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Received: 4 May 2023 | Revised: 9 February 2024 | Accepted: 10 February 2024

DOI: 10.1111/ejed.12623

ORIGINAL ARTICLE

WILEY

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Abstract

STEM teacher shortage remains a serious problem in secondary education in many European countries, despite many interventions and many research studies over the last decades. The observation that past interventions and research outcomes have not significantly contributed to reduce teacher shortage implies that places to effectively intervene in the teacher education system have not been found yet. In this article, a systems thinking approach is presented to evaluate the fundamental and structural problems of an academic teacher education system regarding STEM student entry. A thorough understanding of the systemic structure of a teacher education system is essential to identify leverage points for STEM teacher recruitment. Based on systems thinking principles and theoretical frameworks, a stepwise research framework was defined, which was tested in the Dutch academic teacher education system. First, potential factors of concern were identified based on the collection of many data such as existing public information, reports and long-term student entry data. These potential factors of concern were subsequently investigated by student surveys and structured interviews with stakeholders from science faculties and teacher training institutes. Synthesis of the results led to the identification of three leverage points for increasing STEM student entry in teacher training, which were all found at the organizational and structural level of the academic teacher education system. The systems thinking research framework presented in this article provides a valuable framework to address persistent problems in education and enables the identification of novel and potentially more effective interventions.

KEYWORDS
STEM students, STEM teachers, systems thinking, teacher education, teacher shortage

1 | INTRODUCTION

There are serious concerns worldwide about maintaining an adequate supply of good quality teachers, especially in the field of mathematics and science (European Commission, Directorate-General for Education, Youth, Sport and Culture, 2018; European Commission/EACEA/Eurydice, 2018). In Europe, an average of 15% of the students aged 15 attend schools where teaching is hindered by a lack of qualified mathematics and science teachers. In Western European countries like Belgium, Germany, the Netherlands and the United Kingdom, these percentages are as high as 20%–40% (European Commission/EACEA/Eurydice, 2012). This is even more concerning given the increasing value of science understanding and the belief that science understanding promotes personal well-being and responsible citizenship (European Commission, 2015).

In many countries, alternative and more flexible routes towards a career in teaching have been implemented to target new groups of prospective teachers (Abell et al., 2006; Bolhuis, 2002; Brouwer, 2007; European Commission/EACEA/Eurydice, 2012; Zeichner & Schulte, 2001). Important considerations of such alternative teacher education programs are ease of access, incentives, quality of the education program and retention of teachers in school (Brouwer, 2007; Frederičová, 2020; Luft et al., 2011; Scott et al., 2006). However, the current teacher shortages show that such alternative education programs have not been effective enough in recruiting and retaining secondary school teachers in mathematics and science. Several research studies advocate that characteristics of effective routes to teaching as a career go beyond the teacher training program as such. For example, research studies by Abell et al. (2006), Scott et al. (2006), and Luft et al. (2011) stress the importance of comprehensive and strategic recruitment policies to identify and develop potential science teachers. In addition, Brouwer (2007, p. 34) advocates for a more gradual build-up of activities in alternative teacher education programs, because 'teaching competence is a complex and integrated whole of qualities, which a person cannot build up in a rush'. Furthermore, Ostinelli (2009) states that teacher education does not only concern teachers and teacher education programs but also other actors, like principals, educational consultants, parents and students, and should include lifelong learning.

All these studies illustrate the complexity of the context in which academic teacher education institutes operate: situated in an academic environment recruiting and preparing student teachers for the reality of everyday practice in schools, with many stakeholders, like teacher educators and educational researchers, student teachers and school principals, but also policy and law makers and politicians (Korthagen et al., 2006; Zeichner, 2010). Attempting to capture the complexity of teacher education, several research studies employ integrated research approaches to identify design principles for more effective teacher education. For example, Korthagen et al. identified fundamental principles for teacher training programs and practices by evaluating the central principles underlying three teacher training programs on three continents (Korthagen et al., 2006). Also, Hoban studied teacher training programs within a university context and proposed an integrative four-dimensional conceptual framework to guide teacher education design, thereby taking into account the relationships between four different elements of teacher training being schools, university, teacher trainees and teacher educators (Hoban, 2004). Both research studies emphasize the interrelations between different elements of teacher training programs and the importance of shared ideas and themes among stakeholders. However, the integrated research frameworks proposed in both these studies were informed by the specific context and research questions and did not concern the entry of STEM students into teacher education.

In this study, systems thinking is presented as a more general research approach to deal with the complexity of academic teacher education. The main principle of systems thinking is that the behaviour of a complex system such as an academic teacher education institute is determined by the systemic structure of that system. Therefore, a thorough understanding of the systemic structure of a teacher education system is essential to identify leverage points for change. First, a stepwise research framework was defined based on systems thinking principles and theoretical frameworks. Secondly, this framework was used to evaluate an alternative route to teaching within the Dutch academic teacher education system with the purpose to identify more sustainable interventions to increase the entry of STEM students into the academic teacher education programs.

In 2009, the Dutch government introduced an undergraduate teaching module 2009 as a new, attractive route towards a career in teaching for academic bachelor students. Initial evaluation of the undergraduate teaching module in 2012 was positive because the program appeared to attract new undergraduate students (Ecorys/ResearchNed, 2012). However, at that time it was too early to evaluate whether this undergraduate teaching module led to increased student entry in the graduate and postgraduate teacher training programs. The research question of this study is whether a systems thinking approach to evaluate the effectivity of the undergraduate teaching module provides insight into the systemic structure of a teacher education system and the fundamental and structural problems regarding STEM student recruitment, and enables the identification of leverage points to increase the entry of STEM students in the academic teacher education programs.

2 | THEORETICAL FRAMEWORK: SYSTEMS THINKING

Systems thinking is founded in General Systems Theory, which was developed by biologist Ludwig von Bertalanffy who argued that the idea of investigating an organism not only by its parts but also in organizational relation, could be applied to complex 'wholes' of any kind (von Bertalanffy, 1950). Later, Forrester initiated and developed the field of systems dynamics (Forrester, 1968). Over the years, systems thinking was further developed and applied in a wide range of disciplines including ecology, sustainability, engineering, sociology and economics (Bunge, 1979, 2000; Checkland, 2011; Forrester, 1968; Meadows, 2009; Meadows et al., 1972; Senge, 2007).

The core insight of systems thinking is that the behaviour of a system and individuals within that system is determined by the structure of that system (Meadows, 2009; Senge, 2007). Observable problems are symptoms of systemic structures, which are often hidden, and interventions aimed at solving these observable problems provide only a short-term cure (Senge, 2007). Seeing how the structure of a system relates to its behaviour is the first step to understand how systems work and why they produce poor results. A system is a set of elements or parts that are coherently organized and interconnected in a pattern or structure that produces a characteristic set of behaviours, often classified as 'function' or 'purpose'. A system therefore consists of three kind of things: elements, interconnections and a function or purpose (Meadows, 2009). Systems are dynamic and constantly subject to various forces and feedback mechanisms, which can be stabilizing, but also reinforcing or destabilizing.

One of the most important insights of systems thinking is that certain patterns of structure recur over again and over again across different fields, such as biology, psychology, economics, political science, ecology, management systems. Such common system structures that produce characteristic patterns of behaviour, are called archetypes (Meadows, 2009; Senge, 2007). Especially the long-term behaviour of a system provides important information about the characteristic patterns of a system. By recognizing these kinds of patterns, or so-called archetypes, it becomes possible to identify places in the system where a small change leads to a large shift in behaviour, so-called leverage points (Meadows, 2009). High-leverage interventions, which are those interventions having the most impact, are aimed at underlying structures and change processes (Senge, 2007). Examples of high-leverage interventions are changing information flows, rules and goals of a system, the system itself or changing existing ideas about the system (Kim, 1999; Meadows, 2009).

Cavana and Maani (2000), and Wolstenholme (1992) have described methodologies for system thinking analysis, modelling and interventions. Wolstenholme (1992) focused on the construction of conceptual models for qualitative analysis, while Cavana and Maani (2000) presented an extensive five-step methodological framework starting from problem structuring until implementation and organizational learning, which has been applied to different contexts such as health reform, drinking policies and telecom strategy. Based on these frameworks together with Meadows' general systems thinking principles (2009), a five-step research framework to analyse complex problems and identify interventions was defined.

In the present study, the following five steps were applied to evaluate the relation between the systemic structure of the academic teacher education system and the entry of STEM students into the graduate and postgraduate teacher training:

1. Conceptual model and dynamic behaviour of the teacher education system.
2. Problem analysis of STEM student entry into the teacher education.
3. Evaluation of factors of concern among STEM students in the teacher education.
4. Views of stakeholders in science faculty and teacher education.
5. Identification and prioritization of leverage points.

In the following sections, it is described how this stepwise systems thinking research approach has been operationalized and applied to the Dutch academic teacher education to analyse and understand the effect of the introduction of an undergraduate teaching module on STEM student career choice for teaching, and to identify leverage points to increase STEM students' entry into the academic teacher education.

3 | METHODS AND MATERIALS

The systems thinking research framework consists of five connected steps that each focus on a salient feature of the complex teacher education system. Table 1 provides an overview of the focus and instruments for each research step. In this study, data were collected from three different Dutch universities: Delft University of Technology, Leiden University and University of Groningen. The procedure was approved by the Leiden University ICLON Ethics Review Committee.

3.1 | Step 1: Representing a complex system as a conceptual stock and flow model with long-term behaviour

A schematic stock and flow model of the academic teacher education system was made by placing all required programs leading to a teaching qualification in chronological order and drawing connecting lines. Long-term student entry data for the mathematics and science bachelor studies and the mathematics and science graduate and postgraduate teacher training in the Netherlands were provided by the Association of Research Universities in the Netherlands (VSNU).

TABLE 1 Overview of the stepwise approach for a systems' thinking analysis and how it was applied to academic teacher education.

Stepwise research framework	Instruments
1. Conceptual stock and flow model and long-term behaviour (holistic)	• Identification of the components and interrelations of the academic teacher education program • Student entry data over time
2. Problem analysis	• Identification of the components and interrelations of the academic teacher education program including the undergraduate teaching module • Evaluation of internal and public information about the undergraduate teaching module and teacher recruitment • Exploratory interviews with students and lecturers involved in the teacher education program • Student flow data over time
3. Evaluation of factors of concern among students	Surveys among students from the undergraduate teaching module (based on the results of step 2)
4. Evaluation of factors of concern among stakeholders	Interviews with stakeholders from the management of the science faculties and the teacher training institutes (based on the results of step 2)
5. Identification and prioritization of leverage points	Combination of the results from the student surveys and the stakeholder interviews, and prioritization based on the hierarchy defined by Meadows (2009)

3.2 | Step 2: Problem analysis

For the problem analysis, three types of data were used: public and internal reports, student flow data and exploratory interviews with lecturers and students involved in the teacher training program. Public and internal reports and documents about the undergraduate teaching module and the academic teacher training were used for general background information. These included national policy documents, quality assurance and review reports, formal study guides and regulations for each participating university: Delft University of Technology, Leiden University and University of Groningen.

Student flow data were collected for each of these three universities and their teacher training institutes from the number of mathematics and science bachelor students eligible for academic teacher training modules and student entry numbers of the three teacher training institutes were retrieved for different education tracks, for a time period since the start of the first cohort of bachelor students eligible to the newly introduced undergraduate teaching module (which started in 2011 in Leiden and Groningen and 2013 in Delft). These data were used to describe student flows from the science and mathematics bachelor program into the undergraduate teaching module and subsequently to the combined graduate and postgraduate teacher teaching programs.

Exploratory interviews were conducted with a convenience sample of 12 teacher trainers involved in the undergraduate teaching module for science and mathematics school subjects from all three universities and 6 mathematics and science students who finished the undergraduate teaching module at Leiden University (cohort 2016–2017). The semi-structured interviews lasted for 30–60 min and addressed the following three general aspects of the undergraduate teaching module:

- Why do mathematics and science students choose for the undergraduate teaching module? (Entry factors)
- How is the undergraduate teaching module evaluated? (Teaching module)
- How does the career of mathematics and science students proceed after finishing the undergraduate teaching module? (Career choice)

Notes were taken by the interviewer (the first author) during each interview, and afterwards processed into a summarizing report.

Based on the exploratory interviews and the public and internal reports, first, second and third author discussed to identify issues of concern for the three categories (student entry, undergraduate teaching module, and career choice) which were considered worthwhile for further exploration because of their potential effect on student behaviour in the teacher education system.

3.3 | Step 3: Evaluation of factors of concern among students

The factors of concern identified in step 2 were evaluated using surveys among a larger cohort of science and mathematics students who pursued the undergraduate teaching module at the three universities (cohorts 2017–2018 and 2018–2019). The paper-and-pencil surveys were administered during lectures in the beginning and towards the end of the undergraduate teaching module. Each potential issue of concern (promotion of interest in teaching, perception of teaching, student information, course load, school placement, supervision and support, encouragement by school and teacher training institute, career choice and overall evaluation of undergraduate teaching module) was reformulated into a statement. The survey contained those statements that were scored using a 5-point Likert scale and one open question about career aspirations. The overall response rate of the surveys was 78%.

3.4 | Step 4: Evaluation of factors of concern among stakeholders

The factors of concern identified in step 2 were evaluated using semi-structured interviews (Denscombe, 2017) with the key stakeholders, being the representative from the science faculty concerned with educational affairs (vice-dean or director of education) and the director of the teacher training program. The interviews were audio-recorded and transcribed verbatim. The interviews with the science faculty representatives focused on the student entry factors and career choice of mathematics and science students, and the interviews with the directors of the teacher training institutes focused on student entry factors and appreciation of the undergraduate teaching module. To each of the stakeholders, the following two questions were asked:

- Why do STEM students choose for the undergraduate teaching module?
- What is the most important goal of the undergraduate teaching module?

The answers to these questions were thematically grouped.

3.5 | Step 5: Identification and prioritization of leverage points

The schematic model of the academic teacher education system defined in step 1 was used as a framework for data analysis. The qualitative and quantitative data acquired in steps 2, 3 and 4 were analysed according to this framework by the first, second and third author to identify leverage points. Prioritization of leverage points took place by using the systems thinking principle of hierarchy in intervention or leverage power (Meadows, 2009).

4 | CASE EXAMPLE: THE UNDERGRADUATE TEACHING MODEL IN THE DUTCH ACADEMIC TEACHER TRAINING

In the Netherlands, academic teacher education follows a consecutive model, like in many other European countries, such as the United Kingdom and France. This means that students first pursue an academic subject-specific study program and take a professional course in teaching after completing their master's program (Kempen et al., 2016).

In an attempt to increase teacher recruitment, the Dutch government introduced the undergraduate teaching module in 2009 as a new, attractive route towards a career in teaching for academic bachelor students. The goals of this undergraduate teaching module were threefold: (1) creating students' interest in teaching, (2) offering a teaching qualification for the lower years of secondary school, which, it was expected, (3) would lead to higher student numbers in the graduate and postgraduate teacher training (Rinnooy Kan et al., 2007). The undergraduate teaching module is a one-semester teaching module during the third and final year of the (subject-specific) bachelor study program. It consists of 30 European Credits (EC) of theoretical courses related to educational science and paedagogical content knowledge as well as a practical placement at a secondary school. Upon completion of this teaching module in addition to a subject-specific bachelor program, students receive a teaching qualification for the lower classes of secondary school. To obtain a full teaching qualification, these students can subsequently proceed to a two-year graduate teacher education program, or first finish a subject-specific master's degree and subsequently follow a one-year postgraduate teacher education program (which is comparable to a Postgraduate Certificate in Education (PGCE) in the UK). Students who successfully completed the undergraduate teaching module, receive an exemption of a maximum of one semester for the graduate and postgraduate teacher education program.

At Dutch universities, the teacher training program is organized in different ways. At some universities, teacher training is positioned as a separate institute within the university, but at others, it is organized as a department within a science or humanities faculty. Because of these differences, each undergraduate teaching module at each Dutch university has a unique curriculum and position within the academic organization. Table 2 shows the general characteristics of the three academic teacher training programs at the universities participating in this study. More specifically, it is described which faculties provide science and mathematics students eligible for the teacher training program, how the teacher training program is organized within the university, and how the curriculum of the undergraduate teaching module is organized by the ratio between theoretical courses and school placement.

TABLE 2 General characteristics of the academic teacher education at the universities participating in this study: Delft University of Technology, Leiden University and the University of Groningen.

	Delft University of Technology	Leiden University	University of Groningen
Faculties providing students with teacher training	Seven science and engineering faculties (including architecture, civil engineering, applied mathematics, physics, etc.)	Faculty of Science (biology, chemistry, mathematics and physics)	Faculty of Science and Engineering (biology, chemistry, mathematics and physics)
Teacher Training Organization	Master Science Education and Communication (part of the Faculty of Applied Sciences)	Leiden University Graduate school of Teaching (Interfaculty institute)	Teacher education (part of the Faculty of Social and Behavioural Sciences)
The curriculum of undergraduate teaching module	Theoretical courses 15 EC School placement 15 EC	Theoretical courses 15 EC School placement 15 EC	Theoretical courses 10 EC School placement 20 EC

4.1 | Step 1: Conceptual stock and flow model and long-term behaviour of the Dutch academic teacher education system

As in many other European countries, academic teacher education In the Netherlands follows a consecutive model. Therefore, a conceptual stock and flow model to describe the Dutch academic teacher education system focuses on student flow throughout the system and consists of two elements: an academic subject-specific study program followed by graduate or postgraduate teacher training (Figure 1). As a postgraduate teacher training can be done directly after obtaining the subject-specific master's degree but also many years later, there is a delay in student flow between completion of the subject-specific study program and entry into the academic teacher training.

The long-term behaviour of this system was determined from historical student entry data. Figure 2 shows that the number of students starting in chemistry, physics and astronomy, and mathematics bachelor studies has been increasing since 2007 while the number of students starting in the academic teacher training programs in a mathematics or science school subject remained more or less constant during that period.

This result is important because it provides information about the characteristic patterns of the academic teacher education system. More specifically, it shows that increasing the number of students eligible for the graduate or postgraduate teacher training does not naturally lead to increased student entry into those teacher training programs. Furthermore, these overall student flow data show that the introduction of the undergraduate teaching module in 2009 has not contributed to increased student entry into the combined graduate and post-graduate teacher training programs.

4.2 | Step 2: Problem analysis of the undergraduate teaching module within academic teacher education

The finding that the introduction of the undergraduate teaching module did not lead to an increase in student entry in the (post) graduate teacher training program demands a better understanding of student behaviour and the position of the undergraduate teaching module within the system of academic teacher education.

Based on the general conceptual model of student flows through the academic teacher education system in Figure 1, the conceptual stock and flow model was now extended to three elements: the subject-specific study program, the undergraduate teaching module, and the graduate and postgraduate teacher training (Figure 3). Between finishing the undergraduate teaching module and entering the graduate or postgraduate teacher training program, students first go back to their faculties to finish their subject-specific bachelor studies. Moreover, most students pursue a subject-specific master before entering postgraduate teacher training and the actual time between finishing the undergraduate teaching module and starting either with graduate or postgraduate teacher training appears to be one to 5 years. This is shown by a 'delay' sign in Figure 3. While anyone in the Netherlands who already has a master's degree in science or mathematics is eligible to enter the postgraduate teacher training program (irrespective of age and previous career), the undergraduate teaching module as shown in Figure 3 is specifically aimed at undergraduate students.

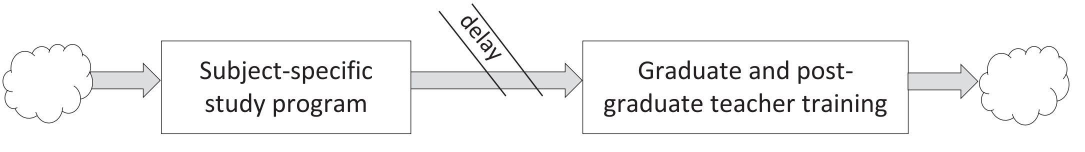

FIGURE 1 Conceptual stock and flow model of the system of the academic mathematics and science teacher education, consisting of the subject-specific study program and the (post) graduate teacher training. The flow of students is depicted by arrows, the boundaries of the system are represented by clouds (Meadows, 2009).

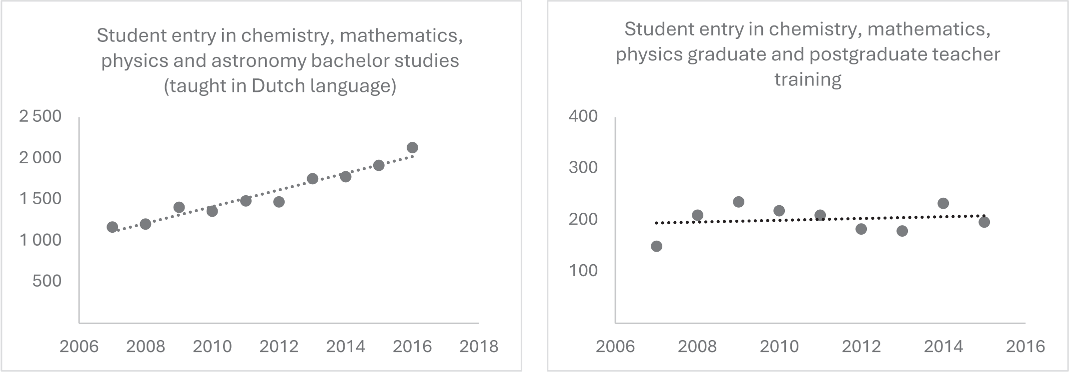

FIGURE 2 The number of students starting a STEM bachelor program compared to the number of students starting a STEM graduate or postgraduate teacher training in the Netherlands.

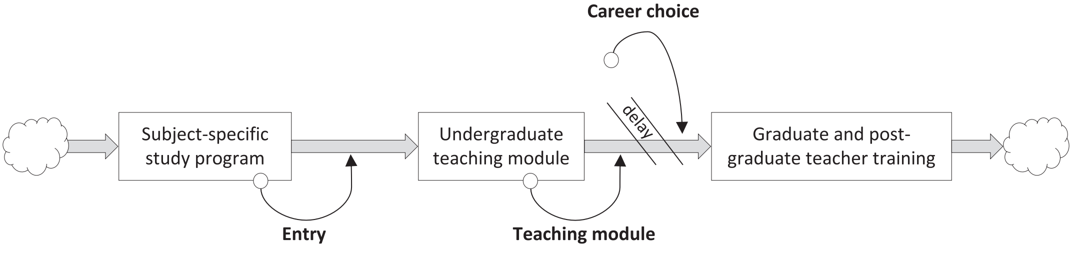

FIGURE 3 Schematic stock and flow model of the system of Dutch academic teacher education, consisting of three elements: the subject-specific study program, the undergraduate teaching module and the graduate and post-graduate teacher training.

Three phases are considered important for the student flow, and the effectiveness of the undergraduate teaching module:

- The entry of science and mathematics bachelor students into the undergraduate teaching module.
- The undergraduate teaching module itself.
- The entry of students who finished the undergraduate teaching module into the (post) graduate teacher training.

Based on public and internal reports and exploratory interviews with teacher trainers and students of the undergraduate teaching module, a list of factors was created that were expected to influence the recruitment of science and mathematics teachers. These potential issues of concern were categorized by system phase (Table 3).

In addition, student flow data were collected for the academic teacher training programs of each participating university (Table 4). Similar to the national trend, the number of students entering science and mathematics bachelor study programs at the universities participating in this study has been steadily increasing since 2007.

Table 4 shows that student flows through the undergraduate teaching module show a similar pattern for all three universities in this study: low student entry numbers, a relatively high success rate for the undergraduate teaching module, and moderate flow into the combined graduate and postgraduate teacher training programs.

The finding that the student flow pattern is institution-independent and does not appear to be related to any curriculum or organizational features, provides an indication for systems behaviour. In addition, the low entry numbers in the undergraduate teaching module are in accordance with the national data on student entry in the

TABLE 3 Potential factors affecting recruitment of science and mathematics teachers, based on public and internal reports (r) and exploratory interviews (i).

Student entry	Undergraduate teaching module	Career choice for teaching
• Promotion of students' interest in teaching (i) • Perception of teaching at science faculty (i) • Collaboration between science faculty and teacher training institute (i) • Student information at science faculty (i)	• Goal of the undergraduate teaching module (r) • Experience during school placement (r) • Supervision & support (i) • Course load (i)	• Personal career choice (i) • Barriers to enter the master teacher training (i) • Encouragement by the school and teacher training institute (i)

TABLE 4 Student flow data from the science and mathematics bachelor study into the undergraduate teaching module (UTM) and subsequently into the combined graduate and postgraduate teacher teaching program based on student data from Delft University of Technology, Leiden University and the University of Groningen.

	Period (cumulative)	*N* (total number of students eligible to UTM)	Entry in UTM (% of *N*)	The success rate of UTM	Entry into graduate and postgraduate teacher training (after UTM)
Delft	2011–2016	10.609	2.9%	86%	12%
Groningen	2009–2016	2.530	2.5%	84%	28%
Leiden	2009–1,016	1.853	4.1%	83%	19%

academic science and mathematics teacher training (as shown in Figure 2), indicating that there is a structural problem with science and mathematics students entering the academic teacher education.

4.3 | Step 3: Evaluation of factors of concern among students

A student survey was used to evaluate the potential factors of concern from step 2 among a larger population of students of the undergraduate teaching module. Table 5 contains student responses for a selection of statements from the surveys that are directly related to the factors of concern in Table 3. The results in Table 5 show that students from the undergraduate teaching module scored below average on statements addressing the entry of STEM students into the undergraduate teaching module, more specifically opportunities for teaching experience during the subject-specific bachelor study, and the perception of teaching as a profession among lecturers of science and mathematics faculties. Statements concerning the school placement and the program of the undergraduate teaching module were evaluated well above average. Interestingly, according to the survey responses, almost 60% of the students who finished the undergraduate teaching module considered education as a potential career option at the end of the undergraduate teaching module, which is much higher than the actual student entry numbers in the graduate and postgraduate teaching module, as shown in Table 4.

The low appreciation of teaching at the science faculty was also explicitly mentioned by students from the undergraduate teaching module during the initial explorative interviews. Students stated for example: 'I think that most science students do not choose for education, because education is not recommended by the faculty, nor despised, more tolerated' and: 'From the beginning, education is mentioned as a career option during career classes, but it seems that there is some kind of contempt for education, that it is work below your level'. The absence of opportunities for teaching experience during the subject-specific bachelor study is a problem of concern.

TABLE 5 Student responses to statements from the student survey (Cohorts 2017–2018 and 2018–2019).

	Statements	University[a]	Mean ± SD	Percentage of students that agree with the statement
Promotion of interest in teaching (Entry)	During my studies, I came into contact with teaching skills (Cohorts 2017–2018 and 2018–2019)	Leiden ($n = 12$)	2.42 ± 1.24	16.6%
		Groningen ($n = 16$)	2.25 ± 1.53	18.8%
		Delft ($n = 81$)	2.26 ± 1.17	14.8%
Teaching perception (Entry)	Within my study, lecturers promote teaching as a profession. (Cohorts 2017–2018 and 2018–2019)	Leiden ($n = 13$)	2.00 ± 0.71	0%
		Groningen ($n = 18$)	2.28 ± 0.67	5.6%
		Delft ($n = 76$)	2.29 ± 0.94	9.5%
School placement	My school was a nice place to work (Cohort 2017–2018)	Leiden ($n = 5$)	4.20 ± 0.45	100%
		Groningen ($n = 7$)	4.29 ± 0.76	85.7%
		Delft ($n = 37$)	4.46 ± 0.77	94.6%
Undergraduate Teaching Module	The undergraduate teaching module offered me a positive introduction to teaching (Cohorts 2017–2018 and 2018–2019)	Leiden ($n = 12$)	4.17 ± 0.72	83.3%
		Groningen ($n = 16$)	4.25 ± 0.58	93.8%
		Delft ($n = 81$)	3.96 ± 0.80	77.8%
Career	Education as a potential career option after UTM (Cohorts 2017–2018 and 2018–2019)	Leiden ($n = 12$)		75.0%
		Groningen ($n = 15$)		66.7%
		Delft ($n = 69$)		52.2%

[a]Delft University is a university of technology and only offers teaching qualifications in science and mathematics. Consequently, the student numbers in Delft are higher than in Groningen and Leiden.

4.4 | Step 4: Evaluation of factors of concern among stakeholders

In systems thinking, high-leverage interventions that have the most impact are aimed at underlying structures, for example, by changing goals or existing ideas about a system. Structured interviews were employed with management representatives from the science faculties and teacher training institutes from the three participating universities to elicit stakeholders' implicit views about the interest and motivation of STEM students for teaching and the goal and position of the undergraduate teaching module within the Dutch academic teacher education system. In policy documents, it is described that the intended goals of the undergraduate teaching module were threefold: (1) creating students' interest in teaching, (2) offering a teaching qualification for the lower years of secondary school, and (3) increasing student numbers in the graduate and postgraduate teacher training (Rinnooy Kan et al., 2007). The goal of the undergraduate teaching module is important because it is related to the underlying structure of the system, such as the content of the program and its position in the academic teacher education system. For example, an undergraduate teaching module predominantly aimed at creating students' interest in teaching (goal 1) could be expected to be less stringent on qualification requirements. Even so, an undergraduate teaching module predominantly aimed at qualification for teaching (goal 2) would benefit from activities creating students' interest in teaching during the prior subject-specific bachelor programs. In the current practice, the undergraduate teaching module is predominantly aimed at qualification for teaching (goal 2), and the intensive course program attracts mostly students who already have an interest in teaching.

Table 6 contains the views of stakeholders on the goal of the undergraduate teaching module and Table 7 is their views on the reasons STEM students choose for the undergraduate teaching module.

The implicit ideas of stakeholders on the goal of the undergraduate teaching module range from 'orientation' and 'creating interest in teaching' to 'qualifying' and 'preparation for teaching as a profession' (Table 6). In university 1, the representatives from the science faculty and the teacher training institute express opposing ideas on the goal of the undergraduate teaching module. In university 2, both stakeholders agree on the qualification goal, and in university 3, both stakeholders agree on the goal of creating interest in teaching.

Similarly, there is a large variation in stakeholders' answers to the question of why STEM students choose the undergraduate teaching module, ranging from 'experience whether teaching in secondary education suits them', 'developing social skills' and 'broaden career perspectives' (Table 7). Three stakeholders express explanations why STEM students don't choose the undergraduate teaching module, such as STEM students prefer 'deepening their knowledge', 'a subject-specific module is considered more valuable' and 'teaching is not on their priority list'.

The results from the interviews demonstrate that stakeholders from the science faculties and teacher training institutes express divergent ideas about the goal of the undergraduate teaching module within the academic teacher education as well as about the reasons why STEM students choose for the undergraduate teaching module.

The vision of the goal of the undergraduate teaching module, whether it provides an orientation on teaching or a qualification for teaching, or both, is important because it defines its position within the whole system of academic teacher education, as explained before. Moreover, the stakeholders' implicit ideas on the motivation for teaching of STEM students are important, because those ideas determine which interventions are considered successful by those stakeholders. For example, a statement like 'STEM students don't want to teach' suggests a fixed view on motivation: students are either motivated for teaching or not. A statement like 'STEM students choose for teaching to broaden their experience' suggests a more flexible view on motivation. A flexible view on students' motivation for teaching, the belief that it can be developed and that it is worthwhile for a science faculty to invest in this, is expected to support the implementation of interventions aimed at creating students' interest in teaching.

TABLE 6 Answers (verbatim) from science faculty and teacher training institutes representatives on the question about the goal of the undergraduate teaching module.

University	Science faculty representatives	Teacher training institute representatives
1	… from the vision of academic education, I consider it emphatically as real **orientation**	The most important goal is to **prepare students** as good as possible for the **profession as a teacher** in the lower classes in secondary schools
2	… currently, it is **a preparation for teaching as a profession**, and I think it should be changed [to attract more STEM students]	The undergraduate teaching module has 2 goals: first a bit of **orientation** to find out whether teaching suits you, and the second is a **qualifying goal**
3	I think that **orientation** is more important than qualification, because, in the end, we need more teachers who finish a postgraduate teacher education program	That students experience something that is worth the effort, with my hope that they actually like education so much that they want to pursue a career in education. So, **creating interest in teaching**…

Note: Key phrases are marked in bold.

TABLE 7 Answers (verbatim) from science faculty and teacher training institute representatives on the question of why STEM students choose the undergraduate teaching module.

University	Science faculty representatives	Teacher training institute representatives
1	… entry from mathematics, physics and astronomy bachelor studies is almost nil … The **physicists and mathematicians prefer deepening their scientific knowledge, instead of thinking let's try teaching** …	Actually, **most students choose to pursue a subject-specific module, because they find it more valuable, and only students who are really motivated for education** choose for the undergraduate teaching module, and in the end, the entry numbers are quite low.
2	… I think it will **be the more motivated students, those who are really motivated to become mathematics or physics teachers**. Science and engineering students are technically oriented. They have two goals: they want to become researchers or work in industry. **And teaching is not on their priority list**.	… if they choose for the undergraduate teaching module or the master teacher training, they mainly do this, because **they do not want to do research, to broaden their career perspectives**…
3	I think that those are **students that just want to experience whether teaching in secondary education suits them**… I think that in general many students do not know what their career aspirations are, and this is not only the case for teaching…	What I see is that students **often choose for the undergraduate teaching module, because they have some teaching experience**. Another reason is that **students like to do something different**, so not only working in a laboratory but also **developing social skills**.

Note: Key phrases are marked in bold.

4.5 | Step 5: Identification and prioritization of leverage points

The stepwise systems thinking analysis in the previous sections led to the identification of three leverage points, which are places in the system where a small change leads to a large shift in behaviour. The first identified leverage point is found in the transition from the subject-specific bachelor study program into the undergraduate teaching module. The student flow data revealed that a low number of STEM students chooses for the undergraduate teaching module. The student surveys and exploratory interviews revealed that currently, subject-specific bachelor study programs do not offer many opportunities to experience teaching and teaching skills, which was also confirmed by evaluation of the curricula of the study programs. In addition, the survey results confirmed that students do not experience that teaching as a profession is promoted by lecturers during the subject-specific bachelor study.

The second identified leverage point is found in the transition from the undergraduate teaching module into the graduate and postgraduate teacher training. While the student surveys showed that a considerable number of students express interest in education as a career option at the end of the undergraduate teaching module (57%, based on Table 5), this is not reflected in the student flow data which show that only 16% enters the graduate or postgraduate teacher training (Table 4). This suggests that there is potential for student recruitment after completion of the undergraduate teaching module, for example by fostering students' interest in education.

The third identified leverage point is found in the divergent ideas of stakeholders from the science faculties and teacher training institutes on the goal of the undergraduate teaching module within the academic teacher education system and on STEM students' choice for the undergraduate teaching module (Tables 6 and 7).

The higher the leverage the most impact an intervention will have. Meadows (2009) proposed a hierarchy of leverage points in which different types of interventions are categorized from lowest to highest leverage. According to this hierarchy, typical low-leverage interventions are aimed at changing numbers and flows, while typical high-leverage interventions are aimed at changing goals and paradigms, which is effectively the mindset out of which the system arises. In a similar way, Senge stresses the high leverage of 'mental models' by stating that many 'new insights fail to get put into practice because they conflict with deeply held internal images of how the world works' (2007, p. 163). Therefore, eliciting and challenging implicit ideas is the first step in shifting ways of thinking within an organization towards recognizing long-term patterns and underlying structures producing those patterns (Senge, 2007).

Based on these notions by Meadows (2009) and Senge (2007), it is expected that the highest leverage to increase STEM student entry in the academic teacher education system will be found in the implicit ideas of stakeholders from science faculties and teacher training institutes on STEM students' motivation for teaching and the goal of the undergraduate teaching module. Moreover, it is expected that when stakeholders from both science faculties and teacher training institutes hold shared visions and goals regarding the teacher training of STEM students within the academic teacher education system, interventions aimed at recruiting STEM students for a career in teaching will become more effective.

5 | CONCLUSIONS

The academic teacher education operates in a complex context: embedded in the academic study program, recruiting and preparing student teachers for the reality of everyday practice in schools. Until now, teacher education policy interventions have not been effective enough in recruiting and retaining secondary school teachers in mathematics and science.

Literature is rich with research that takes a more deterministic lens by studying only parts of the academic teacher education system, such as students' motivations for teaching and teacher education policy interventions. In this study, systems thinking is presented as an ecological approach to evaluate the systemic structure of an academic teacher education system and the fundamental and structural problems regarding STEM student entry with the purpose to identify leverage points for more sustainable interventions for STEM teacher recruitment.

The application of the five-step systems thinking framework to the Dutch academic teacher education system resulted in many new insights concerning the systemic structure of the academic teacher education system and the effectivity the undergraduate teaching module regarding STEM student entry. Long-term student flow data revealed that the introduction of the undergraduate teaching module had not contributed to student entry into graduate and postgraduate teacher training programs. Student surveys revealed that students of the undergraduate teaching module are very positive about their experiences during the undergraduate teaching module and their school placements. From stakeholder interviews, it became clear that stakeholders hold divergent views on STEM student motivations for teaching and the goal of the undergraduate teaching module.

The combination of these insights with the stock and flow model resulted in the identification of three leverage points to increase the effectivity of the undergraduate teaching module. The first leverage point is found in the lack of opportunities for teaching-related experiences and the low appreciation of teaching as a profession during the STEM study programs. The second leverage point is found in the low-transition rates from the undergraduate teaching module into the graduate and postgraduate teacher training. The third leverage point, which is expected to have the highest leverage, is found in the divergent views and goals of stakeholders from science faculties and teacher training institutes.

In addition to the research question, the systems thinking approach described in this study revealed three principles that contribute to new insights into the complex problem of effective academic routes to teaching.

Principle 1: Historic student flow data provide insight into the long-term behaviour of the academic teacher education system and systemic patterns. To visualize parts of the academic teacher education system, and the student flows (interactions) between those parts, a stock and flow model is a powerful tool. A limitation of this approach is that long-term data are sometimes difficult to acquire.

Principle 2: Students' motivation or career choice for teaching is not only a personal characteristic but student behaviour is also affected by the structure and purpose of the teacher education system. Herewith, systems thinking offers a more ecological approach compared to many other research studies in education which use only surveys to measure motivations for choosing teaching as a career (Heinz, 2015; Watt et al., 2012). A limitation of an ecological approach is that the outcomes are context-dependent, as every system has different characteristics. However, in this study, the three universities showed similar outcomes on student flow data, and student surveys, indicating systemic patterns.

Principle 3: Identification of leverage points is essential to get insight into underlying problems in the academic teacher education system and design more effective routes to teaching. A more thorough problem analysis combined with the notion of leverage hierarchy provides directions for redesign which go beyond straightforward interventions. A limitation is that redesigning existing systems on a deeper level is complex because it requires a shift in mindset or beliefs and attitudes from stakeholders and institutions involved (Forrester, 2016; Tamim, 2020).

A systems thinking approach is not a traditional, deterministic research approach with a stringent methodology. Instead, systems thinking strives for a better understanding of the behaviour of a system by a collection of long-term numerical data, but at the same time acknowledges that more insight will also raise more questions. In system thinking, models are used to clarify thinking, but they should be flexible and continuously challenged and tested against evidence. In this study, the model of the academic teacher education system has been validated by triangulation of a large amount of quantitative and qualitative data. A systems thinking approach is worthwhile for complex and persistent problems because a deeper understanding of complex systems provides new insights into the underlying problems. Such insights open new opportunities for optimizing existing interventions and designing new interventions in the academic teacher education system, which are expected to contribute more effectively and sustainably to the recruitment of qualified mathematics science and mathematics teachers.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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How to cite this article: Kuijpers, A. J., Dam, M., & Janssen, F. J. J. M. (2024). A systems thinking approach to capture the complexity of effective routes to teaching. *European Journal of Education*, *00*, e12623. https://doi.org/10.1111/ejed.12623