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Systematic Review

Structure of Science Teacher Education in PISA Leading Countries: A Systematic Review

Melina Doil [1,*] and Verena Pietzner [2]

[1] Institute of Chemistry, Carl von Ossietzky Universität Oldenburg, 26129 Oldenburg, Germany
[2] University of Vechta, 49377 Vechta, Germany; verena.pietzner@uni-vechta.de
* Correspondence: melina.doil@uni-oldenburg.de

Abstract: Within the surveys of the PISA study since 2001, large differences between the performance of the 15-year-old students in the scientific domain have become apparent. German students were able to improve their performance to a limited extent in the past surveys, despite extensive educational reforms. Despite the improvement in performance, Germany has not been able to catch up with the PISA-leading countries. Therefore, the question arises in regard to how teacher education in PISA leading countries (Canada, Finland, Japan, Singapore) is structured. The selection of the countries is based on best possible achieved results in the scientific competence area as well as in another competence area by the selected countries. A systematic review was conducted to clarify the structure as well as relevant content issues. The results indicate various possibilities for adaptation for German teacher education.

Keywords: PISA competencies; science education; systematic review; teacher education

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1. Introduction

The completed PISA studies in recent years examined the competencies of 15-year-old students in various educational areas, including the science domain. On average, students were able to reproduce basic concepts and facts in science. However, there were large differences between countries. The last PISA survey had shown that German students have not managed to catch up with the PISA-leading countries despite extensive education policy reforms. Since the 2018 study, competencies in scientific domains have been declining in Germany. For example, one-fifth of all participating students in Germany only achieved proficiency level II [1]. Based on the mediocre performance of German students in past surveys, the question therefore arises whether there are possible adaptations from PISA-leading countries for teacher education. This publication is based on the analysis of the PISA results and teacher education in the respective countries.

Previous systematic reviews have shown that the three-phase teacher education system in Germany has potential for improvement [2,3]. Teacher education in Germany is divided into the study program, the preparatory service and in-service training [4–6].

Within the study program for science teachers, there are strong differences in teacher education due to the federal education policy in Germany. Furthermore, content knowledge and pedagogical content knowledge vary between the different university locations [7]. The German preparatory service is characterized by high psychological stress, which is also the main reason for leaving this stage of education. The aim of the preparatory service is to train the prospective teachers both practically and didactically. In addition to the psychological stress, the biggest problems of the preparatory service are the non-transparent evaluation and a large discrepancy between the theoretically required and actually taught pedagogical content knowledge [2]. In Germany, continuing education courses are offered in a wide variety of subject areas and subject-specific pedagogical content knowledge. The arising problem for teachers is that they usually do not have the opportunity to take part in

continuing education courses, since the continuing education courses take place during school hours and the coverage of classes must first be ensured [3].

Based on the briefly presented problems in German teacher education, this publication now examines the teacher education systems of Canada, Finland, Japan, and Singapore. The countries just mentioned are among those that participated in the previous PISA surveys conducted by the OECD. Canada, Finland, and Japan are among the OECD member states. Singapore belongs to the partner countries of the OECD and, therefore, also participates in the PISA surveys. The selection of the countries is based on the performance within the science domain as well as another domain with the best possible results in the survey of 2018 [1]. Even though the performance of Finnish students in the last runs represents a downward trend, the performance is still above the German level [8]. Since the education systems of the different countries differ in their organization and focus, the aim of this publication is to identify commonalities of the leading PISA countries in their teacher education systems to derive possible adaptations for German teacher education. In this context, it must be pointed out that due to societal structures, the possible adaptations cannot be transferred one-to-one to German teacher education.

This paper looks at teacher education in the countries presented, as one aspect of success in previous PISA surveys. In addition to this aspect, the PISA studies reveal various other factors influencing the performance of the countries considered, but these are not included in this study, as this was not compatible with the scope of the review. Furthermore, this paper aims to provide an initial overview of the similarities and differences in teacher education, which will serve as a basis for further research.

Research Questions

Based on the initial situation of teacher education in Germany, the following two questions arise:

1. How is teacher education structured in the selected PISA leading countries?

This question aims at the structuring of teacher education. In this context, not only the different phases of teacher education but also organizational structures will be examined. To achieve comparability between the different countries, a pre-structuring will be done. In general, the three phases "study phase", "transition phase" and "in-service training" will be considered. Likewise, legal requirements regarding the restriction and prerequisites of teacher training are considered here.

2. How are PISA relevant competencies integrated into science teacher education?

Based on the elaborated structures of the PISA leading countries, the implementation of PISA relevant competencies in teacher education is investigated. This is relevant for the study because teachers can only teach competencies that they have learned themselves.

2. Materials and Methods

To address the questions, a systematic review [9–11] was conducted in accordance with the preferred reporting items by the PRISMA statement. For this purpose, an extensive online search was first conducted using the following search terms:

> "Lehrer*innenbildung, Lehrerausbildung, Gesetze zur Lehrerbildung, Lehramtsstudium, Praxisjahr, Praxissemester, Vorbereitungsdienst, Fortbildungen, Weiterbildungen, Teacher education, Teacher education laws, teacher study phase, pre-service, teacher training, internship semester, preparatory service, advanced (teacher) training, further (teacher) education"

All the search terms above were used in conjunction with the countries Japan, Canada, Finland, and Singapore. As explained in the Introduction, these countries were selected due to on their above-average performance in at least two PISA domains [1]. Using this structured search, a total of 171 publications were collected. To continue working according to the PRISMA guidelines for a systematic review, the collected publications were then validated within the working group based on previously defined criteria. For this review process, a guideline was designed to justify the decisions. First, all publications should have been published after 2004 because, in that year, a change in education policy was conducted in Germany. Furthermore, they were to come primarily from science education departments and, in addition, from general teacher education and pedagogical departments. A preliminary search showed a large variety of methods and subject areas within the main topic of teacher education. To present a comprehensive picture of science teacher education, we included both qualitative and quantitative sources. In terms of content, the publications were first classified into five main categories based on their title and abstract, which are briefly presented below. Publications that did not correspond to any of the main categories were not included in this work. After the review process, 94 publications remained to be used for the Systematic Review. The following Table 1 shows the steps performed.

Table 1. Categories and Subcategories.

Search strategy for online literature research	
Search Terms:	
• Lehrerbildung, Lehrerinnenbildung • Lehrerausbildung • Gesetze zur Lehrerbildung • Lehramtsstudium • Praxisjahr • Praxissemester • Vorbereitungsdienst • Fortbildungen • Weiterbildungen	• Teacher education • Teacher education laws • Teacher study phase • pre-service • teacher training • internship semester • preparatory service • advanced (teacher) training • further (teacher) education
↓	
The database search results in 171 publications	
↓	
Validation within the working Group based on the established criteria	
Inclusion Criteria:	
• Publications after 2004 • qualitative and/or quantitative data	• teacher education in science • general requirements for teacher training
↓	
Final Database contains 94 publications (see Appendix A)	
↓	
Content-related Analysis	
Categories:	
• Scientific Literacy • Nature of Science • Media and Information Literacy	• Career Motivation • Structural Analysis

For the content-related work, a total of five main categories with several subcategories were defined, which are briefly presented in the Table 2. The first three categories are aimed at PISA-relevant competencies.

First, the concept of Scientific Literacy and Research Based Learning within teacher education will be discussed. Hereby the OECD defines Scientific Literacy as "[. . .] the use

of scientific knowledge to identify questions, acquire new knowledge, explain scientific phenomena, and draw evidence-based conclusions about science-related issues" [12]. Extending the concept of Scientific Literacy, the concept of Nature of Science will be reviewed. Here, the work of Allchin and McComas will be referred to and appropriate subcategories will be formed according to their definitions [13–15]. The last PISA-related competence to be examined is Media and Information Literacy, as defined by UNESCO [16]. This involves the equipment of the individual institutions in which the preparatory service takes place, the thematization of digital media in the classroom and the active use of these. In addition to these three concepts, the self-concept of the prospective teachers will be examined under the umbrella term "career motivation". This includes the stress experience as well as the professional development of the teacher personality. Finally, to be able to embed all the previous concepts in the course of teacher education, the structure of the teacher education systems of the individual countries will be analyzed.

Table 2. Categories and Subcategories.

Category	Subcategory
Scientific Literacy	Use of scientific knowledge to identify questions Acquire new knowledge Explain scientific phenomena Draw evidence-based conclusions about science-related issues Research-based learning
Nature of Science	Communication about science Creativity Variety of scientific methods Social/-cultural impact Theory and scientific law Observation and conclusion Changeability of scientific knowledge
Media and Information Literacy	Equipment at school Use of digital devices
Career Motivation	Self-efficacy expectation Professional Motivation Stress experience
Structural Analysis	Federal states Duration Workload

In the context of this study, linguistic peculiarities are to be expected, since in the different educational systems of the countries terms such as "mentoring" are defined and implemented differently. In addition, social norms of individual countries have an impact on the publications under consideration. Furthermore, the structure of the review with the defined criteria results in a limitation, since only publications that fulfilled all presented criteria were considered. In addition, only the presented categories were examined, so that conspicuities in other areas of teacher education are not considered here.

3. Results

In the following, the different structures of teacher education are briefly described. Building on the structures, the PISA-relevant competencies are then considered. Based on the publications used, the structures can be presented as in Table 3:

Table 3. Overview of the teacher education structure.

Country	Phases	Organization	Selection Process	Study Phase Duration	Subject	Graduation	Transition Phase	In-Service Training
Canada	2	decentralized	Depends on University	3 Years	Biology, Physics, Chemistry	Bachelor	Mentoring	Master Degree Program
Finland	1	decentralized	VAKAVA Test	5 Years	Biology, Physics, Chemistry	Master of Education	Mentoring	Independent training
Japan	3	decentralized	General entrance test for universities	3 Years	Science	Bachelor	Mentoring	Study Lessons, in school training, prefectural training
Singapore	2	centralized	Top third of high school graduates	3 Years	Biology, Physics, Chemistry	Bachelor/Post Graduate Diploma	Mentoring	100 h per year

3.1. Study Phase

As can be seen from the table, in all countries, students first complete a degree program [17–19] or, in the case of Singapore, an undergraduate degree program (for high school graduates) or a Post-Graduate Diploma in Education program for students who have already completed a degree program [20]. The studies are completed with a diploma, Bachelor of Arts, Bachelor of Science or Master of Education. In Finland, for example, the master's degree is a prerequisite for working in schools [21], while in Canada, the master's degree is more of a continuing education program for in-service teachers [22]. In all the countries consulted, only one subject is studied. Following the example of teacher training in Finland, Singapore is currently working on academizing teacher training as well [23]. While, in Singapore and Finland, selection tests are compulsory in order to start the study program [23,24], in Canada, selection procedures are reserved for universities, and in Japan, there is a general entrance test for universities, which is set individually by each university. In all the countries surveyed, the teaching profession has a prestigious social status, which means that there are many prospective students. In Finland, for example, only about 10–15% of applicants receive a teaching degree each year [25,26].

Within this phase of teacher training, content knowledge, pedagogical content knowledge and pedagogical contents are taught in all four countries mentioned. In Canada, Finland and Japan, the administrative structure is quite like in Germany. Here, for example, the MEXT (Japan) or the respective ministries of education (Finland, Canada) issue general guidelines on the content of the study phase [17,24,26,27]. The implementation of these guidelines is the responsibility of the respective universities, which leads to differences in the chosen content and focus of the studies. Only Singapore has centrally prescribed contents of the study program by the Ministry of Education (MOE), which are taught and reviewed by the National Institute of Education (NIE) [23]. In Finland, in particular, in addition to the theoretical content of the course, great attention is paid to practical phases within the study phase. Here, the respective practical phases tie in with the theoretical content, so that a strong link between the two areas of study is established. In order to establish this connection, the pre-service teachers work on their own research projects during their studies, which makes the Finnish teacher study program research-based [18,28]. It becomes apparent that not only the time spent at school is relevant but also the subsequent contextualization of the internships at the university. It is repeatedly emphasized, especially in publications on Finnish teacher education, that the internships are offered in connection with (mostly research-oriented) seminars, so that the internships are always placed in a pedagogical content knowledge or pedagogical context [28,29]. Similar efforts can also be seen in Canada and Singapore, although here the practical phases are not as extensive as in Finland and depend on the chosen teaching profession of the students [22,30].

About the PISA-relevant competencies Scientific Literacy and Nature of Science, it must first be stated that the subjects that fall into the area of science differ between the countries, and thus, the teacher training for these subjects is also designed individually by the countries. While, in Finland, the different STEM subjects (biology, chemistry, physics, etc.) are taught individually, in Japan and Canada (and Singapore), they are combined into

one subject. Thus, the content knowledge that the prospective teachers develop during their studies is different. In addition, in Finland and Singapore, there is a tendency for students to switch from a science degree to a teaching degree [20,23,31]. In Finland, for example, this results in a high degree of similarity between the subject competencies of chemistry students and those of chemistry teacher trainees [31].

In Japanese and Singaporean science teacher education, the relevance of the connection between subject-specific theoretical and practical content is also emphasized for student teachers to be able to teach STEM in a conceptualized way. For this purpose, subject-specific and subject-didactic contents are taught in combination within the course of study. In addition, "Methods of natural science" are also taught in Japanese teacher training, which includes both the content of Nature of Science as well as subject didactic considerations on, for example, robotics competitions, to make the natural sciences more attractive. In this way, the prospective teachers are to be enabled to convey to their students that working in the natural sciences is a creative process [19,32,33]. In addition, prospective science teachers must take lectures as well as practical work around information and communication technology. These courses are intended for both lower and upper secondary school teachers.

As a result of the events within the COVID-19 pandemic, teacher education within Canada is being restructured to also teach Technological Pedagogical Content Knowledge to prospective teachers, as teachers are currently struggling to teach digital literacy. Also following from the COVID-19 experiences, a stronger research-based orientation of the teacher training program as well as a greater focus on teaching scientific literacy is being considered. This is currently being incorporated into the science teacher education program through the testing of new teaching concepts [34].

Media and information literacy is thus explicitly included in teacher training programs in Canada and Japan [22,32,35]. The relevance of digital competencies is also emphasized in Finnish education policy. Explicit mentions of how these competencies are to be integrated into teacher training courses are not available within the database. For Singapore, there are no data available on the specific teaching of media and information literacy within the curriculum.

3.2. Transition Phase

The transition from university to the teaching workforce is characterized by the same hurdles in all countries considered and is a challenging time for young teachers. Therefore, Guo's (2008) term "initial survival phase" is an apt summary of this section here [17]. Every teacher goes through this phase, whether the teacher education system is single-phase, two-phase, or three-phase envisioned by policy. What is evident in this phase, however, is the difference in the way young teachers are treated immediately upon entering the profession. In general, young teachers are confronted for the first time in their careers not only with students but also with parents, school structures, and colleagues [36]. To help with this transition, mentors are available in Canada and Japan to support young teachers during their first year [36,37]. Most of the time, mentors are assigned to supervise young teachers, which in Finland, for example, leads to holding on to old ideas about teaching within the school [38]. In Japan, on the other hand, this transition phase is combined with 100 h of training on various topics in addition to mentoring.

The content of the training varies between pedagogical and subject didactic content [37,39,40]. In addition, the entire teaching staff of a subject works on improving the quality of teaching with the help of lesson studies. Lessons are reviewed unannouncedly by representatives from the school authorities in lesson visits. If it is found that the quality of teaching does not meet the desired standards, the young teachers are required to take part in further training [39,41]. In Japan, a distinction is also made between different mentor groups, which set different priorities in mentoring. The focus of mentoring is placed on newcomers to the profession or on subject-specific tasks [27,37].

In Finland, there is no statutory induction phase. However, the so-called "peer group mentoring" was introduced nationwide in 2010, which is intended to support young teach-

ers in their career entry. Within this offer, career starters are given the opportunity to exchange ideas about the challenges of the profession under the guidance of a trained mentor [37]. Since Finnish teacher education is single-phase, there are no further examinations after completion of the master's program [29]. Although no mentoring is provided from the policy side, offers of group mentoring are provided by individual school boards to facilitate entry into the teaching profession [42]. Within Singapore, there are no explicit offerings for this phase.

3.3. In-Service Training

As outlined at the beginning of the Results, the required degrees for teaching qualifications differ in the selected countries. In Canada, a bachelor's degree is required to teach in a school. Once in the classroom, teachers could participate in a variety of professional development programs that lead to either a Graduate Diploma in Education (GDE) or a Master of Education in Educational Practice (MEd EP). Here, the advanced training measures differ in content. While specific topics such as Inclusive Education or Mentoring and Leading are taught for the GDE, the Master of Education in Educational Practice primarily offers methodological course work [22].

In Japan, in-service teacher training is structured in three levels. Within the school, there are two training formats: Lesson Studies and Professional Lectures. For Lesson Studies, lessons are developed together with the Review Panel, taught by teachers, and then evaluated with their colleagues. Here, the pedagogical content knowledge considerations, the methodical implementation as well as the personal teaching style are evaluated. The focus of the evaluation depends on the needs of the school. The goal is to continuously improve the school's internal teaching by following a fixed sequence of steps [19,27,32,40,41,43]. In addition to these school-internal training measures, there is a wide range of training offered both by the respective prefectural training centers and by MEXT. The local training centers are under the responsibility of the local government (Board of Education). Instruction inspectors (experienced teachers) work in these training centers and are responsible for teacher training in the communities [37]. The highest level is the national training center for teachers, which is a government organization under the surveillance of MEXT. In addition to these training opportunities, it should be noted that active teachers are required to participate in in-service training [27,43].

In Finland, unlike in Japan, there has been no external quality control for teachers since 2000 [44]. Due to their extensive studies, in-service teachers are regarded as professional and trustworthy by society [29]. Independent training with the help of scientific papers is restricted due to partially limited access rights. For science teachers, for example, the Association of Teachers of Mathematics, Physics and Chemistry offers annual in-service days for science teachers [45]. Finland and Singapore also offer ITE programs to keep up with technological advances in education. In addition, teachers in Singapore are entitled to 100 h of in-service training per year. In addition to the aforementioned ITE programs, there is a wide range of courses on offer, primarily in the areas of subject didactics, pedagogy and lesson planning [18,30].

4. Discussion

As the results have shown, there are different approaches to successful teacher education in the PISA leading countries. This is mainly due to cultural as well as structural differences between the individual countries presented. In the following, special features of teacher education from Canada, Finland, Japan, and Singapore are highlighted, which offer adaptation possibilities for the further development of teacher education. Looking at the results presented in more detail from the perspective of the two questions presented, the following overarching observations can be made.

Regarding the first research question, it can be stated that the political guidelines for the structure of teacher education are similar, but there are sometimes major differences

in the actual implementation. Therefore, to establish comparability, three different phases were examined, which are not provided in all countries by politics.

Looking at the study programs, the first major common feature of all the countries surveyed is that the teacher training program is designed for only one subject. This means that the countries have a subject focus that does not exist in Germany, for example. Furthermore, a clear selection of the best potential students can be seen, which is realized through grades or entrance exams designed specifically for the teaching profession. The extensive internships in Finland, which are now also being incorporated into teacher training in Canada and Singapore, seem to be extremely relevant in international teacher education [18,22,28,30]. That this connection is relevant for the educational success of the internships is shown by the results from Canada, where, despite the internships, a large discrepancy between the studies and the actual profession is still criticized by career starters [17]. These differences between the individual countries show that not only the offer of internships is important but also how the experiences of the students are processed within the study program and used for the further course of studies. While the internships in Finland are already a highly researched field, the example of Canada shows that a more detailed monitoring of the internships is of great interest for the further development of study contents.

No uniform structures can be identified for the transition phase in the selected countries. Only the use of mentors to support or further educate the prospective teachers can be found in all countries. In this context, it is of great interest for further work on how mentoring differs in detail in the countries, since based on the data used for this work, only the distinction between career-oriented mentoring and socially supportive mentoring can be made [34,37,42].

In-service training is the final component of international teacher education. In this area, all four countries place great value on in-service training. In Japan and Singapore, particular attention is paid to ensuring that teachers participate in a certain number of relevant in-service training courses. A distinction can be made between internal and externally organized training [37,43,46–48]. Due to the clear relevance of this phase in all countries, a more detailed examination of the structures of Lesson Studies, for example, as well as Singapore's in-service training program should be made based on the findings presented here.

Regarding the second research question, it can be stated that the PISA-relevant competencies are taught to (prospective) teachers in a wide variation of offerings.

Looking first at the concepts of scientific literacy and nature of science, both concepts are taught in different settings in the countries [19,20,28,32]. The publications evaluated show that both concepts are primarily addressed in courses and laboratories specific to the teaching profession. In all countries, there is an effort to train the prospective teachers sufficiently in conveying not only subject knowledge but also scientific methods to the students.

In addition, Finland, Japan and Singapore show a strong effort to closely link subject-specific scientific and didactic content. Likewise, a great relevance of scientific literacy in the teacher training program emerges in the countries considered, in which, for example, lab practices are offered in direct connection with subject-specific lectures and subject-specific didactic seminars [19,20,28,32]. In addition, seminars on the "Method of natural Science" are offered in Japan, which put the basic ideas of Scientific Literacy and Nature of Science into a school-related context [19]. Furthermore, the example of Finland shows that the prospective teachers have a similar level of expertise as the students from the subject sciences [31]. In Japan and Singapore, too, good content knowledge is seen as a basis for being able to plan good lessons [32,49]. Moreover, about Canada, it can be added that the teachers' convictions also make for good science teaching. It can be deduced from this that structured and extensive subject knowledge is considered essential for teachers in PISA-leading countries.

A similar picture emerges when looking at the concept of media and information literacy. The digitalization of recent years makes it essential to address Media and Information Literacy within teacher education. The COVID-19 pandemic has reinforced the relevance of digital media in the educational context in recent years. In this regard, Canada, in particular, shows in the publications used a great effort to integrate digital education in teacher education [22,34,35]. This is not limited to the teacher training program but also includes continuing education measures. Japan, Finland and Singapore also show an explicit interest in integrating media and information literacy into teacher training in sciences. Here, the courses offered in sciences teacher education refer to ICT [30,32].

The results of the two questions show that teacher education in the selected PISA leading countries is similar in some respects, such as the number of subjects studied. In particular, the preparation of school internships, the integration of mentoring in the transition phase and the structures of in-service training programs such as Lesson Studies appear to be promising topics for more in-depth research as well as possibilities for adaptation in the structural area of teacher education. Extending the points already mentioned, the conception of courses that teach Scientific Literacy, Nature of Science as well as Media and Information Literacy seems to be a concept worthy of further consideration. In addition to these results, it also seems to be of interest to what extent the students perceive the teaching of the presented concepts as relevant for their further career.

Based on these results, the points just mentioned will be analyzed in more detail regarding possible adaptations for German teacher education.

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Appendix A

Overview of the Literature Used for the Systematic Review

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