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Student teachers' opportunities to learn through observation, own practice and feedback on the practice while in field practice placements: a graphical model approach

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Abstract

Field practice placement is a crucial part of teacher education, as it affords a real-life context, where teacher and teacher-related skills can be enacted and trained. The present study examined the associations between student teacher opportunities to learn through observation, own practice and the receiving of feedback of said practice, while in field practice placements through a teacher education programme. Chain graph models were used to analyse data from 560 Danish student teachers who had just completed field practice at one of three levels. Results showed that opportunities to learn through observation of fellow students and other teachers was negatively associated with level of field practice, and thus was reported less and less the further along students were in the programme, while opportunities to learn through own practice was positively associated with level of field practice. Opportunities to learn through receiving feedback on own practice was associated with level of field practice only via opportunities to learn through own practice. Results did not reveal gender or age-wise inequity in the opportunities to learn afforded in the field practice. Teacher education programmes could benefit from placing additional focus on opportunities to learn through observation in the later field practice placements.

Keywords: Teacher education; Field practice placement; Opportunities to learn; Chain graph model

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1. Introduction

Teacher education differs across cultures and countries, but a common denominator is that it consists of two parts; the academic (on-campus) part and the non-academic or skills (in schools) part. The manner in which these parts are organized to form a teacher education programme also differs, and the most common form appears to be a subject matter Bachelor degree followed by an education degree at the Masters level, which includes in-school training (Weisdorf, 2020). Teacher education has been a subject of study for many decades (Menter, 2022). Two of the prevailing issues studied are the quality of teacher education, with a more recent strand focusing on the coherence of the academic and non-academic parts of teacher education (e.g. Canrinus et al., 2017; Grossman et al., 2008; Youngs et al., 2022), and the non-academic parts in themselves (e.g. More, 2003; Ulvik et al, 2021).

The non-academic parts of teacher education, also denoted clinical experience, pre-service teaching, student teaching placements, practicum, or field practice placement (the latter term will be used throughout this article) is an integral part of teacher education, as it offers unique opportunities to learn the non-academic skills needed to become a teacher. The research on field practice placements in teacher education appears to be focused mainly on the role of universities and schools (for field practice), what is best learned where and from whom, and teacher development and identity (Menter, 2022). Only more recently, research on opportunities to learn while in field practice has appeared (e.g. Cohen & Berlin, 2020; Nielsen, 2021; Youngs et al., 2022). Opportunities to learn while in field practice are here used to mean opportunities to learn by engaging in real-life teaching activities in the field practice placements, thus focusing on the training of teacher-skills aspects of the education. Cohen and Berlin (2020) divide these into opportunities to engage with representations and decompositions of practice and opportunities to approximate or enact teaching practices. In the current study, both aspects are included as distinct opportunities to learn in field practice: representations of practice through opportunities to learn through observing other teachers, enactment of teaching practice though own practice, and decompositions of practice through receiving feedback on own practice (c.f. Nielsen, 2021).

Hammerness et al., (2020) studied opportunities to learn in teacher education through study, practice, and rehearsal of teaching in five countries. However, the context was not field practice placements, but campus coursework. Opportunities to learn in field practice placement has however, been studied by e.g. Youngs et al. (2022), who had mixed findings, as they found that in mathematics, opportunities to learn about and practise content-specific ambitious instructional practices, during student teaching, were positively associated to their first-year teaching practice through their representation of content and instructional scaffolding. On the other hand, Youngs et al. (2022) also found that these opportunities to learn were negatively associated with the students' ability to create or maintain a productive learning environment.

In the context of Danish teacher education, it appears that only two single studies have been conducted on opportunities to learn while in field practice. Nielsen (2021) used the Field Practice Experience scales (FPE-DK) and found that students who had completed the *first* two (of three) field practice placements scored significantly and substantially higher on opportunities to learn through Observation than did students who had completed the third and thus all field practice placement. With regard to opportunities to learn through own Practice, students who had just completed the *last* two field practice placements scored significantly, but not substantially higher than did students who had completed only the first field practice. Lastly, students who had completed the *last* field practice placement just prior to taking the FPE-DK scored significantly although not substantially higher on opportunities to learn through receiving Feedback on their practice than students who completed the first field practice did. Nielsen and Graf (2021) explored the specific teaching and teaching-related activities in the FPE-DK scales and found differences in which specific opportunities to learn were experienced in the first, second and third field practice placement.

In Denmark, teacher education is an integrated programme focusing on coherence between the teaching subjects, the pedagogical and didactical subjects, and the field practice placements, within a single four-year long teacher education programme (Weisdorf, 2020). Teacher education in Denmark awards a so-called professional Bachelor's degree.

In the Danish teacher education programme, the Ministry of Education and Research regulates the field practice placement, which amounts to a total of 30 ECTS (European Credit Transfer System), which is equivalent to half a year's worth of study intensity. Within a specific teacher education programme, there can be as many as six field practice placements. However, independently of the number of placements, these should demonstrate an education-wise progression corresponding to the nationally defined skills and knowledge objectives within three defined areas of competence for each of three levels of field practice. The competence areas and the included skills and knowledge objectives for each level of field practice are described in Nielsen (2021, the S1 File at https://doi.org/10.1371/journal.pone.0258459.s009).

Students obtain teaching competence in usually three and at least two teaching subjects (Ministry of Education and Research, 2015). One teaching subject has to be Danish or mathematics, while the remaining teaching subject(s) can be any subject taught in primary and lower secondary school. In the teacher education programme studied in the current study, field practice is placed within the first, third and fourth years of study and at varying times in the academic year, depending on the time of admission to the teacher education programme (summer or winter). Furthermore, at the university college in question, there are two campi each with a summer and a winter intake of students, which follow somewhat different study plans, where the time-wise relationship between the various teaching subjects and the field practice is not the same. In the part of the curriculum for the field practice specific to the university college it is explicitly stated that the students should be provided the opportunity both to observe teachers teaching and to practise teaching themselves in all placements (UCL Erhvervsakademi og Professionshøjskole, 2022). In addition, the field-practice handbook at this university college states that it is important in relation to the students' learning processes that they provide each other with feedback and that a three-party (i.e., students, campus teacher and field-practice teacher) supervisory talk is mandatory midway through the placement (Larsen, 2021). Lastly, there is a contractual agreement with the field-practice schools that they should provide a minimum of one hour's supervision and feedback each week for the students.

Recently Nielsen (2021) introduced and validated the three field-practice experience scales (FPE-DK). This instrument is the first Danish instrument to measure specifically the learning opportunities the student teachers experience through observing, practising and receiving feedback on certain teaching-related activities in field practice placement. Thus, the FPE-DK provides the means for investigating students' experienced opportunities to learn through both observation, own practice and feedback on this practice in a standardized manner in the different field practice placements in the Danish teacher education programme.

1.1 The current study

The aim of the current study was thus to conduct a first study of the relationships between opportunities to learn through observation, own practice and receiving feedback while in field practice, as measured with the FPE-DK, with the level of field practice students had just completed as well as the interrelationship between the three field experience scales themselves. This will be investigated while taking into account the dependence (or independence) of the three types of opportunities to learn on the type of teacher education programme students were enrolled in, the campus they studied at, as well as their gender and age, and the relationships between these educational and background variables.

Specifically, it was expected that two of the field practice experience scales would be positively associated with the level of field practice, so that the "rate" of Observation and own Practice would increase with the level of field practice, as students become more advanced learners and therefore can

engage more and more in these processes. No association was expected between level of field practice and the third scale; receiving Feedback on own practice, as there is an equal expectation of the amount of feedback provided at each level of field Practice and the degree of Feedback would then rather be associated directly to the degree of opportunities to learn through own Practice. Lastly it was expected that the three field practice experience scales would be positively associated with each other.

2. Methods

2.1 Participants and data collection

Participants were student teachers (N = 560) who had just completed 6 weeks of field practice placement in a Danish public school (primary and lower secondary school) as part of the Danish teacher-training programme at one of the Danish university colleges. Data were collected using an online survey during four weeks immediately after students had completed field practice placements.

The majority of the students were enrolled in the regular Bachelor of Education programme (85.1%) at one of the two campi (72.9% versus 27.1%) of the university college (Table 1). The majority of the sample identified as female (70.5%), and the mean age of the sample was 26.8 years. These numbers match the distribution of students admitted to this particular university college. Information on the level of the students' latest field practice (i.e. the one in question), was collected from the study administration at the university college. The distribution of field practice levels was uniform in the study sample, one third at each level (Table 1).

Table 1.

Characteristics of the study sample (N = 560).

	Frequency (%)
Campus	
Campus A	408 (72.9)
Campus B	152 (27.1)
BA education programme	
Regular	480 (85.7)
Other	80 (14.3)
Latest field practice placement	
Level 1	185 (33.0)
Level 2	188 (33.6)
Level 3	187 (33.4)
Gender	
Female	395 (70.5)
Male	165 (29.5)
Age groups	
23 years and younger	190 (33.9)
24-26 years	198 (35.4)
27 years and older	172 (30.7)
Mean Age (SD), range	26.8 (6.9), 19-65

2.2 Instruments

The three field practice experience scales each measure student teachers' opportunities to learn through observation, own practice (i.e. enactment) and feedback on their practice of 12 teacher practices while in field practice placement, as part of their teacher education programme (Nielsen, 2021). Student teachers report whether or not they have had the opportunity to observe, practice and/or receive feedback on the 12 teacher practices. Eleven of the 12 teacher practices originated from the Development of Ambitious Instruction (DAI) project (available at www.daiproject.weebly.com). These items were changed by Nielsen (2021) to not refer to teaching mathematics, but instead to refer to subject-specific teaching or to have no specific reference, and a new response scale was designed. These changes were made by Nielsen (2021) so that the instrument could be used with a student-teacher population with diverse teaching subjects and several of them (c.f. the introduction) – see Cohen and Berlin (2020) for the original items directed towards mathematics education). The 12th teacher practice "facilitation of a good socio-emotional learning environment" was suggested by a group of Norwegian researchers to tap into the more relational side of classroom management (Nielsen, 2021). The three resulting 12-item field-practice experience scales were named Observed scale, Practiced scale and received Feedback scale to signal the type of learning opportunities the students experience through the teaching-related activities in field practice placement, while the instrument was named FPE-DK for Field Practice Experience - Danish Language version (Nielsen, 2021). The items of the three field practice experience scales are available in both English and Danish in Nielsen (2021).

As the three field practice experience scales have previously been shown to fit the Rasch model (Nielsen, 2021), the sum score is considered to be a sufficient statistic for the estimated person parameter. In the current study, the choice was thus made to use the sum scores of the three scales in the chain graph model. The sum scores are in reality counting scales where the scores signify the number of opportunities to learn in field practice though observation, through practice and through feedback related to 12 teaching practices, as experienced by the teacher students. The score distributions of the three scales are shown in Figure 1.

Reliabilities reported by Nielsen (2021) were: Observed scale 0.92, Practised scale 0.65, Received feedback scale 0.87. In the current study, reliabilities were similar (Table 2).

Table 2.

Mean (SD) and reliabilities of the three field practice experience scales.

Scale	Min	Max	Mean	SD	Cronbach's alpha
OTL through Observation	0	12	7.29	4.15	0.92
OTL through own Practice	0	12	10.36	1.92	0.69
OTL through Feedback on practice	0	12	8.49	3.51	0.88

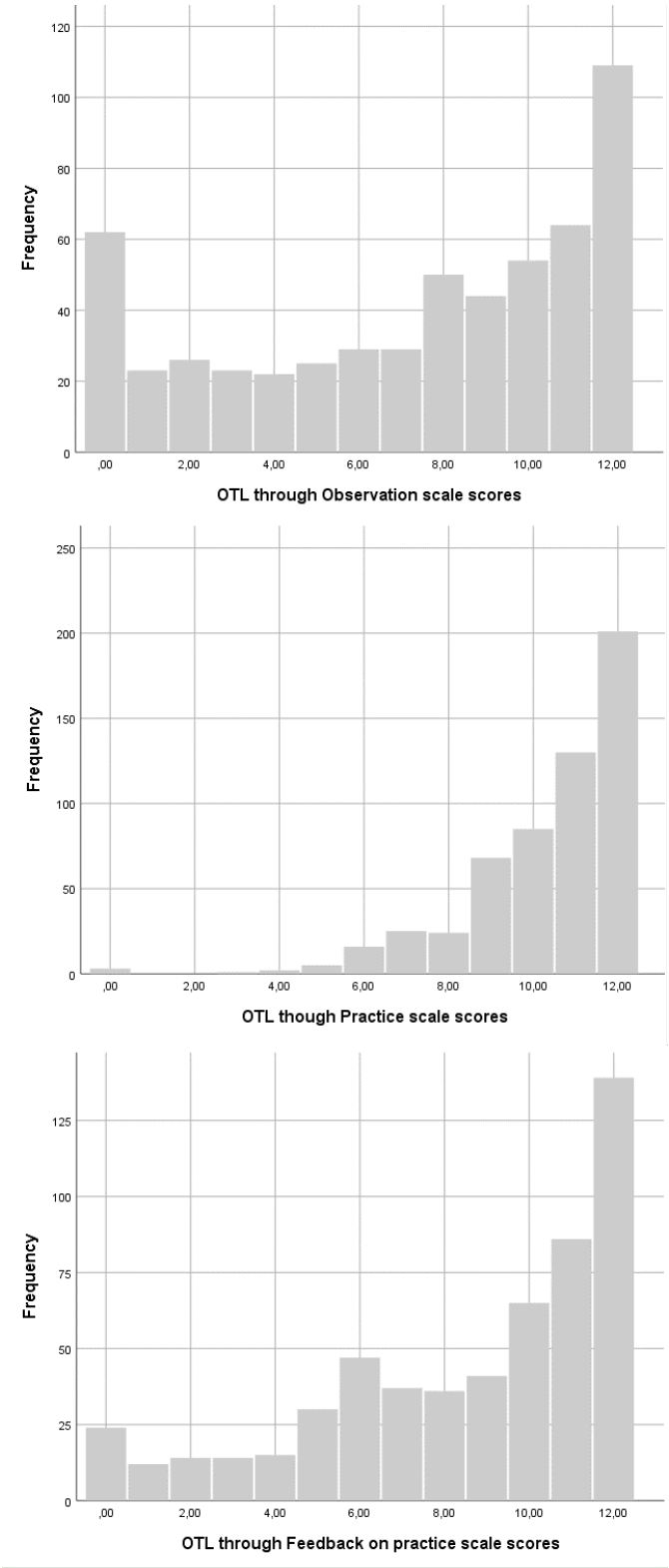

Figure 1. Distribution of scores on the three field experience scales; opportunities to learn through Observation (top), own Practice (middle), and receiving Feedback on practice (bottom).

2.3. Statistical methods

Chain graph models (Lauritsen, 1996) consist of nodes representing variables, directed arrows representing causal associations and undirected edges representing non-causal associations (the latter are not present in the more commonly used Directed Acyclic Graphs, DAGs). Chain graph models have a block-recursive structure where arrows are present between blocks, and edges are present within blocks. All paths between any two variables can be determined by the graph structure. Thus, it is possible to identify a minimum set of variables to condition on when estimating the direct association between two variables, and thereby simplify the analysis (for further details on analysis by graphical models see Lauritzen, 1996, and Kreiner et al., 2009).

The use of chain graph models allowed assessment not only of the relationships between each of the three field practice experience scales and the level of field practice, and the additional background variables; the type of teacher education programme students were enrolled in, the campus they studied at, and the gender and age of the students. The method at the same time allowed assessment of the associations between the three field practice experience scales themselves. Log-linear chain graph models (Lauritzen, 1996) were used and not structural equation models, as the latter would presume at least interval level scale and normally distributed data, which was clearly not the case here (Figure 1), while the log-linear chain graph models are appropriate for counting and ordinal level scales.

Figure 2 shows the block-recursive structure underlying the analysis. Block A consisted of age and gender time with arrows pointing to the blocks occurring later in time. Block B consisted of the campi students were studying at and the type of teacher education programme they were enrolled in, again with arrows pointing to the blocks occurring later in time. Block C consisted solely of the level of field practice of the students. Finally, Block D consisted of the three field practice experience scales.

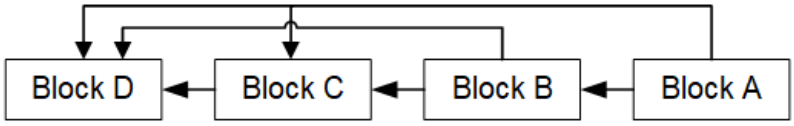

Figure 2. The block structure of the chain graph model used in the study.

Notes. Block A: age and gender. Block B: campus and type of teacher education programme. Block C: level of field practice. Block D: the three field practice experience scales.

The correlation structure was determined based on statistically significant correlations using partial Goodman-Kruskal gamma (γ) correlations (Davis, 1967; Goodman & Wallis, 1954; Kreiner, 1987). The gamma coefficients are rank correlation coefficients for ordinal categorical data, where a γ-coefficient > 0.30 is regarded as a strong association, and a γ-coefficient < 0.10 a weak association.

The DIGRAM software package was used to defines and test the chain graph model (Kreiner, 2003). An automated screening procedure for high-dimensional contingency tables was used first to define a somewhat simpler starting model than the full block-recursive model. This was followed by a stepwise manual model selection strategy aimed at improving the starting model and finally identifying an adequate model for data (Kreiner, 1986). Decisions about including or eliminating interactions in the manual strategy were based on both the strength of the associations and the strength of the evidence (i.e. *p*-values). Thus, on the one hand, weak associations (i.e. $\gamma < 0.10$) were not considered unless the evidence was very strong. On the other hand, strong associations were not considered if the evidence was very weak. The strength of the evidence was evaluated on a continuum distinguishing between weak ($p < 0.05$), moderate ($p < 0.01$) and strong ($p < 0.001$) evidence, as recommended by Cox and colleagues (1977).

Having reached a final model, this was confirmed by testing the necessity of including the associations in the final model as well as testing the adequacy of the associations in the final model. Subsequently, partial correlations were estimated for all associations in the final chain graph model.

The issue of multiple testing was dealt with by controlling the false discovery rate (FDR) using the Benjamini-Hochberg procedure (Benjamini & Hochberg, 1995). The problem of estimating the γ-coefficients and p-values using asymptotic methods was dealt with by using a Monte Carlo procedure with 400 samples to obtain exact *p*-values.

3. Results

The results in the form of a final chain graph model showing associations and the lack thereof (i.e., conditional dependence/independence) are shown in Figure 3 including the partial correlations. No causality other than that imposed by time is implied in the graph (from right to left, cf. the recursive structure in Figure 2).

The three field practice experience scales are mutually associated, so that there are is a strong positive association ($\gamma = 0.30$) between opportunities to learn through Observation and through receiving Feedback on own practice. Also, there is an even stronger positive association between opportunities to learn through own Practice and receiving Feedback on this practice ($\gamma = 0.67$). It should be noted that the latter association is to some degree artificially high, as it is, of course, not possible to score highly on opportunities to learn through Feedback on own practice, if you have not also scored highly on opportunities to learning through own Practice, but it is possible to score highly on Practice, but not so on Feedback (cf. the score distribution in Figure 1). These findings are not entirely in accordance with the a-priory expectations, as the graphical model revealed that there was no positive association between the degree to which students reported opportunities to learn through Observation and through own Practice, in fact these were conditionally independent given the remaining associations in the model.

With regard to conditional dependence (or independence) of the three field-practice experience scores on the included education, the substantial results were first and foremost in relation to the level of the field practice just completed. Opportunities to learn through Observation was strongly and negatively associated with level of field practice ($\gamma = -0.37$), opportunities to learn through own Practice was moderately and positively associated with level of field practice ($\gamma = 0.25$), while opportunities to learn through Feedback on own practice was not associated with level of field practice. Thus, the a-priory expectation of positive associations between the level of field practice and opportunities to learn through Observation and own Practice was only confirmed for own Practice, while a negative association was found for Observation. In addition, there was a weak negative association between the type of teacher education programme students were enrolled in and opportunities to learn through Observation, signifying that students in the regular programme experienced fewer opportunities to learn through Observation than did students enrolled in for example, a trainee programme or a programme for professionally trained students.

With regard to student characteristics such as gender and age, there were no associations (direct or indirect) between the three field practice experience scores and gender. Thus, the degree to which the students experienced having had opportunities to learn through Observation, own Practice and Feedback on own practice, was independent of gender. Age on the other hand was indirectly associated with students' reported opportunities to learn through Observation, own Practice or Feedback on own practice, as all paths from age to the three field practice experience scores passed through either the type of teacher education programme students were enrolled in or the level of the field practice they had just completed.

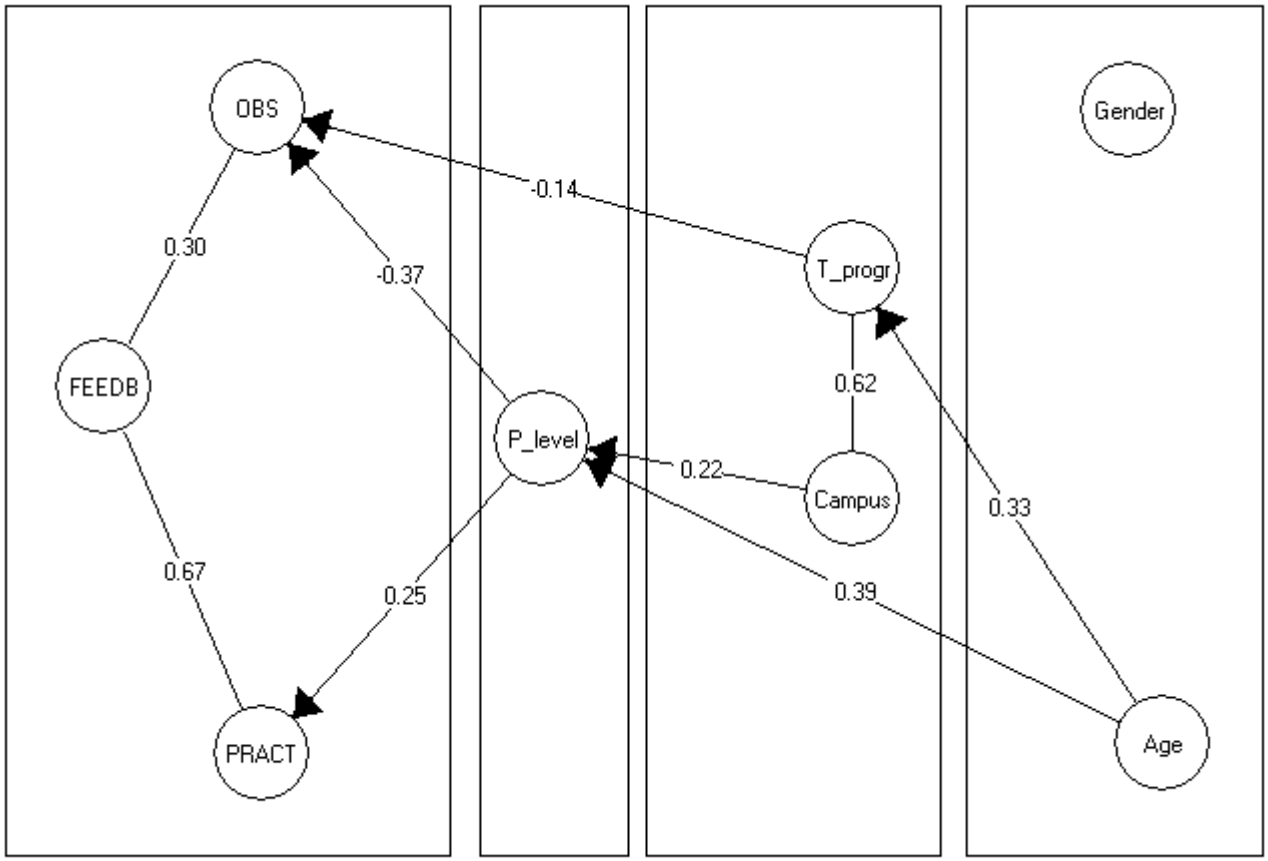

Figure 3. The final chain graph model

Notes. All lines represent significant conditional associations between variables. Correlations are partial Goodman-Kruskal gamma-coefficients (γ).

The results of testing the necessity of the associations in the final model are included in the Appendix (Table A1), as are the results of testing the adequacy of the associations in the model (Table A2).

4. Discussion and implications

The study was primarily aimed at investigating the relationships between the three field practice experience scales; opportunities to learn through Observation, opportunities to learn through own Practice, and opportunities to learn through receiving Feedback on practice, and the levels of field practice students had just completed, as well as the interrelationship between the three field experience scales themselves, to confirm or reject the a-priory expectations of these associations (see current study for details).

The expected positive association between opportunities to learn through Observation and opportunities to learn through own Practice on the one side and level of field practice just completed on the other was only partially met. Only opportunities to learn through own Practice was positively correlated to the level of field practice just completed, while opportunities to learn through Observation, on the other hand, was negatively correlated to the level of field practice just completed. That inexperienced students would observe more than more experienced students might seem an obvious finding. However, when considering the fact that student teachers become more advanced thinkers and

learners through the education, as they learn methods of observation and methods of reflection on these observations as applied to their own pupils, it can also be interpreted as a negative finding. Negative, because the students' advancement as learners are not exploited through increased observation of other teachers, and thus the scaffolding of their teaching self-efficacy through vicarious experience and reinforcement (Bandura et al., 1963) is not optimized. In previous research on observation by student teachers, the focus is more often on the benefit for the student who is being observed and receives feedback from the observing student (e.g. Baeten & Simons, 2014), and not the vicarious benefit of the observing students.

The expected lack of a direct association between opportunities to learn through Feedback and the level of field practice was confirmed. Thus, opportunities to learn through receiving Feedback is only associated with the level of field practice indirectly through opportunities to learn through own Practice. While the correlation between opportunities to learn through own Practice and receiving Feedback on this practice is very high, it is also apparent that not all students are provided this opportunity to learn (c.f. Figure 1 and 3). This finding is in line with the findings of Nielsen and Graf (2021), who found that between 9% and 30% of 345 Danish student teachers reported not having received feedback on 11 of the 12 teacher and teaching activities they had practised during the field practice placement. Thus, it appears that not all student teachers are provided with the classical opportunity of learning and relearning through a feedback-feedforward loop (Hermansen, 2003) in relation to their own Practice, but rather some are left to construct their own learning based on their Practice. Baeten and Simons (2014) found that student teachers benefitted from being observed when enacting and practicing teaching and subsequently receiving feedback on this practice from fellow student teachers. This is further supported by Hill and Grossman's work on learning through teacher observation, which promotes observation and feedback as significant tools in teacher education as well as teachers' post-degree development (Hill & Grossman, 2013).

All three types of opportunities to learn were conditionally independent of gender as well as conditionally independent of age given the level of field practice. While this cannot be considered evidence of equity, it shows that there is no evidence of gender or age *inequity* in the opportunities for learning through observation, own practice and receiving feedback on this practice in the field practice placements of the teacher education. Thus, the teacher education programme appears on track to comply with the Education 2030 Framework for Action (UNESCO, 2015) on gender and age equity with regard to the field practice placement parts of the programme. Research has previously been done on the subject of equity, when it concerns the academic knowledge parts of teacher education aimed at enabling future teacher to ensure gender equity in their own teaching of pupils (e.g. Kollmayer et al., 2020; Lucas-palacios et al., 2022). However, no such research has been identified in relation to teacher training programmes ensuring gender equity in the teaching or opportunities to learn of the student teachers themselves.

Nielsen (2021) called for an extension of the FPE-DK instrument to provide better coverage in regard to a wider set of teacher and teaching-related skills objectives for field practice in the Danish teacher education, thus covering more and more diverse opportunities to learn in this context. In the summer of 2023, a reform of the teacher education programme was implemented in Denmark and field practice will be expanded. Thus, while the 12-item version of the three field practice experience scales provided new insights into the opportunities to learn while in field practice in the current Danish teacher education, it is expected that an expanded version of the FPE-DK will provide new insights into the reformed teacher education field practice. In addition, the 12-item version of the FPE-DK can be used for comparative studies of the reformed teacher education field practice with the current one, and it can be used for international comparisons, as it is available in English.

4.1. limitations

One limitation of the study consists of the predefinition of the recursive structure of the model. Thus, it might be argued that the three variables denoting the level of field practice, the type of teacher

programme followed and the campus in which students were enrolled, should have been placed at the same recursive level in the model, thus allowing them to have undirected associations. The choice of the current structure was based on the time-wise presence of these variables, as campus and the type of teacher education programme is determined already upon application, and level of field practice follows after that.

Another circumstance of the study, which could be considered a limitation, is that the teaching subject(s) of the students were not included as a background variable in the model. As the Danish student teachers obtain teaching competence in usually three (sometimes only two) subjects out of all the subjects taught in the public schools, and these subjects are followed at different times and in varying sequences in the teacher education programme, it would have required many questions in the survey to construct a variable reflecting this. It was deemed unlikely that such a variable would be useful in the analysis, as it would have too many categories to makes sense. However, in hindsight, information on which of the two "forced choice" subjects that was chosen by each student (i.e. Danish language and mathematics) could have been included and may have added to the model.

Another limitation of the study consists of the low reliability of the own Practice scale compared to the other scales. It is not an easily remedied limitation, as it stems from the lower variability in the study sample on this scale compared to the other scales (Figure 1). Inclusion of student teachers from more university colleges and thus other field practice schools might increase the variability in the scores somewhat. However, as the main activity in field practice placements in the teacher education is to practise teaching and other teaching-related skills, it is likely that the own Practice scores will remain right skewed as variability will not increase. It is more likely that the low reliability could be remedied by extending the scales, as already suggested by Nielsen (2021).

A last limitation consists of the limited scope of the findings, as they currently address the Danish teacher education and may extend to countries with a similar structure of teacher education (e.g. Sweden and Norway). This is a very common limitation in research on teacher education, as most is situated in a single-country context. However, as the instrument is available in English and is easily translated to other languages, future research could have a wider and a cross-cultural scope, by including countries in the model.

Keypoints

- Opportunities to learn through observation, own practice and feedback on practice, while in teacher education field practice is studied
- Such opportunities to learn have not previously been studied to determine their relationships with the progression of teacher education programmes
- Chain graph models for ordinal data are used to study these relationships in the Danish teacher education context
- Opportunities to learn through observation of fellow students and other teachers declined as the programme progressed
- Opportunities to learn through own practice increased as the programme progressed

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Ethics

No ethical approval is needed in Denmark for research involving only survey data. Participating students were informed of their right to withdraw from the study at any time prior to data anonymization, as well as of all other rights and of how their data would be treated in accordance with current European data protection regulations.

Data availability

Data is available at Zenodo.org, DOI: 10.5281/zenodo.8123855

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Appendix

Table A1

Testing the necessity of the associations in the final chain graph model.

```
Testing 13 Separation hypotheses related to existing edges

-------------------------------------------------------------------------------------------
                        p-values    p-values (1-sided)    95% confidence
Hypothesis       X²  df asymp exact  Gamma  asymp exact        interval    nsim     n
-------------------------------------------------------------------------------------------
 1:A&C|B      913.3 712 0.000 0.005   0.25  0.000 0.000     [0.15 - 0.34]  1000    554  xx ++
 2:A&C|D      637.4 432 0.000 0.000   0.36  0.000 0.000     [0.30 - 0.43]  1000    560  xx ++
 3:A&D|BE     250.9 206 0.018 0.031  -0.34  0.000 0.000   [-0.44 - -0.24]  1000    555  x  --
 4:A&D|CE     365.9 312 0.019 0.033  -0.40  0.000 0.000   [-0.50 - -0.29]  1000    558  x  --
 5:A&E|D       34.0  36 0.565 0.578  -0.14  0.053 0.041    [-0.31 - 0.03]  1000    560     -
 6:B&C|A     1415.1 789 0.000 0.000   0.67  0.000 0.000     [0.59 - 0.75]  1000    560  xx ++
 7:B&C|D     1030.2 312 0.000 0.000   0.67  0.000 0.000     [0.62 - 0.73]  1000    560  xx ++
 8:B&D|A      188.7 158 0.048 0.044   0.38  0.000 0.000     [0.26 - 0.50]  1000    560  x  ++
 9:B&D|C      137.3 130 0.314 0.439   0.12  0.046 0.049    [-0.02 - 0.27]  1000    560
10:D&F|H       17.6   6 0.007 0.007   0.22  0.003 0.006     [0.06 - 0.37]  1000    560  xx ++
11:D&H|F       87.8   8 0.000 0.000   0.39  0.000 0.000     [0.28 - 0.50]  1000    560  xx ++
12:E&F         36.6   1 0.000 0.000   0.62  0.000 0.000     [0.37 - 0.86]  1000    560  xx ++
13:E&H         12.0   2 0.003 0.003   0.33  0.000 0.000     [0.14 - 0.52]  1000    560  xx ++
-------------------------------------------------------------------------------------------
Benjamini Hochberg rejects if p <  0.044 for FDR = 0.05
                          and p <  0.007 for FDR = 0.01
Significance of
X²        xx : FDR = 0.01    x : FDR = 0.05
Gamma  ++/-- : FDR = 0.01  +/- : FDR = 0.05
```

Table A2

Testing the adequacy of the associations in the final chain graph model.

Testing 34 separation hypotheses relating to missing edges

Hypothesis	X^2	df	p-values asymp	p-values exact	Gamma	p-values (1-sided) asymp	p-values (1-sided) exact	95% confidence interval	nsim	n
1:A&B|CD	835.4	766	0.041	0.614	0.10	0.049	0.041	[-0.02 - 0.22]	1000	529
2:A&F|DE	73.0	67	0.288	0.287	0.14	0.015	0.016	[0.01 - 0.27]	1000	560
3:A&G|DE	75.4	67	0.224	0.216	0.13	0.022	0.019	[0.00 - 0.25]	1000	560
4:A&H|DE	131.7	134	0.541	0.610	-0.08	0.050	0.043	[-0.18 - 0.02]	1000	560
5:B&E|AD	109.8	121	0.758	0.810	0.04	0.378	0.524	[-0.19 - 0.26]	21	517
6:B&E|CD	117.4	97	0.078	0.157	0.14	0.158	0.196	[-0.14 - 0.43]	102	456
7:B&F|AD	130.3	135	0.599	0.875	0.07	0.208	0.292	[-0.10 - 0.24]	24	549
8:B&F|CD	88.8	102	0.821	1.000	-0.05	0.328	0.333	[-0.28 - 0.18]	21	477
9:B&F|DE	35.1	40	0.691	0.429	0.01	0.439	0.476	[-0.14 - 0.16]	21	560
10:B&G|AD	139.3	137	0.430	0.750	0.08	0.167	0.208	[-0.08 - 0.24]	48	554
11:B&G|CD	124.1	102	0.068	0.177	0.13	0.100	0.145	[-0.07 - 0.34]	124	491
12:B&G|DE	47.0	40	0.206	0.217	0.13	0.026	0.030	[-0.00 - 0.27]	1000	560
13:B&H|AD	273.4	267	0.381	0.762	0.01	0.433	0.429	[-0.12 - 0.14]	21	555
14:B&H|CD	259.6	229	0.080	0.381	-0.05	0.260	0.476	[-0.20 - 0.10]	21	523
15:B&H|DE	75.7	80	0.615	0.571	-0.05	0.180	0.286	[-0.16 - 0.06]	21	560
16:C&D|AB	347.0	302	0.038	0.667	0.06	0.277	0.292	[-0.13 - 0.25]	24	509
17:C&E|AB	150.1	120	0.033	0.204	-0.15	0.183	0.204	[-0.47 - 0.17]	54	382
18:C&E|AD	207.9	191	0.190	0.381	-0.03	0.396	0.333	[-0.23 - 0.18]	21	517
19:C&F|AB	186.0	160	0.078	0.429	0.09	0.237	0.286	[-0.15 - 0.33]	21	469
20:C&F|AD	223.7	211	0.262	0.691	0.11	0.077	0.079	[-0.04 - 0.27]	1000	549
21:C&F|DE	77.2	61	0.079	0.062	0.09	0.081	0.100	[-0.04 - 0.23]	1000	560
22:C&G|AB	177.1	162	0.197	0.810	0.07	0.300	0.333	[-0.18 - 0.32]	21	476
23:C&G|AD	224.9	215	0.307	0.714	0.07	0.175	0.333	[-0.08 - 0.22]	21	554
24:C&G|DE	81.1	61	0.043	0.034	0.14	0.014	0.015	[0.01 - 0.26]	1000	560
25:C&H|AB	404.7	326	0.002	0.163	-0.04	0.344	0.380	[-0.22 - 0.15]	92	531
26:C&H|AD	456.4	416	0.084	0.289	0.04	0.245	0.237	[-0.07 - 0.16]	38	555
27:C&H|DE	135.1	122	0.197	0.225	0.00	0.492	0.525	[-0.10 - 0.10]	40	560
28:D&E|FH	6.6	12	0.881	0.952	0.07	0.289	0.333	[-0.17 - 0.30]	21	560
29:D&G|FH	16.2	12	0.184	0.190	-0.13	0.062	0.058	[-0.29 - 0.04]	1000	560
30:E&G|H	4.2	3	0.239	0.333	0.01	0.481	0.571	[-0.25 - 0.27]	21	560
31:F&G|E	2.8	2	0.252	0.228	-0.19	0.049	0.054	[-0.41 - 0.03]	1000	560
32:F&G|H	3.2	3	0.368	0.317	-0.12	0.128	0.118	[-0.32 - 0.09]	246	560
33:F&H|E	5.4	4	0.249	0.242	0.04	0.321	0.333	[-0.13 - 0.22]	33	560
34:G&H	3.1	2	0.209	0.190	0.11	0.072	0.072	[-0.04 - 0.25]	1000	560

Benjamini Hochberg rejects if p < 0.001 for FDR = 0.05
and p < 0.000 for FDR = 0.01

Significance of
X^2 xx : FDR = 0.01 x : FDR = 0.05
Gamma ++/-- : FDR = 0.01 +/- : FDR = 0.05