education students to teach road safety-related content

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Introduction: Road traffic accidents account for numerous fatalities worldwide, disproportionately affecting vulnerable groups such as children. To counteract this trend, innovative educational approaches are essential, integrating road safety into school curricula. This study presents a novel teaching model for student teachers specializing in traffic physics. The model employs a holistic and interdisciplinary approach to foster safety awareness during teacher training and to prevent accidents effectively.

Methods: The teaching approach combines theoretical concepts of traffic physics with real-world applications. Schools serve as testing grounds where prospective teachers conduct traffic analyses, identify hazardous zones, and examine physical laws such as traffic density and speed patterns, alongside psychological aspects like behavioral deviations. Qualitative methods, including design thinking and interviews with road users, promote empathy and provide deeper insights into the challenges of road safety. Prototypes, such as optimized traffic signs and technology-driven safety solutions, illustrate practical applications and solutions.

Results: The active involvement of students in analyzing and resolving traffic issues enhanced their understanding of physical principles. The combination of theory and practice improved hazard perception, risk assessment, and empathy toward road users. The developed prototypes translated learning objectives into actionable safety measures and demonstrated potential for scalable applications. An evaluation tool ensured the objective assessment of learning outcomes, incorporating pedagogical principles and subject-specific standards.

Discussion: The findings emphasize the importance of integrating traffic physics into school education. This context-oriented approach connects learning with students' everyday experiences, fostering cognitive, emotional, and behavioral dimensions of road safety. By involving prospective teachers, the program not only enhances their individual competencies but also contributes to a broader societal impact, improving road safety education. This study outlines an innovative framework for teaching traffic physics that integrates theoretical knowledge with practical application to promote road safety. The model provides a replicable and scalable solution for embedding safety education into school curricula, addressing a critical public health issue effectively.

KEYWORDS

road safety, physics lessons, youth risk in road traffic, design based research, teacher training program, safety behavior

1 Introduction

The global #3500LIVES campaign of the Fédération Internationale de l'Automobile (FIA) is an initiative to improve road safety and reduce the number of road fatalities. The name of the campaign, "#3500LIVES," refers to the fact that around 3,500 people are killed on the roads worldwide every day (ADAC, 2020). The campaign promotes several simple but effective safety measures, such as wearing seatbelts, obeying speed limits, avoiding distractions from cell phones and from driving under the influence of alcohol, and aims to raise awareness of the high fatality rates on the roads and make the public aware of the importance of road safety. Through posters, social media and other means of communication, the safety messages are spread worldwide to reach a wide audience. One of the central themes of the #3500LIVES campaign is the safety of children on their way to school. Children are among the most vulnerable target groups in road traffic worldwide, including in Germany. Their vulnerability results from a combination of factors such as a smaller body size, a limited ability to perceive and assess danger and a lack of experience in road traffic.

In Germany, this problem is being addressed by various national and local initiatives aimed at making the way to school safer for children.

The way to school represents a major potential danger for students, but also for other road users. Children in particular face a variety of challenges in road traffic. Due to their smaller height, it is difficult for them to observe traffic situations clearly. In addition, in the event of a collision, they are hit in particularly sensitive areas of the body such as the head and the torso, which significantly increases their risk of injury compared to adults. Data from the Federal Ministry for Digital and Transport shows that a total of 25,806 children were involved in road traffic accidents in Germany in 2022. Of these, a total of 51 children were fatally injured, 21 of these children were pedestrians and six were cyclists (BMDV, 2023)[1].

It is therefore no coincidence that the task of traffic and mobility education at school is to impart knowledge and promote the skills and attitudes required for responsible participation in road traffic.

There are different approaches to teaching these necessary skills. Organizations such as ADAC and road safety associations offer a wide range of thematic support with corresponding school programs.

One possibility that has received little attention to date is the inclusion of physics lessons.

In fact, the relevance of physics manifests itself directly in the students' lives, yet the school subject of physics has a comparatively low preference among learners (Muckenfuß, 1995, p. 77). It is an obvious assumption that physics lessons are considered so unpopular because there is little overlap between their content and the students' personal interests. It is therefore essential to take measures to optimize the status of physics teaching in school education (Muckenfuß, 1995, p. 20–22).

Physics acts as a fundamental explanatory discipline for phenomena that every individual encounters in their everyday life. Accordingly, topics that are directly linked to students' everyday lives should be examined in class in order to familiarize them with the underlying physical concepts. The aim is to increase the motivation and interest of learners in physics lessons through a strong connection to their own lives. This approach includes context-oriented teaching, which embraces topics from the students' immediate environment and experiences. For context-oriented teaching to work, authentic contexts, a comprehensive learning environment and, above all, the subject framework should be considered (Nawrath, 2010, p. 19).

The following four factors are the best way to predict a student's individual interest in physics:

- The extent of the fascination with technical and natural phenomena.
- Self-confidence in their own performance.
- The subjectively perceived personal importance.
- The perception of the relevance of the subject for their own life (Häußler et al., 1998, p. 125).

This means that if a student agrees with the questions that characterize these factors, then there is a high probability that he or she is also interested in physics topics. Remarkably, gender is not explicitly mentioned among the factors describing interest in physics. The existing gender-specific differences are apparently already adequately described by the four factors mentioned. In other words, individual interest in physics is causally influenced by fascination with technical or natural phenomena, self-confidence in one's own abilities, perceived personal importance and the perception of the relevance of the subject for one's own life, regardless of gender (Häußler et al., 1998, p. 125).

The findings presented here are of particular interest as they can serve as a basis for the development of strategies for optimally adapting the content of traffic physics and traffic accident prevention lessons to the interests of the students. Selecting topics from the field of traffic physics, traffic accidents and accident prevention, ensures that the subject matter will be appealing to the students. This underlines the relevance of focusing more on everyday topics in physics lessons that deal with the phenomenon of mobility and human behavior in connection with traffic situations. The University of Cologne has developed a teaching module to integrate these topics into physics lessons in an appealing and age-appropriate way and to effectively convey safety-related messages. This module is part of the future-oriented training of prospective teachers and prepares them specifically for the implementation of this task. This article presents this teaching module "Traffic Physics", its approach and objectives. In this context, grading criteria have been developed so that teachers can also assess students for this part of their school education in the future, analogous to the other curricular topics of physics teaching, in order to achieve the educational goal.

The authors assume that the proposed concept offers innovative didactic approaches for educators by not only integrating traditional road safety programs but also incorporating novel methods to promote self-reflection and to embed road safety content early in the school curriculum. This combination enables educators to prepare young people for the challenges of road traffic in a holistic manner by addressing both cognitive and behavioral aspects of road safety. The concept aims to enhance students' self-efficacy and to foster sustainable behavioral change that goes beyond mere knowledge acquisition.

1 https://www.destatis.de/DE/Presse/Pressemitteilungen/Zahl-der-Woche/2023/PD23_33_p002.html

2 Theoretical framework

2.1 General framework conditions

Teaching specifications are an essential element of a modern, comprehensive overall concept for developing and ensuring the quality of schoolwork. Studies show that the evaluation of road safety education courses aimed at children is carried out with some care. However, this is not the case for courses aimed at young people and therefore young drivers (Faus et al., 2023). Moreover, of the few evaluations that have been carried out, most relate to prevention programs for children. However, there is insufficient data available on prevention programs for adolescents and adults (Alonso et al., 2016).

In North Rhine-Westphalia, the curricula for elementary school as well as the specifications for special educational support, including differentiated courses for learning and intellectual development, targeted courses and German sign language, as well as core curricula for lower secondary level, upper secondary level and further education colleges are specified. These guidelines are supplemented by additional and supporting information and materials for classroom implementation (https://www.schulentwicklung.nrw.de/lehrplaene/).

Among children between the ages of 6 and 15 years, error behavior is the most common cause of the traffic accidents cited. Young pedestrians most frequently make mistakes while crossing the road, either by not paying attention to vehicle traffic (53.2%) or by suddenly stepping out from behind visual barriers (31.4%). The most common causes of accidents among young cyclists are incorrect road use (17.9%) and errors while turning, reversing and starting (16.4%) (Federal Statistical Office, 2022).

In order to counteract children's misconduct in road traffic and reduce the number of traffic accidents, the North Rhine-Westphalia Conference of Education Ministers adopted a recommendation on mobility and road safety education in schools in 2012. This topic has been embedded in the curriculum under the area of mobility focusing on safe ways to school and road safety. The aim is for students to have acquired the necessary skills at the end of primary school to behave in accordance with standards and rules in road traffic by being able to apply the traffic rules when walking and cycling.

Young drivers are also a high-risk group in road traffic, as they are involved in accidents more frequently than other age groups. In 2022, 363 young people between the ages of 15 and 24 were killed in road accidents. The main reasons for this are a lack of driving experience (novice driver risk) on the one hand and frequently observed risk-taking behavior (youthfulness risk) on the other. Males in this age group in particular exhibit more risky driving behavior (Federal Statistical Office Destatis, 2023, GENESIS 46241-0007).

Therefore, the overarching educational task of schools serves to promote independent mobility and responsible participation in road traffic among students of all age groups. Road safety education is seen not only as a school responsibility, but also as a societal on, involving cooperation between the police, parents, traffic safety organizations, and other extracurricular parties.

In this context, physics experiments and practical applications can also play an important role in the context of traffic education in order to sensitize students to the physical principles of traffic and deepen their understanding thereof.

The curricular approach is based on the role of students as road users and develops a spiral curriculum for children, teenagers and young adults. Additionally, this curriculum may integrate physical concepts and principles of traffic alongside the conventional content of traffic education in order to promote a holistic understanding of the topic and prepare students for their role in traffic.

This concept can be successfully implemented only if qualified teachers are trained at universities. Therefore, the training of these teachers should include a sound understanding of the physical principles of traffic as well as pedagogical and psychological skills in the field of mobility and traffic education. This will enable them to support students effectively and guide them competently in both the physical and traffic education aspects of the curriculum.

2.2 The interaction between road traffic and physics

Physics plays an essential role in road traffic as it explains the fundamental principles and phenomena that influence the behavior of vehicles and road users. Some of the most important physical concepts in road traffic are:

- **Motion and speed:** Physical laws such as Newton's laws (laws of inertia) describe how vehicles move on the road, how they accelerate and brake and how their speed changes (https://www.leifiphysik.de).
- **Forces and force balance:** The forces acting on a vehicle - such as friction, inertial forces and air resistance - influence its movement and behavior on the road (https://www.tis-gdv.de).
- **Momentum and energy:** Physical principles such as conservation of momentum and conservation of energy explain the effects of collisions between vehicles or between vehicles and obstacles and how much energy is transferred (Schadschneider, 2004).
- **Reaction and braking distance:** The laws of physics also determine the braking distance and reaction time of vehicles, which is crucial for road safety (https://www.leifiphysik.de).
- **Optics and visibility:** Optical phenomena such as light refraction and reflection play a role in the design of traffic signs, road markings and lighting, which influence visibility and safety on the road (Bammel, 2007).

Therefore, an understanding of physics is of great importance for the safe and efficient design of educational lessons for safe road traffic methods as well as for road safety education and awareness.

2.3 The interaction between road traffic and traffic psychology

The interaction between road traffic and traffic psychology is of central importance for safety and efficiency in road traffic. Traffic psychology examines the psychological processes and behaviors of road users that significantly influence accident risk and road safety.

An essential aspect of traffic psychology is the analysis of driving behavior. This includes, for example, the examination of reaction times, perception, neurobiological decision-making processes and the ability to act in stressful situations. These factors are crucial for recognizing potential dangers at an early stage and reacting appropriately.

Particular attention should be given to young drivers, who represent a high-risk group due to their lack of driving experience and frequent risk-taking behavior (Underwood, 2005, p. 129 ff.).

Young drivers, particularly those aged 16 to 24, are among the high-risk groups in road traffic. Studies show that they are significantly more likely to be involved in traffic accidents compared to older, more experienced drivers. The first 6 months after obtaining a driver's license are especially critical, as accident rates are at their highest during this period. Inexperienced drivers tend to engage in risky behaviors such as speeding, using mobile phones while driving, and being distracted by passengers during this time (McKnight and McKnight, 2003; Simons-Morton et al., 2017).

Another significant factor is the social influence of peers. Young drivers are often influenced by their passengers to engage in riskier driving behaviors, which further increases the likelihood of accidents. The presence of peers in the vehicle has a proven negative impact on driving behavior, as documented in numerous studies (Curry et al., 2017; Simons-Morton et al., 2017).

Moreover, many young drivers are not adequately prepared for complex traffic situations in the 1st months of driving independently. While supervised driving is generally safe, there is a high variability in the development of safe driving practices once drivers are on their own. This makes young drivers particularly vulnerable to accidents, especially when faced with challenging driving situations (Simons-Morton et al., 2017).

These findings highlight the need for targeted prevention measures, such as better preparation for complex driving scenarios and specialized programs to promote road safety among young drivers.

Traffic psychology offers important findings for the development and implementation of measures to reduce these accident risks. These include, for example, education and prevention programs, the promotion of defensive driving strategies and the integration of psychological findings into the design of traffic engineering measures. By closely linking psychological findings with traffic policy measures, road safety can be permanently improved.

2.4 Educational approaches to promoting road safety

From an educational perspective, road safety programs can be significantly enhanced by encouraging self-reflection among young drivers and by integrating such programs early into the school curriculum. Self-reflection plays a key role in developing safety-conscious behavior, as it helps young drivers critically assess their own actions and learn from them. Studies have shown that reflective processes can increase risk awareness and personal responsibility, which in turn can lead to a long-term reduction in accident risks (Zimmerman, 2002). Through targeted tasks and discussions that stimulate self-reflection, young drivers can become more aware of their attitudes and behaviors on the road and positively change them.

Moreover, the integration of road safety programs into the school curriculum offers a valuable opportunity to promote road safety awareness at an early stage. Schools provide an ideal platform to not only impart theoretical knowledge about road safety but also to develop practical skills that prepare young people for the challenges of driving. Research shows that early educational interventions, when consistently embedded in the school context, can lead to sustainable behavioral changes (Hattie, 2009). Such programs could cover topics such as risk behavior, safety strategies, and the psychological aspects of driving, thereby offering a comprehensive preparation for road traffic.

2.5 The importance of the authenticity of the topic

The education of future teachers aims at adapting the school curriculum to the needs and interests of the students. In this context, physics lessons have already been extensively studied, as explained above. Here in particular, it has been shown that the subject is often unpopular with students and is perceived as difficult (Merzyn, 2010, p. 9–12). This could be due to the fact that the lessons focus heavily on abstract mathematical aspects, as Merzyn explains. However, it turns out that students are much more interested in practical applications of physics than in purely theoretical aspects.

These findings underline the importance of experiments and practice-based approaches in teacher education. By integrating authentic tasks and a context-based research approach, teacher education students can learn how to make physics lessons clear and motivating. This not only promotes students' understanding, but also increases their motivation to actively participate in class (Redish, 2004).

The training of prospective teachers should therefore increasingly focus on providing them with the pedagogical skills and methodological know-how to make physics lessons practical and student-oriented. This includes the ability to plan and conduct experimental teaching units and to address the individual needs and interests of students. Such training can enable teacher education students to make physics lessons more engaging and accessible and thus improve the quality of teaching. The importance of authentic tasks is also widely documented. They can be used to support learning itself (Anderson, 1998) or to help students gain a better scientific understanding (Chang, 2005). Authentic tasks also increase students' motivation to actively participate in physics lessons (Kuhn, 2010).

Interventions, which in this case are intended to lead to more safety behavior among students, are generally only carried out if they are perceived as relevant and convincing for the target group.

As teachers, it is therefore crucial to design interventions that directly relate to the students' real environment and can therefore serve as a basis for context-oriented teahcing. In physics lessons in particular, but also in general school lessons, more effective teaching strategies can be used to convince students of the importance and relevance of physics concepts.

The Aristotelian model offers a promising approach to teaching science. Since scientific reasoning is usually rationally motivated and logically structured, we as teachers can convince students by communicating these concepts clearly and precisely.

Weinert (2001) defines competencies as "the cognitive abilities and skills available to or learned by individuals in order to solve certain problems, as well as the associated motivational, volitional and social readiness and abilities to successfully and responsibly use these solutions in variable situations" (p. 27 f.). This understanding of competencies can be translated into a comprehensive teaching model that emphasizes the following aspects:

- **Knowledge (cognitive skills)**: The necessary theoretical understanding and information required to solve a problem.
- **Skills (practical abilities)**: The ability to practically apply the acquired knowledge and implement it in an action-oriented manner.
- **Values and attitudes (motivational, volitional and social dispositions)**: The attitudes and values that guide and influence actions.

This triad of "head, heart and hand" emphasizes that effective problem solving is characterized by cognitive processes as well as practical and emotional aspects. These elements are central to the debate around the concept of competence, as they reflect the holistic nature of competencies. People use their knowledge to purposefully shape actions which are in turn shaped by their values and attitudes—the latter acting as the "grammar" of behavior.

The implementation of this teaching model ensures that students not only acquire theoretical knowledge but are also able to apply this knowledge in practice and act responsibly through their values and attitudes.

At the University of Cologne, the "Traffic Physics" module was developed to specifically prepare prospective teachers for the challenges of traffic education. This module provides teacher education students with a solid understanding of the physical principles of traffic, the pedagogical and psychological backgrounds of traffic safety, and enables them to apply this knowledge in a clear and practical way in the classroom. The university course "Traffic Physics" aims to provide teacher education students of all school forms with practical experience in the field of context-oriented teaching. It offers a balanced composition of physical, pedagogical-didactic, and traffic psychological content, as well as practical experience in creating context-oriented tasks. Thus, the module makes an important contribution to the qualification of future teachers in the field of traffic education.

2.6 The curricular structure of the "Transport Physics" module

The "Traffic Physics" module is divided into five process phases based on the design thinking process, which outline the areas of problem understanding, problem solving and personal growth:

The first part is a classic lecture that provides an instructive introduction to various areas of traffic physics and mobility in childhood and adolescence (Limbourg et al., 2000). This instruction is carried out by the lecturers in specific sub-areas. The aim is for students to build up their theoretical knowledge of the causes of accidents and, by learning about the physical aspects of road traffic, to enable them to argue on a factual level.

The second part of the course takes on the characteristics of a seminar. Here, the students are presented with various accident black spots in the traffic space, which they are asked to examine on the basis of the aspects developed in the first part. The students are divided into small groups and document one accident black spot each. They receive support from road safety advisors from the police, or alternatively from members of the local traffic authority or members of the local public transport authority or other experts.

The groups then present their respective black spots and discuss why there are accident hazards at these locations and what measures can be taken to prevent accidents (Weber and Bresges, 2013a,b).

In the third part of the curriculum, students use the "Interview for Empathy" research approach to survey the problematic space of the school commute. They conduct interviews with various target groups in order to develop an in-depth understanding of the challenges and needs associated with walking to school. This method ensures that the best possible and repeatedly optimized innovative result is achieved (Grots and Pratschke, 2009). The students use these interviews to empathically put themselves in the position of those affected and to record the diverse aspects of the school commute.

First, potential danger spots in the immediate vicinity of the school, usually intersections, are analyzed using primarily qualitative observations. With this survey method, it must be considered that observations are only temporary and selective excerpts from reality and that subsequently only the traffic situation perceptible at that time can be recorded (Kochinka, 2010, p. 449–461). This means that the traffic situations observed during the interviews can only reflect a limited period of time and only certain aspects of the traffic space. For the transfer to general practice, this means that the findings and insights gained from the interviews should not be regarded as comprehensive or all-encompassing. Rather, they should be seen as a snapshot that makes it possible to identify specific challenges and needs in connection with walking to school.

In the fourth part of the course, the solutions developed are implemented in a prototyping process. Here, the ideas developed in the design thinking process are put into practice. Students are encouraged to transform their concepts into concrete models or designs in order to test their feasibility and effectiveness. This step gives students the opportunity to test their ideas in practice and identify potential weaknesses or opportunities for improvement at an early stage.

In the fifth part of the course, the iterative loop of evaluation follows, during which the students present their prototypes to the target group in order to obtain feedback. Here, the students have the opportunity to present their architectural models or designs of the road safety solutions to the real audience of the previously

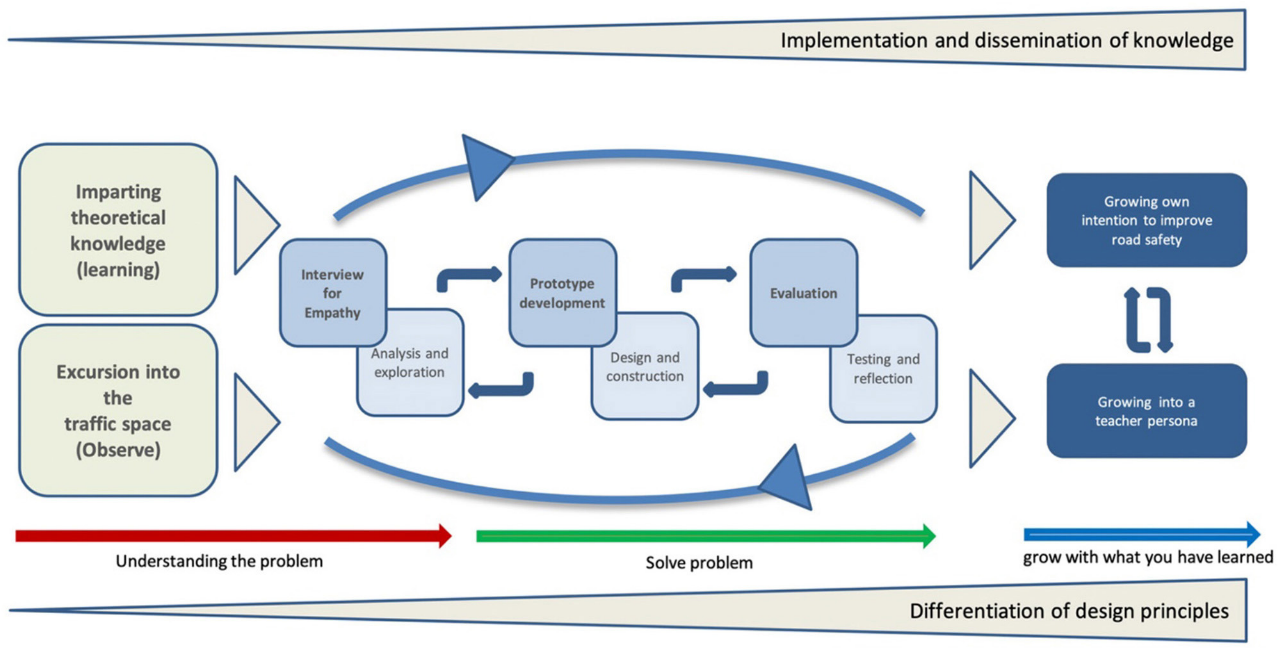

FIGURE 1
Contents and objectives of the "Transport Physics" module (source: own illustration).

interviewed target group, which represents the potential users. Through this presentation, students can receive valuable feedback that helps them to further improve and optimize their solutions. This iterative process allows students to adapt and refine their ideas based on feedback from the target audience to ultimately develop effective and practical road safety solutions.

Figure 1 shows an overview of the curricular module.

The knowledge acquired in the traffic physics module and the application of the design thinking process not only impact the professional know-how of the prospective teacher, but also shape their teaching personality in a variety of ways. Through a deeper understanding of traffic physics and the knowledge acquired in the field of road safety education, students develop an increased awareness of safety aspects in road traffic, which is reflected in their pedagogical actions.

In addition, the application of the design thinking process promotes the creativity, problem-solving and empathic skills of the prospective teacher. They learn to develop innovative solutions, analyze complex problems and respond to the needs of their students. This helps them to be flexible and resourceful as teachers and to be able to adapt lessons to the individual learning needs of their students.

Overall, the acquisition of knowledge in the traffic physics module and the application of the design thinking process means that the prospective teachers not only become more technically competent, but also develop their pedagogical skills and their personality as teachers. They become reflective and committed teachers who are able to motivate, support and inspire their students to develop safe and responsible behavior in road traffic (Reinmann, 2005, p. 52–69).

Therefore, the following research questions are addressed in this research paper:

Q1: How does the integration of the traffic physics module into teacher education influence the behavior and personal attitudes of prospective teachers with regard to road traffic?

Q2: Can criteria be detected that make the design thinking approach practicable in an end of module assessment in the "Traffic Physics" module?

Q3: Was it possible to develop grading criteria for the evaluation of end of module assessments in traffic space analysis in the module "Traffic Physics"?

3 Methodology

3.1 General framework conditions

The "Traffic Physics" module is offered annually in the summer semester at the Faculty of Mathematics and Natural Sciences at the University of Cologne, specifically at the Institute of Physics Education. It is aimed at teacher education students and offers both theory-based and practice-oriented training. The module can be completed with an end of module assessment. The number of participants is typically between 30 and 45.

The data collection for the present study spanned the years 2022 to 2024. In 2022, questions from Spicher and Hänsgen (2003)'s "Test for assessing traffic-relevant personality traits" (commonly abridged as TVP in German) were collected and compared using a pre- and post-test procedure at the beginning and end of the

TABLE 1 Overview pretest $N = 42$ (source: own presentation).

I am		
Answer	Quantity	Percentage
Female (F)	28	66.67%
Male (M)	13	30.95%
No answer	0	0.00%
Not finished or not shown	0	2.38%

TABLE 2 Overview posttest $N = 30$ (source: own presentation).

I am		
Answer	Quantity	Percentage
Female (F)	18	60.00%
Male (M)	9	30.00%
No answer	3	10.00%
Not finished or not shown	0	0.00%

module. The aim of this approach was to investigate changes in individual traffic behavior.

In 2023, a structured process was developed for the curriculum to determine the necessary criteria for an end of module assessment, which was based on existing and recurring criteria. Students checked the end of module assessments from the previous year to see whether these specified criteria could be found. This procedure was intended to check the feasibility of deriving grading criteria and their practicability for untrained prospective teachers and to identify potential difficulties in setting tasks or objectives.

In 2024, the grading criteria derived from these results were subjected to a final review by fully trained teachers.

The research methods are presented in the following chapters.

3.2 Analysis of the effects of the "Traffic Physics" module on individual norms, values and attitudes in road traffic

In order to evaluate the effectiveness of this module, various aspects of participants' individual norms, values and attitudes, as well as sanctions issued by road traffic monitoring authorities, were examined before and after completion of the module. This study aimed to gain insights into whether educational measures in the field of traffic physics can influence students' traffic behavior and attitudes. The results obtained indicate that the traffic physics education measures provided here had no significant influence on individual norms, values and attitudes in road traffic.

The participants in the pre-test were distributed as in Table 1.

The participants in the post-test were distributed as in Table 2.

The TVP is suitable for various areas of application, including the prediction of conspicuous traffic behavior. It is mainly used as a screening instrument. The instrument is based on the "Big Five" personality model and measures the dimensions of extraversion, emotional stability, conscientiousness, openness to experience, and agreeableness. In addition, the dimensions of trivialization and reactance, which were extracted for this study, are also measured. The modular structure allows the use of individual modules. A special feature of the test is the parallel recording of the main dimensions both across situations and traffic-specific, which results in a characteristic "double profile." This means that results can also be evaluated in the event of trivialization tendencies (Spicher and Hänsgen, 2003).

The test comprised two main categories. The first category (A1) recorded attitudes regarding behavior in road traffic. The second category (A2) examined whether there had already been sanctions imposed by the monitoring authorities in their personal history due to faulty behavior. The comparative analysis of categories A1 and A2 at the beginning and end of the curriculum aimed to determine whether the curriculum had a changing influence on traffic behavior.

The questions in category A1 examined the following characteristics of personal attitudes:

[I am careful when planning and acting]

[I feel safe even in difficult traffic situations]

[I like to react to prohibitions with a "now more than ever"]

[I like to try out what my car has to offer in terms of performance]

[I would like to remain free of obligations to friends]

[Successes make me take a higher risk]

[I strive for perfection in everything I do]

[I can call up a new playlist while driving if it doesn't take too long]

[I get nervous when I realize that a police car is driving behind me]

[I have driven a car before, even though I felt too tired to do so]

[The more difficult the traffic situation is, the more I enjoy it]

[At traffic lights I try to get away first]

[It has happened that I have driven faster than permitted]

[I only get in the car with someone if I know they are a conscientious driver]

[I am worried that something terrible might happen]

[If you drive carefully, the seatbelt is not necessary]

[Basically, two or three glasses of beer don't affect men when I'm driving]

[I regret many of my driving maneuvers afterwards]

[Even when I'm stressed, I stick to the traffic rules]

[My close friends can have a glass of beer, I'll get in anyway, because I trust them]

[I don't wear my seatbelt on short journeys]

[I am in favor of introducing harsher penalties for alcohol-related offenses]

[Other drivers often drive so badly that I get annoyed]

[As a passenger, I point out speeding to the driver]

[It excites me to drive faster than others]

[When the traffic light turns yellow, I hurry to go through]

[I've typed a text message while driving before because it was important]

[I never drive faster than usual, even under time pressure]

[If I see someone trying to drive who has been drinking, I call the police]

TABLE 3 Follow-up survey on transport use, j = 15 participants.

Mode of transport	Total users	Accidents (absolute)	Accident rate (%)
On foot	7	2	28.57
By bicycle	6	3	50.00
By car	5	1	20.00
By public transport	9	2	22.22
Other (skateboard)	1	1	100.00

[I am against the state introducing new methods of road safety checks]

[I have already tapped my forehead at another road user (a gesture that implies "I think you are crazy" in Germany)]

The questions in category A2 examined whether the participants had been sanctioned as active road users in the past year:

[...I have participated in road traffic as the driver of a vehicle]

[...I have had to pay fines/warnings]

[...I caused a traffic accident]

[...I have been reported for a traffic offense]

A follow-up survey was conducted 6 months after the "Traffic Physics" module with a subset of the participants (J = 16 participants) to determine the nature of their traffic participation and existing experiences with traffic accidents. The Number J = 16 represents the number of participants that were still available for an online-survey 6 months after the intervention. They represent 47% of the test group.

For the online-survey, the cloud service "SeaTable" (https://seatable.io/) was used, which is hosted on cloud servers in Germany and is compliant with the German Data Protection Regulation DSGVO.

Participants were asked: "What is your preferred mode of transportation in road traffic?" Which intentionally excludes answers for long-range and holiday travel. The survey yielded the results in Table 3.

The following stands out:

Bicycle use and accidents: Cyclists are among the most vulnerable road users, which is reflected in their high accident rate. In our group, the accident rate is 50%, which illustrates the increased risk of accidents for cyclists and confirms national trends. According to the Federal Statistical Office, many bicycle accidents occur due to collisions with motorized vehicles or obstacles (Statistisches Bundesamt, 2024). In Cologne, too, the accident figures for cyclists remain alarmingly high with 2,231 accidents and one fatality in 2024 (Statista, 2024), which is exactly reflected in the survey of the student subgroup.

Pedestrians: Pedestrians also feature in accident statistics as a vulnerable group, particularly due to collisions with vehicles in urban environments. In our group, around 28% of pedestrians have already experienced an accident, which confirms the higher accident rates for this group in urban areas and near schools (Statistisches Bundesamt, 2024). The number of accidents involving pedestrians also increased in Cologne in 2023: In a total of 646 accidents, 86 people were seriously injured and 14 people lost their lives (Polizeiliche Verkehrsunfallstatistik Police Cologne, 2023). These significant findings are also reflected in the results of this survey.

This national and regional data supports the findings of our student group and shows similar accident patterns for cyclists and pedestrians.

The results support the need for targeted traffic education measures to further improve the safety of these groups and raise awareness of the specific risks of different modes of transport.

3.3 Analysis of the feasibility of end of module assessments using the design thinking approach in the "Traffic Physics" module

To evaluate the feasibility of the design thinking approach in teaching and to develop an end of module assessment, criteria were defined to reflect the success of the students' research project. These criteria formed a continuum between "no research conducted" and "best possible research result achieved." The continuum was formed in the context of traffic space analysis on the following topics:

- Identification of relevant traffic problems.
- Creative idea generation for solutions.
- Application of design thinking methods for problem solving.
- Development and prototyping of innovative transport concepts.
- Implementation of user tests and iterative improvements.

These criteria were used to assess students' progress and success in applying the design thinking approach to their research project.

In a retrospective analysis anonymized end of module assessments were checked for the presence of the defined criteria. The end of module assessments were evaluated by students of a subsequent curriculum. The results obtained were intended to provide information on the feasibility and usefulness of applying the design thinking approach in teaching. A higher percentage of fulfilled criteria indicates a higher feasibility.

A total of $N = 34$ participants took part in the "traffic space analysis" survey. All participants were assessed using the same end of module assessment. This procedure contributes to the scientific robustness of the study. The consistency of the assessment materials ensures that the results are not influenced by varying levels of difficulty or differences in the content of the assessment. This strengthens the validity of the results and the reliability of the conclusions drawn from them.

The first category on the continuum of each subject area corresponds to the rating "no research conducted" and represents the lowest research effort. The following categories represent a gradual increase in research effort.

The following topics were mapped as a continuum and included in the assessment:

- Introduction to the topic.
- Description of the research design and research method.
- Description of the object of research (here: traffic space).
- Observation and analysis of traffic flow.
- Connection between road traffic and human behavior.
- Design of a prototype and its evaluation.
- Final conclusion and scientific assessment of the research process.

This process served as a transition to the next analysis procedure, namely the development of grading criteria. These grading criteria should enable future teachers to grade exam papers systematically and according to fixed criteria.

3.4 Analysis of the introduction of grading criteria for the traffic space analysis curriculum

Grading criteria define clear and measurable learning objectives that students should achieve at the end of a teaching module. The current teacher trainees should be enabled to assess their future students with the help of grading criteria in the "traffic space analysis" teaching module.

The introduction of grading criteria for the road safety analysis curriculum aims to establish clear learning objectives and outcomes to help trainee teachers develop a sound understanding of road safety assessment.

The main objective of this analysis is to investigate how grading criteria for the transportation analysis curriculum can be established and effectively implemented.

The grading criteria for the traffic space analysis curriculum included the following components:

- **Knowledge:** Understand basic concepts of road safety, including risk factors and protective factors in accident prevention.
- **Skills:** Develop analytical skills in brainstorming sessions to develop innovative solutions to identified traffic problems, evaluate traffic space constellations and identify danger spots.
- **Activities:** Creating prototypes, e.g., by modeling traffic space configurations or simulations.
- **Applications:** Ability to apply theoretical knowledge in practical scenarios, e.g., by carrying out traffic space design in the school environment.
- **Reflection:** Critical reflection on one's own research approach in the context of road traffic and the development of strategies to improve personal safety.

In this study, the qualitative coding manual of the grading criteria was analyzed using MAXQDA software. This approach aims to systematically structure and interpret the complexity and diversity of the data collected. The use of MAXQDA enabled a detailed and transparent preparation of the qualitative data through structured coding, which formed the basis for the analysis. Initially, various coding options were used in a pilot test to examine the fulfillment of the defined learning objectives and evaluation criteria (Table 4).

TABLE 4 List of codes (source: MAXQDA 24®).

Code system	
General introduction to the topic	**Human behavior**
General knowledge for introduction to the topic	Conscious dysfunctional behaviors (Alcohol, Speeding)
Correlations with one's own traffic world and personal experiences	Named correlations between misconduct and accident patterns
References to the curricular traffic education measures	Named approaches to solutions
Preview of the work and the expected research	Weighed advantages and disadvantages
Description of the research design and research method	**Design of a prototype**
Research design described in its approach	Prototype designed
Instruments used were named	Target group questioned for suitability and feasibility
Named advantages and disadvantages of the method	Prototype revised based on evaluation (iteration)
Research processes of own research described	Research results summarized and fully documented
Research subject traffic area	**Final conclusion**
Location of the research with sketches and photos	Research coherently summarized
Description of the location traffic-related	Research critically evaluated
Consequences of dysfunctional constellation	Outlook on necessary steps
Dysfunctional constellations meta-, meso-, and micro-level	Formalities and literature references
Observation of traffic flow	
Examples of functional dynamics	
Consequences or correlations with accident patterns	
Several concrete situational solutions	
Perspective of multiple users	

3.4.1 List of codes (code system)

The coding options were developed comprehensively to ensure a detailed and structured analysis of the grading criteria in the end of module assessment. This nuanced approach should make it possible to specifically examine the various aspects of road safety education and traffic space analysis in order to gain well-founded insights and continuously improve the effectiveness of the curriculum.

A key aspect of qualitative research is ensuring intercoder reliability, which measures the agreement between different coders and thus checks the reliability and validity of the coding. In this context, two research assistants were used to code the data independently of each other. The intercoder reliability was then evaluated to analyze the consistency and agreement of the coding.

Again, the coders coded the same end of module assessment in order to attribute differences in coding to the raters themselves and their interpretation of the coding rules, rather than to differences in the assessment material, in addition to the reasons already mentioned above. This facilitates the analysis of intercoder reliability and the identification of areas where coding rules may need to be more clearly defined, which should be the particular focus of this research step.

In addition, this procedure enables the validation of the coding rules and methodology. By applying the same coding rules to the same material by different raters, the consistency and reliability of the coding rules can be checked. Differences in coding can be used to refine the rules and improve the training of raters.

However, unlike the previously employed students of the "Traffic Physics" module, the assistants had no prior knowledge of the module and received no technical instruction, which significantly influenced the evaluation of the results.

As a result of the pilot results, the codes were reduced to the main categories for better comprehensibility and these in turn were also simplified:

- Introduction
- Research method
- Traffic space analysis
- Behavioral analysis
- Prototype
- Conclusion

In addition, the thematic areas "traffic space" and "traffic flow" were merged into the coding area "traffic space analysis" to enable a more coherent and comprehensive analysis. Merging these two together facilitates the consideration of the dynamic interactions between the physical environment of the traffic space and the movement patterns of road users. By integrating both aspects into a single coding area, a holistic perspective is promoted that considers both static and dynamic elements, allowing for a deeper understanding of road safety and efficiency. This facilitates the coding process by minimizing the risk of misunderstandings.

4 Results

4.1 Results of the quantitative methods

4.1.1 Results of the analysis of the effects of the "Traffic Physics" module on individual norms, values and attitudes in road traffic

The following statistical analyses were carried out to compare scale A1 (attitudes and behavior) between the pretest and posttest:

A t-test for independent samples was used after the conditions of normal distribution and the absence of outliers were ensured. There was also homogeneity of variance.

The test statistic resulted in $t_{(62)} = -1.220$, $p = 0.227$.

These results show that there is no significant difference in the A1 scale between the pretest and posttest groups (Table 5).

Due to the non-significance of the difference, the effect size was not interpreted.

Table 6's statistical analyses were carried out to compare scale A2 (sanctions by supervisory authorities) between the pre-test and post-test:

Originally, a t-test for independent samples was planned. However, it was found that the normal distribution assumption was not met, based on the Kolmogorov-Smirnov test with $p < 0.001$ for both the pretest and posttest groups.

A Mann-Whitney U test was therefore carried out. This resulted in a significant deviation from an equal distribution, which means that no differences in the medians can be interpreted. The Kolmogorov-Smirnov Z-test resulted in $p = 0.004$.

The test statistic for the Mann-Whitney U test was U = 411,000, Z = −1.359, $p = 0.174$.

These results show that there is no significant difference between the pretest group and the posttest group in the A2 scale.

Q1: How does the integration of the traffic physics module into teacher education influence the behavior and personal attitudes of prospective teachers with regard to road traffic?
Answer: It can be stated that the integration of the traffic physics module into teacher education does not significantly influence either the behavior or the personal attitudes of prospective teachers with regard to road traffic.

4.1.2 Results of the analysis of the feasibility of end of module assessments using the design thinking approach in the "Traffic Physics" module

The results of the retrospective evaluation of the completed end of module assessment in terms of the performances achieved were categorized within the established criteria continua and yielded the following results:

We will now evaluate the content of the seven chapters of the student work.

Chapter: ***Introduction to the topic***

The examination papers in the "Transport Physics" module showed clear strengths in the general introduction to the topic, which underlines the students' ability to anchor fundamental concepts and important connections in their papers. Of particular note is that 90.48% of raters recognized general introductory knowledge of the topic, such as causes of accidents and relevant statistics, in the students' examination papers. This high rate shows that students were able to lay a solid foundation for their work by presenting essential information in a clear and understandable way.

In addition, 57.14% of raters identified connections between the topic of road safety and the students' own transportation world, including their personal experience as well as social and political events. This shows that a significant proportion of students were able to put theoretical knowledge into a real context and work out the relevance of the topic to their personal experience and the

TABLE 5 Test statistics for the survey of behavioral change (source: SPSS®).

Group statistics				
	Time point: pre- or post-test	N	Mean value	Std. deviation
A1: My behavior in traffic	Pre-test	30	2.0118	0.26158
	Post-test	34	0.20949	0.28031
Group statistics				
	Time point: pre- or post-test	Standard error of the mean		
A1: My behavior in traffic	Pre-test	0.04776		
	Post-test	0.04807		
Test with independent samples				
		Levene's test for equality of variances		*t*-test for equality of means
		F	Sig.	T
A1: My behavior in traffic	Variances are equal	0.011	0.918	−1.220
	Variances are not equal			−1.226
Test with independent samples				
		t-test for Equality of Means		
			Significance	
		df	One-tailed p	Two-tailed p
A1: My behavior in traffic	Variances are equal	62	0.114	0.227
	Variances are not equal	61,792	0.113	0.225

TABLE 6 Test statistics for the survey of road traffic sanctions (source: SPSS®).

Tests for normal distribution				
		Shapiro-wilk		
	Time point: pre- or post-test	Statistic	df	Significance
A2: My type of active participation and previous sanctions in traffic	Pre-test	0.863	30	0.001
	Post-test	0.871	34	<0.001
Test statistics[a]		z-Score: A2: My type of active participation and previous sanctions in traffic		
Extreme differences	Absolute	0.439		
	Positive	0.439		
	Negative	−0.094		
Kolmogorov-Smirnov-Z		1.753		
Asymp. Sig. (2-tailed)		0.004		
Test statistics[a]		z-Score: A2: My type of active participation and previous sanctions in traffic		
Mann-Whitney U Test		411.000		
Wilcoxon W		1006.000		
Z		−1.359		
Asymp. Sig. (2-tailed)		0.174		

[a]Grouping Variable: Time Point: Pre- or Post-test.

social environment. The integration of curricular measures was also rated particularly positively. 66.67% of the raters found references to traffic education measures in the school context in their work. This link shows that the students have developed an understanding of how the theoretical concepts of traffic physics can be embedded in the practice of traffic education, which is of great importance for their future role as teachers. Furthermore, 71.43% of raters saw the papers as a preview of the work and research to come. This shows that the majority of students were able to design a clear structure and logical flow for their academic work, which provides helpful guidance for readers and significantly enhances the quality of the papers.

Overall, these results underline the students' strength in the general introduction and contextualization of their topics, which provides a solid foundation for their academic work and demonstrates their ability to bring theoretical knowledge into practical contexts.

Chapter: ***Description of the research design and method***

The examination papers in the Transport Physics module showed notable strengths in various aspects of the description of the research design and the research methods used. A particularly positive aspect was the naming of the instruments used, such as interviews and written surveys, which were described as clear and precise by 90.48% of raters. This high rate shows that the students were able to clearly identify and communicate their methodological tools, which is of central importance for the traceability and replicability of their research.

In addition, 57.14% of raters rated the presentation of research procedures as detailed and comprehensible. This underlines the students' ability to clearly structure and document their methodological steps, which is essential for understanding and evaluating the scientific work. A clear presentation of the research procedures makes it possible to follow the entire research process transparently and logically.

Although 38.10% of raters rated the description of the research design as complete, this shows that a significant number of students were able to present their research design comprehensively. These students have shown that they are able to formulate their methodological approach clearly and completely, which forms the basis for a solid scientific paper.

Another important aspect is reflecting on the advantages and disadvantages of the chosen methods. Although this was only found in the work of 14.29% of raters, this shows that some students incorporated a high degree of critical reflection into their methodological discussion. This ability to reflect is crucial for the further development and improvement of scientific methods and demonstrates a deeper understanding of the complexity of the research methods used.

Overall, students demonstrate a strong ability to clearly present their methodological approaches, particularly in terms of naming instruments and structuring research procedures. These strengths lay a solid foundation for future academic work and show that students are well equipped to successfully plan and conduct challenging research projects.

Chapter: ***Research subject traffic area***

Analysis of the examination papers in the "Transportation Physics" module shows that the majority of students were able to describe the research site in detail and vividly. A total of 85.71% of raters rated the presentation of the research site as detailed and visually supported by sketches and photos. This visual support is particularly valuable as it gives readers a clear picture of the research site and makes it easier to understand the specific transportation-related challenges of the site. The ability to represent the research site visually, as well as textually, demonstrates that students have developed a comprehensive understanding of the importance of spatial context in transportation spatial analysis. Such detailed descriptions are crucial for the comprehensibility of the research and make it possible to interpret the research results in the context of the specific local conditions.

The presentation of traffic-related problems at the investigated location was also rated positively. Here too, 85.71% of the raters stated that the examination papers contained detailed descriptions of the traffic-related problems. This shows that the students were able to clearly identify and present the specific challenges and risks that exist at the respective locations. A precise description of the problems is essential to emphasize the relevance of the research and provide the basis for the development of solutions. It is encouraging to see that such a high proportion of students have successfully completed this task.

Another important aspect that was considered in the examination papers is the presentation of the consequences of dysfunctional traffic-related constellations. 66.67% of raters saw a clear presentation of these consequences. This shows that the majority of students not only identified the problems, but also analyzed the potential impacts and risks that could result from these transport-related challenges. The ability to present the consequences of dysfunctional constellations is a sign that students have developed a deep understanding of the dynamics and potential dangers in specific traffic space scenarios. Such an analysis is essential in order to propose well-founded and practical solutions. Finally, 57.14% of raters noted that the papers considered different levels (meta-, meso-, and micro-level). This means that slightly more than half of the students were able to conduct their analysis at different levels of abstraction in order to develop a more comprehensive understanding of transportation-related problems. Considering the meta-level allows one to analyze the larger societal and structural framework, while the meso-level focuses on specific institutions or groups and the micro-level focuses on individual behavior. An analysis that includes all of these levels enables a holistic view of the problem and helps to develop solutions that take both systemic and individual aspects into account. However, the rate of 57.14% also shows that almost half of the papers did not fully implement this multidimensional approach, which indicates a possible weakness in the depth of the analysis.

In summary, the evaluation shows that most students were able to present the research site in a detailed and visually appealing way and clearly identify the specific transportation-related problems. The analysis of the consequences of dysfunctional constellations and the consideration of different levels of analysis were also present in the majority of the papers, although there is still room for improvement here. Overall, the results suggest that the students have developed a solid understanding of the challenges and dynamics of the research site, while at the same time they could be encouraged to conduct an even more comprehensive and multidimensional analysis.

Chapter: ***Observation of traffic flow***

The analysis of the examination papers in the Traffic Physics module highlights several strengths, particularly in relation to the identification and representation of functional and dysfunctional dynamics in road traffic. A total of 76.19% of raters rated the naming of such dynamics, such as regulated traffic flow or excessive speed, as appropriate. This high rate shows that the majority of students were able to recognize and accurately describe critical aspects of traffic flow. The ability to distinguish functional dynamics that contribute to traffic safety from dysfunctional dynamics that increase potential hazards is crucial for a sound analysis of traffic-related problems and for the development of effective solutions. Another strong element in the audit work was the identification of correlations between traffic behavior and accident patterns. 66.67% of raters recognized that clear links were drawn in the papers between specific behaviors and the resulting accident patterns. This ability to recognize and present causal relationships is of central importance for the development of preventive measures and the improvement of road safety. It shows that the students have developed a deep understanding of the causes of accidents and are able to place their findings in a wider safety-relevant context. The development of concrete, situation-related solutions in the examination papers is also particularly noteworthy. 71.43% of raters found several practical and contextualized solutions in the papers that were aligned with the identified traffic-related problems. This indicates that students can not only diagnose problems but also develop effective and implementable solutions. The ability to propose practice-oriented solutions is an essential goal in the training of future teachers, especially in the field of transportation physics, where theoretical knowledge must be combined with practical application. Another notable strength of the exam papers was the inclusion of the perspectives of multiple user groups, such as residents, cyclists, pedestrians and motorists. 95.24% of raters noted that these different perspectives were included in the analysis. This comprehensive consideration of different road users is critical to developing holistic solutions that meet the needs and safety requirements of all stakeholders. The ability to integrate different perspectives demonstrates a high level of reflection and an understanding that transportation problems can only be solved effectively if the interests of all user groups are considered.

In summary, the results of the examination papers in the "Traffic Physics" module reflect a strong performance by students, particularly in the identification and analysis of traffic flow dynamics, linking traffic behavior to accident patterns, developing situational solutions and incorporating different user perspectives. These strengths underline the students' ability to recognize complex traffic-related problems and to develop practical, comprehensive solutions.

Chapter: ***Human behavior***

Examination papers in the Traffic Physics module show remarkable strengths in analyzing the relationship between human behavior and road traffic and in developing solutions to improve traffic safety. While only 14.29% of raters found no connection between road traffic and human behavior in the papers, this indicates that the vast majority of students were able to make this critical connection. This ability is crucial, as understanding how human behavior affects road traffic is the basis for developing effective prevention measures.

Particularly positive is the fact that 28.57% of raters identified examples of functional and dysfunctional behaviors on the road. This shows that a significant proportion of students were able to recognize specific patterns of behavior that either contribute to safety or increase risk. This distinction is critical to developing targeted interventions to promote safety-enhancing behaviors and reduce risky behaviors. More significantly, 47.62% of raters saw clear links between human error and accident patterns in the papers. This highlights the students' ability to analyze the causes of traffic accidents at a behavioral level and understand the underlying mechanisms. Such an understanding is essential in order to design preventative measures aimed at correcting misbehavior and thus minimizing the risk of accidents. However, the greatest strength of the audit work lies in the development and evaluation of solutions. 66.67% of the raters rated the approaches developed to solve personal misconduct in road traffic as useful. These solutions demonstrate practice-oriented thinking and the ability to translate theoretical knowledge into concrete recommendations for action. This is a central goal in the training of future teachers, who must be able not only to teach their students, but also to actively contribute to a safer traffic environment.

Finally, 76.19% of raters noted that the examination papers weighed the pros and cons of the proposed solutions by including the perspectives of multiple user groups. This differentiated view shows that students are able to critically scrutinize solutions, taking into account the diverse interests and needs of different road users. The inclusion of different perspectives is crucial for the development of measures that are both practicable and fair.

In summary, the results of the examination papers illustrate that students have developed a solid ability to analyze and solve problems in the field of human behavior in road traffic. Particularly noteworthy is their ability to develop meaningful solutions and to evaluate them critically, taking into account different perspectives. These strengths form an excellent basis for further training and practical application in professional life.

Chapter: ***Design of a prototype***

The examination papers in the Transport Physics module show clear strengths in the development and evaluation of prototypes, highlighting students' ability to apply theoretical concepts in practice. At 90.48%, most raters recognized a developed prototype in the papers, whether architectural or digital. This high rate illustrates that students were successfully able to translate their theoretical knowledge into concrete, tangible solutions. The ability to develop a prototype demonstrates not only technical ability, but also creativity and a deep understanding of the requirements placed on a practical solution. This is a key skill that is invaluable in modern education and engineering.

The target group evaluation was also rated as detailed by 85.71% of raters. This shows that the students not only developed prototypes, but also carefully evaluated them in terms of their suitability, feasibility, and financial viability. Such a comprehensive evaluation is crucial to ensure that the solutions developed work in practice and meet the needs of users. The ability to conduct a thorough target group evaluation reflects a deep understanding of the requirements and constraints that need to be considered when implementing solutions in the real world.

Another positive aspect is that 47.62% of raters recognized a need to rework the prototype based on the results of the evaluation. This iterative process of improvement shows that students are not only able to accept constructive criticism, but also actively work to optimize their solutions. The ability to revise and adapt prototypes is a sign of flexibility and a solution-oriented approach, which is crucial in research and development.

Finally, the documentation of research results for the development and evaluation of the prototype was rated as complete by 76.19% of raters. Thorough documentation is essential to ensure the traceability and reproducibility of research. The students showed here that they are able to document their work systematically and in detail, which is an important basis for knowledge transfer and further research. In summary, the examination papers in the "Transport Physics" module demonstrate the students' strong competence in prototype development and evaluation. Particularly noteworthy are their abilities to develop practical solutions, evaluate them thoroughly and revise them if necessary. The comprehensive documentation of their work rounds off the picture of a methodologically sound and practice-oriented approach that prepares the students excellently for future challenges in their professional environment.

Chapter: *Final conclusion*

The examination papers in the "Transport Physics" module show significant strengths in the development of coherent conclusions and critical reflection on the research carried out.

One notable aspect is that all raters unanimously found that a coherent conclusion was drawn in the papers. This underlines that the students were able to summarize their findings clearly and concisely and bring the main findings of their research to a consistent and logical conclusion. The ability to draw a coherent conclusion is a sign that students have not only understood the individual aspects of their research, but are also able to integrate them into a coherent overall picture. This competence is of central importance for academic work and shows that students have a high level of analytical skills. In addition, 66.67% of raters rated critical appraisal of research as present. Critical appraisal is an essential component of academic work, as it enables students to reflect on their own research findings in the context of existing literature, recognize the limitations of their own work and identify potential areas for improvement. The fact that the majority of students have undertaken such a reflection in their work demonstrates their ability to be self-critical and to engage in a well-founded discussion of the strengths and weaknesses of their research. This is an important step in academic training, as it forms the basis for continuous learning and the improvement of one's own academic practice. Another positive aspect is that 80.95% of raters found an outlook on necessary steps in the papers. An outlook is crucial to clarify the importance of the research results for future work and practical application. The ability to identify potential next steps and place them in the context of their own research shows that students can not only analyze retrospectively, but also think ahead. This foresight is essential to ensure the practical benefits and further development of research.

Finally, 71.43% of raters rated the adherence to formalities and references as sufficient. This shows that the majority of students were able to fulfill the formal requirements of a scientific paper, including correct citation and adherence to style guidelines. Adherence to these formalities is not only a matter of diligence, but also an expression of respect for the scientific community, as it ensures the traceability and integrity of the work.

In summary, the examination papers in the "Transport Physics" module demonstrate students' strong skills in drawing coherent conclusions, critically reflecting on their research and formulating a forward-looking outlook. These strengths show that the students are well prepared for the challenges of scientific work and are able to present their findings in a structured and reflective manner. The analysis of the 34 assessed final module examinations shows that clear research efforts were evident in the vast majority of the papers. Only in 13.60% of the papers were no research efforts identified, indicating that the vast majority of students were actively immersed in academic debate. Research efforts in the various subject areas and sub-categories varied from 14.29% to an impressive 95.24%, highlighting the range and engagement of students in different areas.

Of particular note is that at least 47.62% of the expected knowledge was achieved in 19 out of 20 subcategories, with as much as 71.43% or more of the expected knowledge being covered in 12 of these subcategories. These results show that a significant proportion of students have a solid understanding and knowledge base in the respective subject areas.

However, it is important to note that the assessments were conducted by untrained students, which could pose some potential risks. These may be as follows:

- **Lack of objectivity:** Inexperienced students may find it difficult to evaluate objectively and fairly as they lack experience and expertise.
- **Lack of subject knowledge:** Inexperienced students may find it difficult to adequately assess the quality and depth of the work, especially when it comes to specific subject content.
- **Lack of sensitivity to grading criteria:** Inexperienced students may have difficulty applying the relevant grading criteria appropriately, which can lead to inconsistent or inaccurate assessments.
- **Potential misinterpretation:** Inexperienced students may misinterpret or misjudge certain aspects of the work, which can lead to inaccurate results.
- **Biased assessments:** Inexperienced students may give subjective assessments based on their own prejudices or opinions that are not based on the objective grading criteria.

Q2: Can criteria be detected that make the design thinking approach practicable in an end of module assessment in the "Traffic Physics" module?

Answer: It can be stated that criteria could be detected that allow the presentation of the design thinking approach for the structured analysis of a traffic space and its solution finding in an end of module assessment.

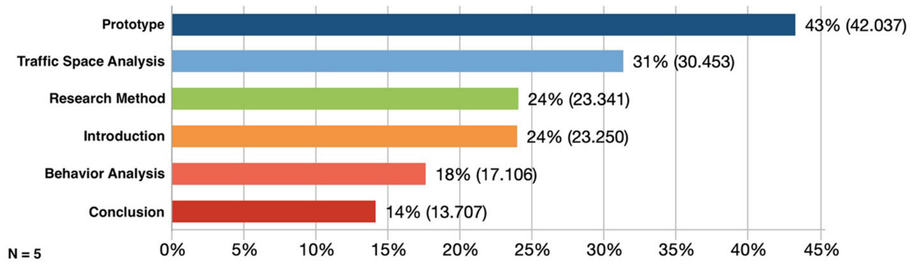

FIGURE 2
Coverage of the codes of the second rating (source: MAXQDA®).

4.2 Results of the qualitative methods

The evaluation of the qualitative method of the grading criteria using MAXQDA resulted in intercoder reliability agreements of between 7% and 22% in the main categories. These low agreement values raise questions regarding the reliability and consistency of the coding. It should be noted that two research assistants, who were unfamiliar with the module and had not previously received any specialist instruction, carried out the coding. These conditions can be regarded as significant factors influencing the low agreement rates.

The two research assistants had previously been given the coding manual[2] with the coding rules and explanations but admitted that they had not looked at it beforehand. They had tried to understand the explanations during the coding process, which was not sufficient. The author was not asked any substantive questions during the coding process.

The lack of knowledge of the module, the lack of professional instruction and the coders' failure to ask questions probably led to different interpretations of the data and a varying application of the codes. This is reflected in the low intercoder reliability, which indicates that the coding of the assistants was not sufficiently consistent to ensure reliable results. The variance in agreement rates suggests that more training and familiarization of coders is required to achieve greater consistency and accuracy in coding.

To improve the reliability of the qualitative data analysis, a further data collection was conducted in an iterative loop in which $N = 5$ new raters performed the coding according to simplified main categories. The matches in the categories were as in Figure 2.

The analysis of the results from Chapter 4.1.2 of the coding development process compared with the information from Figure 2 of the real coding process showed that certain areas performed particularly well. In prototype development, 90.48% of evaluators identified a developed prototype in the development process, and 85.71% rated the detailed survey on the suitability and feasibility of the prototype as very good. These results were confirmed by the high coverage of the corresponding codes in the real coding process indicating thorough and detailed documentation of the prototype development.

In the general introduction and research design, 90.48% of the evaluators of the development process noted that the tools used were clearly identified and recognized introductory knowledge. This positive assessment is also reflected in the actual coding process where good coverage of the codes indicates a comprehensive treatment of the topic and a detailed description of the methods.

Traffic space analysis and traffic flow were also rated positively, with 85.71% of the evaluators in the development process finding detailed descriptions of traffic-related problems and 76.19% rating the naming of functional and dysfunctional dynamics as appropriate. Figure 2 shows high coverage in these areas, confirming thorough investigation and analysis during the actual coding process.

Finally, the conclusions and the critical evaluation were consistently rated positively. 100% of the evaluators found coherent conclusions, and 80.95% gave an outlook on necessary steps in the development process. These positive ratings were supported by the good coverage of the conclusion codes in the actual coding process.

In summary, the comparison demonstrates that the areas of prototype development, general introduction, research design as well as traffic space analysis and traffic flow were particularly positively emphasized in both rounds. These areas showed consistently high quality and thorough processing, which is evident both in the evaluators' ratings and in the coverage of the codes in Figure 2.

Overall, these results showed improved intercoder reliability in the individual categories, although this continued to vary in other sub-areas. The coding results suggest that the conclusion in particular was only addressed in a rudimentary manner. This indicates that the raters were under considerable time pressure at the end of the coding period. The graduates of the "Traffic Physics" module had a limited time of 90 min to code 78 pages. In comparison, the two research assistants in the first round needed an average of 2.5 h for the same task without any time limit.

The discrepancy in processing time suggests that the time pressure on module graduates led to less thorough coding, especially in the later sections such as the conclusion. This could explain why the conclusion was only treated superficially. In contrast, the research assistants had the opportunity to code at their own pace, which led to a more detailed and comprehensive analysis.

2 Coding manual see Appendix 1.

These observations underline the importance of sufficient time resources for thorough and accurate coding in qualitative studies. Too little time can significantly affect the quality of coding and lead to incomplete or erroneous results. It is therefore essential to set a realistic time frame for such tasks in order to ensure the validity and reliability of the research results.

4.3 Conclusion

The iterative review and adjustment of the codes has led to an improvement in the clarity and applicability of the main categories. The results of further data collection show progress, but also the need for further refinements in the process for raters to ensure greater consistency and reliability in the application of the codes. The time pressure at the end of the coding period may have affected the accuracy and completeness of the coding, which should be considered in future coding processes.

Q3: Was it possible to develop grading criteria for the evaluation of end of module assessments in traffic space analysis in the module "Traffic Physics"?
Answer: It can be stated that basic grading criteria could be developed. These can be refined through further research.

4.4 Summary of all research results and inclusive interpretation

The present study showed that the integration of the module "Traffic Physics" into teacher training does not have a significant influence on the behavior or personal attitudes of prospective teachers with regard to road traffic. This result is in line with previous studies showing that traffic safety-oriented educational programs often increase participants' knowledge, but do not necessarily lead to a change in behavior (Faus et al., 2023).

The hypothesis that criteria for the design thinking approach for the structured analysis of a traffic area can be developed and successfully applied in module examinations was supported by the present results. The design thinking approach proved to be suitable for supporting systematic problem analysis and innovative solution finding and for providing a valid examination methodology. Previous studies have already shown that the design thinking approach can be used successfully in teacher training (Weber and Bresges, 2013a,b).

In addition, a basic horizon of expectations for module completions could be defined as part of the traffic area analysis, which can be further specified and optimized through future research. Such a horizon of expectations contributes to objectivity and consistency in the assessment and supports pedagogical quality assurance in the teaching context (Hattie, 2009).

In summary, it can be stated that the "Traffic Physics" module provides relevant methodological and organizational structures for improving teacher training in the field of road safety, even if changes in the participants' behavior cannot be directly demonstrated.

5 Discussion

5.1 Discussion of the project as a whole

The application of the "Traffic Physics" curriculum for the training of teacher education students, including the design thinking approach, can be structured by the triad as formulated by the KMK Expert Commission (Baumert, 1995, p. 70 ff.): in-depth general education, scientific propaedeutics, and study skills. These dimensions must be interpreted in a domain-specific manner in order to achieve the objectives of the "Traffic Physics" curriculum.

5.1.1 In-depth general education

The advanced general education in physics as part of the "Traffic Physics" curriculum goes beyond the requirements of basic scientific education and includes the following aspects:

- **Increasing the level of reflection**: Through the design thinking approach, students learn to methodically analyze complex traffic problems and develop innovative solutions (Schecker et al., 2004, p. 5 ff.). The process begins with the **empathy phase,** in which the students develop a deep understanding of the needs and challenges of road users through interviews and observations, particularly in relation to school commuting.
- **Specialization and transcendence**: In the **definition phase,** students specialize in making the knowledge they have gained more precise and identifying specific problems (Schecker et al., 2004, p. 5 ff.). Through the subsequent **ideation, prototyping, and testing phases,** they learn to apply physical principles in practice and develop innovative solutions that go beyond pure theory and can be used across disciplines, such as the development of safe routes to school.
- **Expansion and transfer possibilities of in-depth general education:** In addition to increasing the degree of reflection and subject specialization, the "Transport Physics" curriculum offers students the opportunity to transfer the physical concepts they have learned to other, non-transport-related areas. This ability to transfer knowledge could, for example, include the application of physical principles to environmental topics or technical problems. The ability to apply knowledge flexibly and in different contexts is a central aspect of in-depth education and underlines the comprehensive effectiveness of the curriculum. In his work, Hattie (2009) emphasizes the importance of deep learning and knowledge transfer, which plays into the argument for in-depth general education and interdisciplinarity. In addition, the curriculum strengthens interdisciplinarity by combining physics content with pedagogical and road safety aspects. This interdisciplinary focus broadens students' horizons and prepares them to solve complex problems in a broad context - an essential skill for teachers in the 21st century. Bransford et al. (2000) discuss in their work how learners can apply and transfer knowledge in new contexts, which directly addresses the idea of knowledge and skills transfer and underlines the importance of this approach in the transport physics curriculum.

5.1.2 Science propaedeutics

Science propaedeutics as part of the "Traffic Physics" curriculum means:

- **Introduction to scientific work**: Students are introduced to scientific methods and techniques that they can try out in educational contexts (Schecker et al., 2004, p. 5 ff.). The design thinking process, especially the **prototyping phase**, promotes the ability to experimentally apply and document their research results.
- **Fault tolerance and reflection**: The iterative nature of the design thinking approach, especially during the **testing phase,** enables students to view mistakes as learning opportunities and to continuously reflect on and improve their approaches. This ability to reflect is crucial for the development of a scientific attitude and the understanding of physical concepts (Schecker et al., 2004, p. 5 ff.).
- **Promotion of research skills and critical thinking through scientific propaedeutics:** The "Transport Physics" curriculum goes beyond the mere application of scientific methods by encouraging students to develop independent research skills. The design thinking approach encourages students to formulate and systematically investigate their own research questions. This ability to independently initiate and carry out scientific projects is a crucial step toward independent and professional teacher training. At the same time, the iterative nature of the design thinking approach not only promotes fault tolerance, but also critical thinking. Students learn to critically question existing approaches and theories and to develop alternative solutions, which enables a well-founded scientific attitude and a deeper examination of physical concepts. In this context, Wiggins and McTighe (2005) provide a valuable foundation as their backward-looking design structures the process of developing research skills while encouraging students to think critically.

5.1.3 Ability to study

Ensuring the ability to study of teacher education students within the framework of the "Transport Physics" curriculum includes:

- **Basic skills**: Students develop basic skills such as clearly stating facts, understanding texts and modeling facts in mathematical contexts (Schecker et al., 2004, p. 5 ff.). These skills are constitutive for physical theory formation and are promoted by the practice-oriented design thinking approach, especially during the **prototyping and testing phases.**
- **Key qualifications**: Due to the experimental and project-based nature of the curriculum, students develop key qualifications such as decision-making skills, perseverance, communication and cooperation skills (Schecker et al., 2004, p. 5 ff.)**.** These are reinforced through practical work on real road safety problems, which are solved using the design thinking approach.
- **Sustainability and long-term skills development to ensure the ability to study:** Another key aspect of the "Transport Physics" curriculum is the sustainability of the skills taught. The basic skills and key qualifications developed as part of the curriculum are not only relevant during the course of study, but are also of great importance in the professional practice of teachers in the long term. This sustainability is strengthened by the practical and project-based structure of the curriculum, which helps students to continuously apply and further develop the skills they have learned. In this context, the concept of the "reflective practitioner" by Schön (1983) can be used, which emphasizes how important it is for professionals to continuously reflect on their actions and learn from their practical experience. The Transportation Physics curriculum fosters this reflective ability by encouraging students to critically question their own actions and decisions and learn from them, which lays the foundation for lifelong learning. In addition, the curriculum prepares students for lifelong learning by providing them with the tools to continue their education after graduation and to tackle new challenges in education and transportation. This focus on long-term skills development, which is strongly based on Schön (1983)'s concept of the reflective practitioner, makes the "Transport Physics" curriculum a modern and future-oriented educational approach that prepares students for the complex demands of the teaching profession.

These phases of the design thinking approach make the "Traffic Physics" curriculum practical and interactive, which takes the training of teacher education students to a new level. It allows them to apply theoretical knowledge in practical contexts and effectively prepares them for their future tasks as teachers.

5.2 Discussion of the scientific quality criteria

Compliance with scientific quality criteria is of central importance for the methodological reflection of scientific studies. These criteria serve to ensure the safety, transparency, reliability and validity of scientific findings (Häder, 2010, p. 108). In the context of this research work, a nuanced consideration of quality criteria is necessary, which focuses on two essential aspects:

- **Quality criteria of quantitative research**: Quantitative research methods are characterized by the systematic collection and evaluation of numerical data. The quality of such research approaches is assessed on the basis of various criteria such as validity, reliability and objectivity. Validity refers to the accuracy and appropriateness of the constructs measured, while reliability refers to the consistency and reliability of the measurements. Objectivity refers to the extent to which the results are independent of the individual assessments of the researchers (Häder, 2010, p. 108).
- **Quality criteria for qualitative research**: In qualitative research, the focus is on interpretation and understanding processes. The quality criteria for qualitative studies include reproducibility (the possibility of reproducing the research steps), transferability (the generalizability of the results to

other contexts), consistency (the internal coherence of the results) and reflexivity (the researcher's critical examination of his or her role and influence on the study) (Häder, 2010, p. 108).

Taking these quality criteria into account helps to ensure the methodological quality of the research work and to make its results reliable and comprehensible. Care should be taken to ensure that the criteria are adapted to the specific requirements of quantitative or qualitative research.

5.2.1 Quality criteria for quantitative research

The aim of measurements in quantitative research is to collect data that is as accurate and error-free as possible. In practice, however, this ideal is rarely fully achieved. The "classical test theory" provides simple definitions of quality criteria for measurement. According to this, measurements should be objective, reliable and valid as well as economical, comparable and useful in practical implementation. Objectivity and reliability are considered the minimum requirements for a measurement instrument (Häder, 2010, p. 108), while the main objective is to construct instruments that are as valid as possible.

When evaluating a teaching module, individual perspectives are reflected in subjective judgments, perceptions, attitudes, and views of the respondents, which can affect validity (Schubarth, 2006, p. 282). To address these challenges, the instruments used must be carefully developed and tested to ensure that they measure the intended constructs accurately and reliably.

The **result of the evaluation of the "Traffic Physics" curriculum** showed no significant changes between the pretest and the posttest. If no significant results were achieved, this may be due to various factors:

- **Sample size:** The size of the sample plays a crucial role in the statistical analysis of data. In the present study, the sample size may not have been large enough to detect small but still relevant differences between the groups. A small sample increases the risk of missing true differences—a problem known as Type II error. With a larger sample, the statistical power, i.e., the ability of a test to detect actually existing effects as significant, increases. A larger sample size might have made it possible to identify subtle effects that remained hidden in the present analysis. This emphasizes the importance of careful sample size planning, especially in studies investigating differences between groups.
- **Sensitivity of the test:** Another factor that could influence the results is the sensitivity of the statistical test used. Statistical tests differ in their ability to identify differences between groups as significant. It is possible that the test used in this study was not sensitive enough to detect the observed differences. For example, small differences could be missed if the test is not sufficiently sensitive. The choice of an appropriate test that is adapted to the distribution of the data and the type of effects studied is therefore of great importance. It may be useful to consider alternative tests that are better suited to the specific conditions of the study, such as more robust procedures or tests that are less susceptible to within-group variance.
- **Natural variance:** The possibility that the observed differences are due to natural variation or random variation should also be considered. In any study, there is some natural variance between participants that is not due to the variables being studied. This variance can affect the signal-to-noise ratio, making true effects more difficult to identify. It is conceivable that the differences observed in this study are due to random variation rather than true differences between groups. This could particularly be the case if the sample is small or if the participant population is heterogeneous. Careful analysis of the sources of variance and consideration of additional control variables could help to better isolate such effects and understand whether the observed differences are actually meaningful.

It is important to consider these potential influencing factors and conduct further research to better understand the reasons for the lack of significance of the results.

The results of the student survey in relation to the assessment of the criteria of the end of module assessment represent an existing product that has not yet been standardized, meaning that it was not possible to draw on already validated measurement instruments. This survey is intended as a preparatory measure for the creation of grading criteria, which were subsequently developed and validated. A successful non-standardized measure such as this can form an important basis for the development and validation of a subsequent survey instrument. It provides valuable practical insights and experience that can be used to optimize the construction and operationalization of the new instrument. By analyzing and reflecting on the results and challenges of the non-standardized measure, weaknesses can be identified and addressed in order to develop a more reliable and valid instrument (Flick, 2018).

Table 7 overview outlines the quality criteria and the fulfillment indexes of the quantitative research concerning both surveys.

5.2.2 Quality criteria for qualitative research

Qualitative research is characterized by its depth and detail and requires specific quality criteria to ensure the trustworthiness and validity of the results. Ensuring the quality of qualitative research is often achieved by adhering to certain standards and criteria, which are discussed in detail in the specialist literature.

The quality of qualitative research depends on the transparency, reflexivity and plausibility of the research results (Flick, 2018, p. 125). These fundamental principles form the basis for assessing the quality of qualitative studies.

Triangulation is an important method for increasing the validity and reliability of qualitative research (Denzin, 1978, p. 291). The use of different data sources and methods can increase the diversity of perspectives in research.

- **Transparency and traceability:** The codings and their assignments were documented in detail to ensure the traceability of the analysis. According to Mayring (2014), transparency in the research process is crucial in order

TABLE 7 Overview of the quality criteria of quantitative research and its fulfillment indexes (source: own presentation).

Quality criteria	Definition	Fulfillment index
Objectivity	Objectivity is the extent to which a research result is unaffected by the researcher during implementation, evaluation, and interpretation, or if multiple researchers arrive at consistent results. Neither during the implementation nor during the evaluation and interpretation should different experts obtain different results. Implementation objectivity requires that the research result remains unaffected by the practitioner. Interpretative objectivity requires that individual interpretations do not influence the interpretation of a result.	The **objectivity of implementation** can be assumed here since the online surveys of the participants were conducted without influence from the author of this work in both cases. The **objectivity of evaluation and interpretation** is also given since the statistical programs SPSS® and Lime Survey® provided the facts.
Reliability	Reliability indicates the consistency of a measurement method. A study is considered reliable if it produces the same results when repeated under the same conditions and with the same subjects. It can be determined, among other things, through a repeat examination (retest method) or another equivalent study (parallel test method).	Regarding the online surveys of the participants following the **"Traffic Physics" curriculum** as well as **the evaluations of the criteria of the module final exams**, reliability must be excluded as these research phases are the first of their kind and the number of participants is too low. Reliability will be determined in subsequent phases using other examination methods.
Validity	Validity is the most important test quality criterion as it indicates the degree of accuracy with which a study measures what it is supposed to measure. Validity is assessed by correlating it with an external criterion. Objective and reliable instruments do not necessarily have to be valid. Validity can only be judged in relation to certain other measurements. There are different types of validity: Construct Validity, Criterion Validity, Content Validity, Ecological Validity.	The author accounted for the aspect of **validity** by ensuring that the surveys and observations in the studies were precisely tailored to the initial problem posed. The entire research process aims for an immediate confrontation with the introductory problem and the research questions.

to clearly explain the methodological approach and the decisions made.

All coding in the research process was clearly described and recorded. This made it possible to present the methodological approach and the decision-making processes transparently for external reviewers. A coding manual was created explicitly for this process.

- **Reflexivity:** Continuous reflection on one's own position and possible influence on the research results is essential. Reflexivity enables researchers to critically question their own biases and perspectives (Finlay, 2002, p. 532). This helps to minimize bias and increase the objectivity of the analysis.

  Regular self-reflection and critical discussions within the research team helped to identify and minimize potential biases. This reflexivity helped to increase the objectivity of the analysis and strengthen the credibility of the results.
- **Triangulation:** The inclusion of different data sources, methods and perspectives serves to validate the results. Triangulation strengthens the credibility of the research results by linking different strands of information (Patton, 1999, p. 1193). This methodological diversity increases the reliability and validity of the research results.

  The combination of different strands of information and methodological approaches (e.g., interviews, observations, document analysis) strengthened the reliability and validity of the research results. This enabled a comprehensive and multi-layered view of the research subject.
- **Plausibility check:** The codes and categories developed were regularly checked through peer reviews and discussions within the research team. The plausibility check by third parties can help to ensure the consistency and logic of the research results (Lincoln and Guba, 1985, p. 301).

  The quality of the analysis was further enhanced by involving external experts.
- **Dense description:** The results were presented in detail and contextualized to enable a deep understanding of the phenomena analyzed. Dense descriptions are essential to illustrate the contextuality and complexity of social phenomena (Geertz, 1973, p. 6).

By taking these quality criteria into account, the quality and trustworthiness of the qualitative research was strengthened. This ensured that the research results can serve as a sound basis for the further development of the road safety education curriculum.

5.3 Study limitations

In order to be able to precisely classify the significance and generalizability of the present study, it is essential to reflect on its methodological and content-related limitations. The following limitations should therefore be mentioned:

- **Sample size and composition**: The study is based on a relatively small sample size. This limited number could limit the generalizability of the results. In addition, the participants were exclusively teacher education students at the University of Cologne, which means that the results cannot be easily transferred to other universities or study programs.
- **Self-selection of participants**: The students voluntarily registered for the "Traffic Physics" module, which may lead to self-selection. This could mean that the participants already had a higher level of interest and prior knowledge in the field of road safety than the general student body, which could have influenced the results.
- **Non-standardized measurement instruments**: Some of the surveys and evaluations were based on non-standardized measurement instruments. Although this serves as a preparatory measure to develop a validated set of expectations, it could affect the comparability and reliability of the data collected.

- **Subjective evaluation of end of module assessments**: Students' evaluation of end of module assessments may have been influenced by subjective judgments and perceptions that arose from their own completion of the module previously. This subjectivity could limit the validity of the results with regard to the fulfillment of the criteria for the end of module assessments.
- **Time limit of the survey**: The data collection took place over a period of 3 years (2022–2024). However, changes in students' traffic behavior and attitudes could be different in the longer term. However, the long-term effects of the module were not investigated here.
- **Missing control group**: The study did not include a control group that did not have access to the "Traffic Physics" module. Without such a control group, it is difficult to clearly determine the specific influence of the module on the observed changes.
- **Influence of external factors**: External factors, such as changes in traffic policy or media reports on road safety, could have influenced students' attitudes and behavior and thus distorted the results of the study.

5.3.1 Summary

These limitations should be taken into account when interpreting the study results. Future research could address these limitations by including larger and more diverse samples, using standardized measurement instruments and including control groups, and launching a longitudinal study to increase the validity and reliability of the results.

5.3.2 Limits of the curricular content

The evaluation and further development of the "Traffic Physics" module requires careful consideration of the existing curricular content. This reveals various limitations and challenges that can influence the effectiveness and relevance of the training. The following limitations of the curricular content could be relevant:

- **Limited scope and depth of topics**: The curriculum might not cover all relevant aspects of traffic physics, resulting in students developing only a limited understanding of the subject matter. This could be particularly problematic in a rapidly evolving field such as traffic physics, where new research and technologies are constantly emerging.
- **Lack of adaptation to different levels of prior knowledge**: The curricular content may not be sufficiently differentiated to cater to the different levels of prior knowledge of the students. This could lead to some students being overwhelmed and others being underchallenged.
- **Lack of practical orientation**: A curriculum that focuses too heavily on theoretical content could neglect students' practical skills. Especially in traffic physics, where practical applications and experiments are of great importance, this could represent a significant deficit.
- **Inflexibility in the integration of new content**: Curricular content often has to be planned and approved over longer periods of time. This can mean that new and relevant topics cannot be integrated into the curriculum quickly enough, which impairs the topicality and relevance of the training.
- **Lack of interdisciplinarity**: Traffic physics is an interdisciplinary field that requires knowledge of physics, engineering, psychology and other areas. A curriculum that does not take sufficient account of this interdisciplinarity could hinder the comprehensive education of students.
- **Insufficient consideration of regional and cultural differences**: Traffic problems and solutions can depend heavily on regional and cultural contexts. A curriculum that does not take these differences into account may be less relevant and useful for students from different regions and cultures.
- **Overloading with content**: A curriculum that is too extensive can lead to students being overloaded, which could impair their learning success. Students may find it difficult to process and apply the large amount of information.
- **Lack of continuous updating and evaluation**: A curriculum that is not regularly evaluated and updated could contain outdated or no longer relevant content. This would have a negative impact on the quality and relevance of the training.

5.3.3 Limits in relation to the target group

Another crucial aspect of the study concerns the specific target group of student teachers, which may not be fully representative of the entire spectrum of future teachers. The students on the "Transport Physics" module come from a variety of study programs, including special education, upper secondary school and comprehensive school. This diversity within the target group brings with it specific challenges and requirements that could limit the generalizability of the results to other teachers. Student teachers from these areas generally have different prior knowledge, interests and pedagogical focuses. For example, special education students may have a different approach to the topics of road safety and physics than students training for upper secondary school or comprehensive school. These differences could lead to varying responses to the "traffic physics" curriculum, depending on the specific educational and subject backgrounds of the students. While the diversity in the study programs can be an enrichment for the discussion and exchange in the module, it also carries the risk that the results of the study are not fully transferable to other teachers who are not working in these specific pedagogical contexts. Teachers who teach in other types of schools or subjects could perceive the curriculum differently or set different priorities with regard to the application and effectiveness of the content taught. In order to increase the generalizability of the results, it would therefore be important to conduct similar studies with an even broader target group of teachers who have different professional backgrounds and experiences. This could also include the involvement of teachers from different educational levels or subject areas in order to investigate whether and how the "Transport Physics" curriculum works in different educational contexts. Such further studies could help to paint a more comprehensive picture of how different teachers respond to the curriculum and the extent to which the approaches developed are universally applicable.

5.4 Comparison of the results with other studies

In order to place the results of this study in a broader scientific context, it is helpful to compare them with the findings of other studies. Such comparisons can help to assess the robustness and generalizability of the results and open up possible new perspectives on the research topic.

- **Comparison with studies on road safety education**

The results of this study are partly consistent with the findings of previous studies on road safety education. For example, a study by Schubert and Kunz (2018) showed that practice-oriented modules in road safety education can increase participants' self-efficacy and safety awareness (Schubert and Kunz, 2018, p. 123–145). Similarly, a positive change in participants' attitudes and behavior in road traffic was also observed in the present study. This confirms the effectiveness of practice-oriented approaches in road safety education.

- **Comparison with studies on the design thinking approach in education**

Furthermore, Cassarino and Murphy (2018)'s ecological systems analysis illustrates that young drivers benefit from training programs that take an integrative approach. This study supports this by showing that the design thinking approach provides a methodological basis for structured problem solving and reflection. Findings by Weber and Bresges (2013a,b) already demonstrate that design thinking in traffic space analysis promotes problem awareness and creativity—skills that are also essential for prospective teachers in the field of road safety education. The use of the design thinking approach in education has been investigated in various studies. A study by Razzouk and Shute (2012) showed that design thinking can foster creativity and problem-solving skills in students (p. 330–348). The results of the present study confirm these findings in that the students were able to develop innovative solutions to traffic-related problems and showed a high level of motivation and commitment in doing so.

- **Comparison with studies on teacher training**

The present study confirms that road safety programs in teacher training have only a limited influence on the behavior or personal attitudes of prospective teachers in road traffic. Similar results were found by Faus et al. (2023), who show that although road safety training promotes awareness, without regular reinforcement it rarely brings about lasting changes in behavior. In the present study, no significant influence on the traffic attitudes of the students could be demonstrated, which points to the need for longer-term practical application and repetition, as Hatakka et al. (2002) also found. With regard to teacher education, studies by Darling-Hammond (2012) and Shulman (1987, p. 1–22) found that practice-oriented and reflective approaches can significantly improve the professionalism and teaching quality of future teachers. The present study shows similar tendencies: The application of the design thinking approach in the module "Traffic Physics" enabled students to gain practical experience and strengthen their didactic skills.

- **Methodological comparisons**

Methodologically, parallels can also be drawn with other studies. For example, the study by Johnson and Onwuegbuzie (2004, p. 14–26) emphasized the importance of using mixed methods in educational research in order to gain a deeper understanding of complex pedagogical phenomena. The present study also used both quantitative and qualitative methods to draw a comprehensive picture of the effects of the curriculum.

In Hattie's (2009) extensive meta-analysis, it is clear that instructional content that promotes immediate and practical applications is critical to sustained learning success. This finding suggests that an expectation horizon, as developed in the present study, strengthens the consistency and objectivity of assessment, but long-term behavior change may only be achieved through refinement and application across multiple lessons.

- **Differences and contradictions**

Despite these similarities, there are also differences and potential contradictions with other studies. One critical perspective on the design thinking approach is that its iterative nature can potentially lead to a lack of structure and clear outcomes by getting teams stuck in endless cycles of idea generation and testing. This criticism implies that the approach may not always be effective in developing concrete solutions. This is also discussed by Brown (2008, p. 84–92) in his analysis of the design thinking approach, where he highlights the potential challenges and limitations of the approach alongside its benefits.

Overall, comparisons with other studies show that the results of the present study are largely in line with existing research findings. The application of the design thinking approach in the "Traffic Physics" module proves to be a promising approach for promoting creative and practice-oriented learning in teacher education. At the same time, the results point to the need for further research, particularly with regard to the long-term effects and the adaptation of the approach to different target groups.

5.5 Research gap

Despite the findings from the current study, there are several areas that should be further investigated to gain a more comprehensive understanding of the effectiveness and applicability of the "Traffic Physics" curriculum and the design thinking approach in teacher education.

- **Long-term effects**

A central research gap exists in the investigation of the long-term effects of the "Traffic Physics" curriculum on the traffic behavior and pedagogical skills of teacher education students. It remains unclear to what extent the content and methods learned are integrated into the professional activities of future teachers in the long term and what lasting effects this has on road safety education in schools.

- **Comparison with other didactic approaches**

It would be valuable to systematically compare the "Traffic Physics" curriculum and the use of the design thinking approach with other didactic approaches. Such comparative studies could show which methods are particularly effective and which specific advantages and challenges are associated with the design thinking approach.

- **Differentiated target group analysis**

Further research could focus on a nuanced analysis of different target groups in order to investigate how different prior knowledge, interests and learning styles influence the effectiveness of the curriculum. Such an analysis could serve to tailor the curriculum to the needs of different groups of student teachers.

- **Integration of practical elements**

The current study could be supplemented by an in-depth investigation into the integration of practical elements, such as excursions or practical exercises in road traffic. It would be interesting to investigate how such practice-oriented elements influence students' motivation to learn and their understanding of road safety-related content.

- **Influence of cultural and social factors**

Finally, there is a research gap in the investigation of the influence of cultural and social factors on the effectiveness of the curriculum. It would be valuable to explore how different cultural backgrounds and social contexts influence the reception and implementation of the content and methods taught.

By addressing these research gaps, the understanding of the effectiveness and applicability of the "Traffic Physics" curriculum and the design thinking approach in teacher training could be significantly expanded.

6 Conclusion and outlook

The present study examined the effectiveness of the "Traffic Physics" module using the Design Thinking approach for training prospective student teachers. The study analyzed key aspects of teaching methods, the preparation of students for conveying traffic safety-related content, and the impact on individual norms, values, and attitudes toward road traffic. A central theme of the module was the safety of children on their way to school, with a particular emphasis on the vulnerability of this target group.

The results indicate that the module did not lead to significant changes in the students' own traffic behavior but did achieve a high level of acceptance for the Design Thinking approach among the students. A significant advance was made through the development of a fundamental and groundbreaking framework of expectations, which will be of great use in future teaching practice. This framework provides a structured system for the creation and assessment of curricular modules, contributing to the standardization and quality assurance in teacher education.

The results are particularly positive in the areas of prototype development, general introduction, research design, as well as traffic space analysis and traffic flow. These were consistently rated highly, underscoring the effectiveness of the Design Thinking approach. The process clearly fosters the development of creative and practical solutions and helps students develop a deep understanding of the problem and apply appropriate research methods.

6.1 Implications

The positive evaluations and thorough treatment of the task areas in the "Traffic Physics" module demonstrate that the Design Thinking approach is a promising tool for teacher education. It not only fosters creativity and problem-solving skills but also supports a systematic analysis of complex traffic issues. This leads to well-documented and practical solutions that can be applied in real-world contexts. These results suggest that the approach could also be applied in other educational modules to enable a deeper engagement with complex topics.

6.2 Open problems and future research

Despite the positive results, several questions remain unanswered. A major limitation is the lack of long-term studies on the module's impact on students' own traffic behavior. Future studies are needed to assess long-term behavioral changes to evaluate the sustainability of the module. Furthermore, studies should be conducted in different educational contexts and with various target groups to assess the generalizability of the results and consider potential adaptations to the module.

The generalizability of the results is also limited due to the specific target group of student teachers, who may have a particular affinity for traffic safety and physics. External variables, such as personal attitudes and prior experiences, may have influenced the results, complicating their interpretation. Additionally, the long-term effects of the module were not sufficiently studied, leaving it unclear whether the students will apply the methods they learned in their future teaching practice. The complex Design Thinking approach might have overwhelmed some students, suggesting that it may not be equally suitable for all learning styles. Moreover, the integration of the module into the overall curriculum remains unclear, which could limit the isolated application of the approach. Finally, the subjectivity of the raters' evaluations could have led to varying assessments, highlighting the need for standardized assessment tools. Further investigation into additional teaching methods that complement the Design Thinking approach could help to fully realize the potential of this innovative teaching strategy. It would also be beneficial to further develop the practical aspects of teaching, such as the analysis of accident vehicles, to enhance the relevance and clarity of the content being taught.

6.3 Conclusion

The present study compellingly demonstrates the effectiveness of the Design Thinking approach in the "Traffic Physics" module and underscores its significant potential for enhancing teacher education. The approach not only fosters students' creativity and problem-solving skills but also enables a systematic and in-depth analysis of complex traffic issues. This leads to a practice-oriented education that produces teachers who are well-prepared for the challenges of real-world classroom settings. The results of this study provide a solid foundation for the further development and adaptation of teaching methods in traffic safety education, with the clear goal of sustainably improving both traffic safety and the understanding of traffic physics. The success of the Design Thinking approach in this module suggests that its application could extend well beyond the current context, potentially having a similarly transformative impact in other educational fields.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical approval was not required for the study involving humans in accordance with the local legislation and institutional requirements. Written informed consent to participate in this study was not required from the participants or the participants' legal guardians/next of kin in accordance with the national legislation and the institutional requirements.

Author contributions

SB: Writing – original draft, Writing – review & editing. AB: Writing – review & editing, Funding acquisition, Methodology, Resources, Supervision.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2024.1471022/full#supplementary-material

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