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Title   Reducing Fragmentation in University Pre-Service Teacher Education – Conditions and Strategies

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Abstract   We report on findings from a design research project in higher education that aims to overcome pre-service teachers' experiences of fragmentation in their educational programmes. We have developed an approach to reduce fragmentation in which we initiate and conduct boundary crossing between subject matter and subject matter didactics courses at university. Following

this approach, the design principle *boundary crossing by design(ing)* for interlinking subject matter and subject matter didactics has been developed and implemented in two subjects in pre-service teacher education at university, one in mathematics and one in English language teaching. The linking between subject matter and subject matter didactics we strive for is twofold: On the one hand, it requires curricular and organisational *dovetailing* of the courses involved (boundary crossing by *design*). On the other hand, it needs a study space where pre-service teachers are urged to try to *interlink* the courses' contents in their thinking and acting (boundary crossing by *designing*). Following our design principle, a nested design approach is implemented in which pre-service teachers' designs of teaching practice is interlocked with the design of courses at university level. This practical outcome is complemented by theoretical findings about the new phenomenon of linking course contents in teacher education at university and its conditions of success. We illustrate two kinds of findings with empirical examples: A *conditional model* for the intertwined realisation of the two types of linking, and *interlinking strategies* as heuristics for the pre-service teachers' thinking and acting.

Reducing Fragmentation in University Pre-Service Teacher Education – Conditions and Strategies

Erik Hanke / Stefanie Hehner / Angelika Bikner-Ahsbahs

1.0 Introduction

Research indicates that pre-service teachers[1] often perceive components in their study programmes of higher education as unrelated (Hellmann, 2019; Mehlmann & Bikner-Ahsbahs, 2018). In this context, many of them also tend to regard subject matter courses in the respective disciplines as little relevant to their teaching profession (e.g., Cramer, Horn, & Schweitzer, 2009). To solve this problem, often characterised as fragmentation, the Teacher Education Policy in Europe (TEPE) network has called for explicitly "linking educational sciences with subject methodologies" (Hudson & Zgaga, 2017, p. 6). Recent research on *coherence* (Brouër, Burda-Zoyke, Kilian, & Petersen, 2018; Degeling et al., 2019; Glowinski, Borowski, Gillen, Schanze, & von Meien, 2019; Hellmann, Kreutz, Schwichow, & Zaki, 2019; Meier, Ziepprecht, & Mayer, 2018) has addressed this problem by investigating coherence at the organisational level of teacher education study programmes. Little is known about how to improve such coherence, more precisely, how to develop concrete transferable conceptions, tools and strategies for teaching designs that establish more coherence, and how these designs may affect the students' perception of fragmentation. "Spotlights Lehre" ('Spotlights on teaching') contributes to fill this gap by solving the problem of fragmentation at the University of Bremen conducting an educational design study. This study develops subject matter and subject matter didactics courses (domain-specific pedagogy) (Rothgangel & Vollmer, 2020) in two sub-projects, "Spotlight-Y" in mathematics and "Varieties of English in Foreign Language Teacher Education" in English linguistics, which allow for linking their contents. Our design study is guided by three research questions:

1) Which design characteristics of courses for subject matter and subject matter didactics in teacher education programmes foster the linkage between course contents?

2) Which conditions foster or hinder the formation of links between subject matter and subject matter didactics, both on course level and in pre-service teachers' thinking and acting?

3) In which ways do pre-service teachers relate course contents from subject matter and subject matter didactics in their thinking and acting?

[1] A pre-service teacher is a student enrolled in a teacher education programme at university.

These questions lead to the two types of interrelated findings in design-based research: findings from design choices and from theory building. The first research question addresses the development of teaching designs involving a specific design principle. The second and third research questions aim to reconstruct conditions of success, as well as theoretical and empirical insights to be included in the re-designs (see Prediger, 2019). This way, we achieve three interconnected results: A design principle, a conditional model of success for linking subject matter and subject matter didactics, and a concept for how pre-service teachers enact this linking in their thinking and acting.

The outline of the article is as follows: Section 2 describes the problem of fragmentation, which we wish to mitigate in the two subjects mathematics and English as a foreign language. In section 3, we first define the concepts of *dovetailing* ('Verzahnen') and *interlinking* ('Vernetzen') (subsection 3.1) of *subject matter knowledge* and *subject matter didactical knowledge* (*SMK* and *SMDK*) in pre-service teacher education as specific forms of relating the course contents. Then, we present the teaching designs from the mathematics and English course as a reaction to the problem statement (subsections 3.2 and 3.3). Here, we also describe subject specific circumstances and our design changes over the course of three years. In section 4, we elaborate on the overarching framework and in section 5 on our methods of data collection and analysis.

We subdivide our results into three parts. The main result on the design level is the design principle *boundary crossing by design(ing)*, which methodically guided nested design cycles and was thereby developed, enacted, and confirmed in three sequential steps (section 6). Section 7 contains an answer to research question 2) in form of a conditional model for dovetailing and interlinking. Section 8, responding to question 3), provides three types of interlinking strategies, which describe how pre-service teachers actually link subject matter and subject matter didactics in their thinking and acting. In the last section, we summarise our results and embed our research into the broader discourse on *coherence* in teacher education.

2.0 Problem Statement: Fragmentation in University Teacher Education Programmes

In Germany, teacher education programmes at university are divided into subject matter ('Fachwissenschaft'), subject matter didactics ('Fachdidaktik') and educational sciences ('Erziehungswissenschaft'). When speaking of subject matter (SM), we refer to the academic discipline, which unfolds to the students during their study programme, *not* the school subject with its special activities (Deng, 2012; Stengel, 1997; Vollstedt, Heinze, Gojdka, & Rach, 2014). Subject matter didactics (SMD) is the academic discipline that focuses on research of learning and teaching a particular subject (Rothgangel & Vollmer, 2020). It mainly deals with the teaching and learning of the school subject, questions about the ontology and epistemology of the subject in gen-

eral, as well as societal and anthropological circumstances (Rothgangel & Vollmer, 2020; see also Eckhardt, 2019; J. Bauer, Diercks, Rösler, Möller, & Prenzel, 2012). Academic research in subject matter didactics is also concerned with the education of pre- and in-service teachers. We call the scientific knowledge addressed in these courses *subject matter knowledge (SMK)* and *subject matter didactical knowledge (SMDK)* respectively.

Empirical studies indicate that pre-service teachers of several subjects perceive the mentioned study components as only poorly related to each other; particularly the subject matter is seen as a rather isolated part in the study programmes (Abel, 2006; Cramer, Horn, & Schweitzer, 2009; Hellmann, 2019). In this case, it is assumed that this perceived fragmentation stems from the fact that subject matter, subject matter didactics, and educational sciences are usually taught in separate courses, often even in different faculties (König et al., 2018). Furthermore, said components also seem to be valued differently: Whereas components that are closely linked to teaching practice – such as subject matter didactics, for example – are often considered important for the future teaching profession, many students only see little relevance in subject matter components (T. Bauer & Partheil, 2009; Cramer, Horn, & Schweitzer, 2009). A reason for this impression might be the complex and abstract nature of subject matter contents, in particular in mathematics, which are not always directly addressed in school and therefore seen as less important for the actual teaching practice (Hefendehl-Hebeker, 2013). In this case, seeing subject matter as a detached study component with little relevance for the teaching profession can cause motivational problems that inhibit the learning process (T. Bauer & Partheil, 2009); consequently, students are at risk of developing only a rudimentary base of knowledge in the subject matter. Since profound knowledge in both the subject matter and subject matter didactics is necessary for successful teaching (Mehlmann & Bikner-Ahsbahs, 2018), this critical situation demands more research, which addresses practical approaches to reducing fragmentation.

Against this backdrop, several attempts to improve university teacher education in German speaking countries have been realised in the past years. As a part of this objective, many projects have aimed to strengthen the links between the study components subject matter and subject matter didactics in different subjects and with individual emphasis (e.g., Barzel et al., 2016; T. Bauer & Partheil, 2009; Beutelspacher, Danckwerts, Nickel, Spies, & Wickel, 2011; Diehr, 2018; Freudenberg, Winkler, Gallmann, & von Petersdorff, 2014; Hecke, 2010; Prediger, 2013; Weiglhofer, 2004). Moreover, a federal campaign funded by the German Ministry of Education and Research (BMBF) has been implemented in 2016 with the aim to reduce fragmentation and improve coherence in higher education teacher training: This superordinate initiative "Qualitätsoffensive Lehrerbildung" consists of numerous projects developing individual interdisciplinary approaches to link subject matter, subject matter didactics, and educational sciences with different foci (Brouër et al., 2018;

Glowinski et al., 2019; Hellmann et al., 2019; Meier et al., 2018). One of these projects is "Spotlights Lehre", which links courses in subject matter and subject matter didactics and by that aims to link knowledge from these two areas in pre-service teachers' thinking and acting.

3.0 Project Characteristics and Design

"Spotlights Lehre" approaches the previously described challenges in three ways: By designing innovative teaching formats, which dovetail subject matter and subject matter didactics on the curricular level in different subjects, by investigating conditions of dovetailing and inter-linking, and by reconstructing pre-service teachers' interlinking strategies (Mehlmann & Bikner-Ahsbahs, 2018). The project exemplarily focuses on two subjects: The sub-project "Spotlight-Y" is located in mathematics and the sub-project "Varieties of English in Foreign Language Teacher Education" in English linguistics. In three iterative cycles, innovative teaching formats for both subjects have been developed, put into practice, empirically validated, and refined on the design level as well as on the theoretical level. During this process, we examined the linkage of SMK and SMDK and its conditions with portfolio scaffolds. After defining our concepts *dovetailing* and *interlinking* in the next subsection, we briefly describe the teaching designs in the two sub-projects, including the developments over the course of the three cycles, before moving to a more abstract level and presenting the joint findings.

3.1 Dovetailing and Interlinking

To distinguish between the institutional and the individual level of linking course contents, we introduce two different kinds of links between subject matter and subject matter didactics in teacher training (Hanke & Bikner-Ahsbahs, 2019; Mehlmann & Bikner-Ahsbahs, 2018): *Dovetailing* ('Verzahnen') and *interlinking* ('Vernetzen'). Dovetailing deals with links between SMK and SMDK on an institutional and structural level of the study programme. Interlinking is concerned with the procedural linking of SMK and SMDK within pre-service teachers' thinking and acting. Dovetailing can thus comprise various curricular aspects, such as the design of courses for a pre-service teachers' study programme, and the actual ways in which teacher educators put their course design into practice. These, however, need not necessarily result in students' interlinking. Interlinking may become visible when pre-service teachers demonstrate connections between SMK and SMDK, for example, when they create tasks, which implement contents coming from subject matter courses, and justify their decisions during this process by using SMDK.

The literature shows that the main kind of linking dealt with in research so far is dovetailing, while interlinking (on the cognitive and performative level) is rarely explicitly addressed. In addition, there is only little empirical research providing insight into how SMK and SMDK

can be dovetailed on the curricular level, how pre-service teachers can be supported in interlinking both knowledge components and how this interlinking occurs in the students' thinking and acting.

3.2 "Spotlight-Y" in mathematics

Pre-service mathematics teachers attend many of their lectures together with students in the pure or applied mathematics Bachelor programme. In "Spotlight-Y", we developed an innovative lecture format for these lectures in terms of a so-called *Y-model* (Hanke & Schäfer, 2018). Lecturing according to the Y-model means that the lecture is split up after a joint part, which all students attend (around 10 of 14 weeks of teaching), into two *profession specific branches*. The branch for pre-service teachers and the branch for pure and applied mathematics majors are taught by different lecturers. This structure is implemented in the course on complex analysis, the final mathematics course in the pre-service teachers' Masters programme. The joint part is conducted as a common mathematics lecture with accompanying exercise classes and homework. It is devoted to the core subject matter of an introductory lecture on the topic at hand, concluding with a major result (such as the residue theorem in complex analysis). In their branch, students of pure or applied mathematics continue with deeper mathematical results needed in future mathematics studies. The pre-service teachers continue with sessions that dovetail the mathematics lecture with mathematics didactics for the classroom, for example in a seminar that prepares pre-service teachers for their semester internship and covers task design explicitly (see Figure 1).
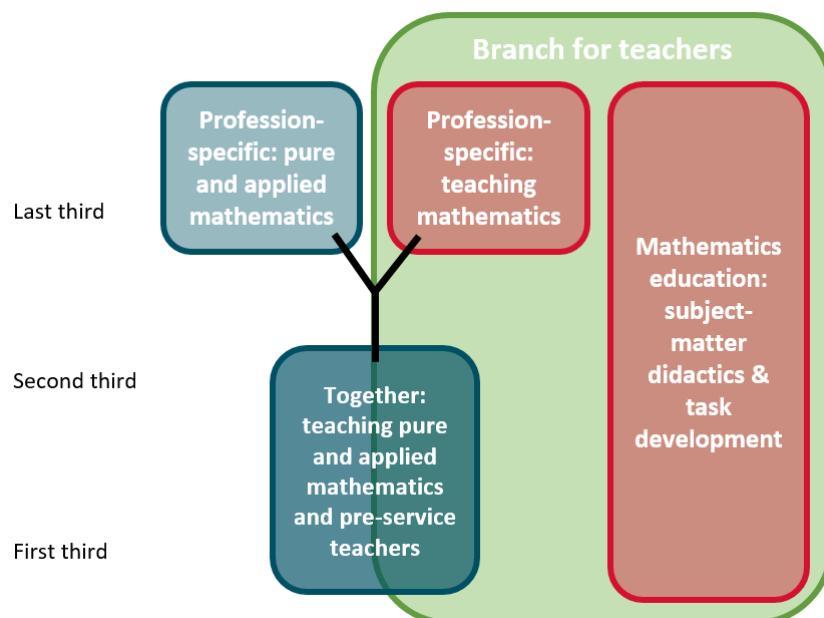

Figure 1: The "Y-model" for a mathematics lecture, accompanied with a seminar in mathematics didactics (cf. Figure 1a in Hanke & Schäfer (2018))

The main task in the pre-service teachers' branch is to select a mathematical phenomenon related to the lecture and to prepare a learning arrangement for pupils from upper secondary schools ('gymnasiale Oberstufe'). The first week of the teacher branch deepens geometric aspects of complex analysis such as the interpretation of the complex derivative as dilation-rotation and Riemannian surfaces. The rest of the sessions is devoted to group work for the preparation of the learning arrangements for pupils. Two lecturers intensively supervise the pre-service teachers, interacting with each group individually. Then, in the non-lecture period, pupils from local secondary schools in their penultimate year participate in a day of experimental mathematics (*XMaSII*),[2] where the pre-service teachers put their learning arrangements into practice (see Hanke & Schäfer, 2018).

The Y-model was also adopted in the stochastics lecture, which is located in the last (sixth) semester of the Bachelors programme, however, with a shorter duration of two weeks for the specific branch for pre-service teachers plus individual supervision.

[2] Day for eXperimental *Ma*thematics for upper classes in secondary school (*Sekundarstufe II*).
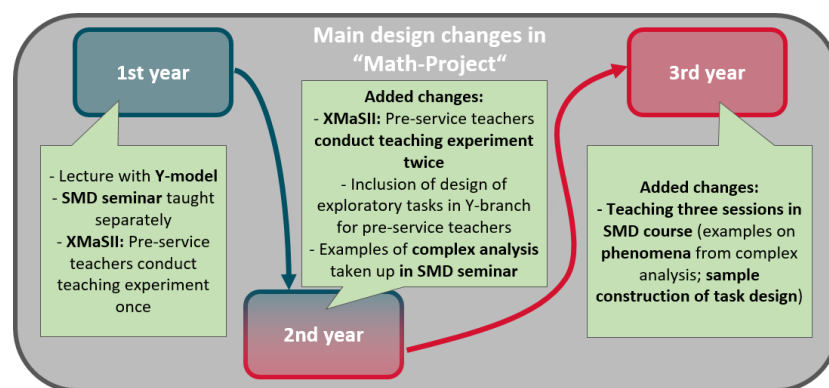

Figure 2: Main design changes from 1st to 3rd year in "Spotlight-Y"

The main design changes from year 1 to year 3 are summarised in Figure 2. In the first year, it turned out that many secondary pupils finished working on the assignments prepared by our pre-service teachers sooner than expected. Some pre-service teachers noted explicitly that they underestimated the pupils' capabilities, which they expressed in their reflections in various ways, such as "I was surprised by the comprehensive content knowledge ('umfangreiche Fachwissen')" of the pupils; the pupils "understood issues partly faster than expected"; or "The group of pupils was done unexpectedly quickly" (translated). As the pre-service teachers conducted their teaching only once, they could not improve their teaching during XMaSII. From the second cycle on, we therefore decided that all groups should conduct their teaching experiments twice in a row, but with a shorter duration of 45 minutes instead of 90 minutes as in the first cycle. Furthermore, complex analysis is quite demanding for the pre-service teachers. As the pre-service teachers had never constructed exploration tasks before in their study programme, we made the issue of connecting SM and SMD more explicit: We underpinned SMD contents with complex

analysis on the one hand, and we took up elements from exploratory task construction introduced in the SMD course in the Y-branch on the other. Since we still noticed many conceptual errors with respect to complex analysis in the pre-service teachers' planning processes, we dovetailed the lecture and the SMD seminar further in the third cycle. This was achieved by explicitly engaging the pre-service teachers in constructing tasks about conformal mappings (these are certain complex functions) for secondary pupils in three sessions of the SMD seminar in addition to the previous improvements.

3.3 Varieties of English in Foreign Language Teacher Education"[3]

The teaching format in English language teaching consists of two seminars in the M.Ed. programme; one in linguistics and one in English didactics, which deal with the same content from two perspectives and lead to a joint practical phase at the end (see Figure 3). Both seminars focus on English as an international language and World Englishes – relatively new fields in linguistics, which involve implications for language teaching (Rose & Galloway, 2019). The English language has spread around the world and is used as lingua franca in many contexts by millions of speakers. However, teaching curricula and materials do not yet reflect the linguistic and cultural diversity of the numerous Englishes used around the world, even though scholars have been calling for a paradigm shift for some time (Rose & Galloway, 2019). "Varieties of English in Foreign Language Teacher Education" follows the twofold goal of dovetailing and interlinking SMK with SMDK, and establishing this innovative approach in English language teacher training. In the course of one semester, the linguistics course covers models and theories of World Englishes, concepts of teaching English as an international language, and linguistic analyses of specific varieties. The parallel didactics course focuses on the visibility and description of the diversity of Englishes in curricula and textbooks, the implications for teaching English as an international language as well as approaches to lesson planning. Subsequently, groups of pre-service teachers plan actual lessons with the support and supervision from the lecturers and in cooperation with in-service teachers at local schools. At the end of the semester, the pre-service teachers put their lesson plans into practice at the local schools. When planning and conducting the lessons, pre-service teachers need knowledge from both seminars, thus the task requires them to interlink linguistic and didactical knowledge.
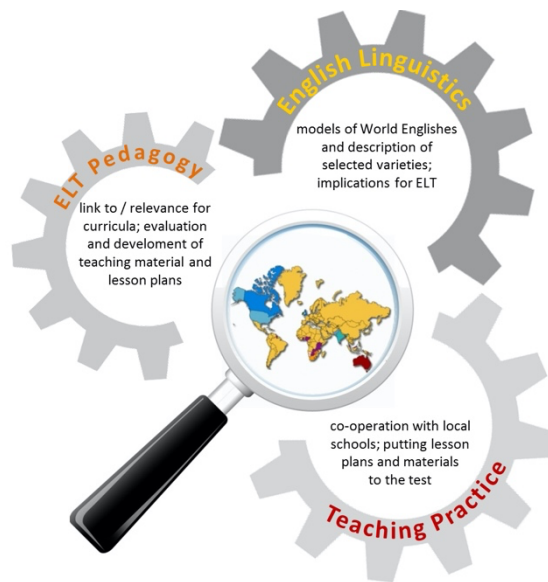
Figure 3: Main components of the teaching model (Figure 1 from Callies et al. (2022))

Figure 4 shows the main design changes in "Varieties of English in Foreign Language Teacher Education". Its design was drastically changed after the first year due to insights from the first pre-service teachers' reflections and interviews (see section 5), as well as informal feedback from the in-service teachers at the partner schools. These data showed that the pedagogy component was perceived as too small, the free choice of topics was very demanding for the students, and the overall workload was perceived as too large for just one seminar and three ECTS. For example, one student considered "the two foci together […] a bit overwhelming". Furthermore, the aim of institutional sustainability of the design required us to distribute the lecturers' teaching load in a way that allows counting the actual teaching loads, which is only the case for complete seminars and not just partial ones. For these reasons, the tandem design shown in Figure 4 was developed and implemented in year 2. Therein, a seminar in language teaching pedagogy was adapted in content and was linked to the linguistics seminar. Besides, we made changes with respect to formal course requirements and types of tests. From the second to the third year, the design has been consolidated with slight adaptations. These asked for an additional reflective text from the students (see section 5) making their lesson planning process more transparent.
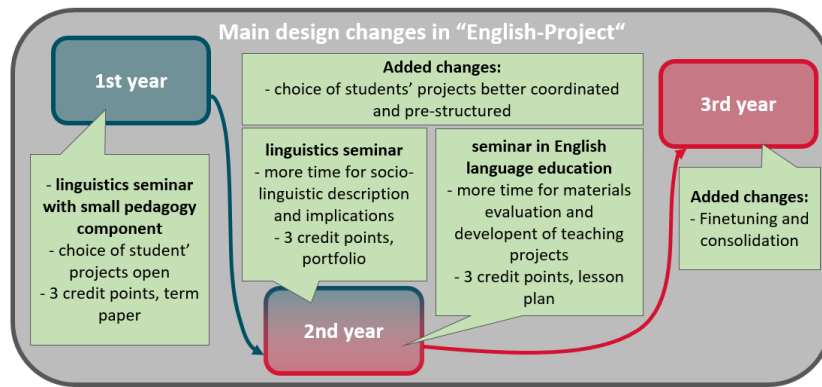
Figure 4: Main design changes in "Varieties of English in Foreign Language Teacher Education"

4.0 Theoretical Foundations

Developing the design principles (see section 6) pointed to the scientific need for theorising crossing the boundary between SM and SMD. In this section, we describe the boundary crossing theory and apply it to linking SM and SMD.

4.1 Boundary Crossing

The social practices of the SM courses contribute to enculturate pre-service teachers into the academic disciplines, for example, complex analysis and linguistics. The academic discipline of the teaching and learning of the school subject shapes the social practices of SMD. Thus, SMD is more concerned with how to plan, shape, and conduct teaching-learning in school as an activity (Leont'ev, 1977). The two activities, doing academic mathematics / linguistics and doing academic mathematics / linguistics didactics, follow different motives related to distinct kinds of institutions with distinct kinds of acting and interacting. Therefore, the sociocultural differences of the activities in the courses of the two domains – subject matter and subject matter didactics – lead to discontinuities in action and interaction. Following Akkerman and Bakker (2011), these discontinuities are experienced as boundaries between actors in the two domains, which may well be fluently crossed by some pre-service teachers, whereas others do not even see a boundary.

As connecting SM and SMD courses entails to counter the discontinuity in action and interaction, we conceptualise the approach of overcoming fragmentation by means of the concept of *boundary crossing* (Akkerman & Bakker, 2011; Star, 2010; Star & Griesemer, 1989).

Boundaries are conceptualised as "sociocultural differences that give rise to discontinuities in interaction and action" (Akkerman & Bakker, 2011, p. 239). Looking at concepts or objects from the perspectives of different sociocultural domains can help to solve particular problems, to mediate between agents within the different domains, or even initiate cooperation across these domains as a way of crossing the

boundary. More generally, Bakker and Akkerman (2014) understand boundary crossing as "efforts by individuals or groups at boundaries to establish or restore continuity in action or interaction across practices" (p. 225). This idea can be fruitfully applied to education, which brings knowledge of many different domains together.

Boundary crossing may happen in various ways and can be facilitated by so-called *boundary objects*. Boundary objects "satisfy the informational requirements" of the domains meeting at a boundary, "adapt to local needs and constraints", and are "robust enough to maintain a common identity across sites" (Star & Griesemer, 1989, p. 393). Thus, they can compose a basis for boundary crossing. Most importantly, their "materiality derives from action, not from [...] 'thing'-ness" (Star, 2010, p. 603). Akkerman and Bakker (2011, p. 147) propose to regard a non-materialistic boundary object as a "shared problem space". This means that actors in one or more domain(s) face a problem from the perspectives of multiple domains. Through contextuality, many things can become boundary objects: "They are weakly structured in common use, and become strongly structured in individual-site use" (Star & Griesemer, 1989, p. 393). This dualism of being simultaneously weakly and strongly structured makes them useful in different contexts at the same time (Akkerman & Bakker, 2011; Star, 2010; Star & Griesemer, 1989). However, objects, which function as a boundary object from the perspective of some actors, do not necessarily need to be perceived as such by everyone.

Akkerman and Bakker (2011) reconstruct four learning mechanisms of boundary crossing based on dialogical forms of learning. By means of these mechanisms, they explain how learning at boundaries may function (Guile, 2011). In our own formulation, "*[i]dentification* is about finding out particularities of the social practices and seeing the relevance of different practices which meet at a certain border" (Hanke & Bikner-Ahsbahs, 2019, p. 3047; emphasis in original). This mechanism is considered a form of boundary crossing because practices or activities are recognised with regard to their scope within a domain, concretising boundaries through recognition of the domain-specific. The second and third mechanisms of *coordination* and *reflection* are characterised as follows:

"*Coordination* means to mediate between social worlds. *Reflection* differs from identification in the sense that particularities of one community's practice are made explicit for another community (*perspective making*) or are regarded from the viewpoint of the other community (*perspective taking*)." (Hanke & Bikner-Ahsbahs, 2019, p. 3047; emphasis in original)

The fourth mechanism *transformation* is about establishing profound changes within or across practices, or about forming new practices within the context of the problem that is addressed through boundary crossing (Akkerman & Bakker, 2011; Bakker & Akkerman, 2014).

Engeström et al. (1995), as cited by Akkerman and Bakker (2011, p. 134), see people involved in boundary crossing to "face the chal-

lenge of negotiating and combining ingredients from different contexts to achieve hybrid situations". It is important to point out that boundary crossing, as used in our approach, does not strive for the hybridisation of SM and SMD into a new fully fledged domain. The hybridisation aimed at in our approach is local, that is, creating an institutionalised space for pre-service teachers to relate SMK and SMDK. In fact, as we express in the methodology section (section 5), our project design creates two hybrid situations: The first one is on the lecture level where (advanced) SMK is linked to SMDK through special course designs at university. The second one appears in the work of our students, that is, in learning arrangements, which introduce phenomena from SMK to pupils.

When pre-service teachers are required to teach a specific phenomenon to pupils, they have to create an activity acting on the SM level as well as on the SMD level. In this process, we expect the pre-service teachers to link knowledge from both domains (e.g., when creating a worksheet or other materials) while planning and conducting their teaching session.

4.2 Dovetailing and Interlinking Through Boundary Crossing

Dovetailing is devoted to *initiating* boundary crossing, which may lead to interlinking as part of the learning mechanisms involved. However, the mechanism of identification in boundary crossing theory falls short of the requirements for interlinking, but it may serve as a precondition. In order to observe interlinking by the pre-service teachers, the relationships between SMK and SMDK they create have to be recognisable in the products of their actions or even made directly explicit by the pre-service teachers, for example by identification. This is an important issue to be addressed in the methodological approach.

5.0 Methods of Data Collection and Analysis

To study the twofold phenomenon of dovetailing and interlinking (see above), reflective assignments are used. The students' reflections[4] serve two purposes. First, we use them as a developmental tool for learning how to teach since it supports the pre-service teachers in diagnosing and improving their own teaching, and in rethinking their stance towards the disciplines of mathematics or linguistics. Second, we consider reflections as relevant data that show *how* pre-service teachers interlink the two knowledge areas in question, and *which* conditions support or hinder this process (cf. Bakker & Akkerman, 2014). For the latter reason, we collected pre-service teachers' reflections in form of written portfolios at the end of the semester. In the first two years of the complex analysis part in "Spotlight-Y", we had 11 groups with 36 students in total. 10 groups with a total of 33 students gave their permission to use their written reflections for research. Dur-

[4] We follow Nguyen, Fernandez, Karsenti, and Charlin (2014) in defining reflection as "the process of engaging the self in attentive, critical, exploratory and iterative interactions with one's thoughts and actions, and their underlying conceptual frame, with a view to changing them and with a view on the change itself" (p. 1182). In the case of pre-service teacher training, components of reflection include descriptions of past events of own teaching situations, descriptions, and judgements of situations from the perspectives of different actors, considerations of alternative actions, explicit adaption of pedagogical or didactic theories or models to a past teaching action, or explicit consideration of skills already perceived as mastered or to be developed (Levin & Meyer-Sieber, 2018). According to Schön (1983), reflective practitioners are able to *reflect on-action* as well as *in-action*. We focus on *reflecting on-action*, understood as the use of domain specific theoretical knowledge to reflect on past actions with the aim to adopt revised actions in similar situations in the future.

ing the same period, 37 students were enrolled in the English linguistics and didactics courses, 31 of whom were willing to participate in the research.

Reflective assignments were collected at different points in "Spotlight-Y": In the first week of the *profession specific branch* of the lecture, we urged the students to specify their topic and the mathematical background needed in a short preflection, that is, an anticipated consideration of what their learning arrangement will be about and what they expect to happen (Bikner-Ahsbahs, 2017). Right after XMaSII, the pre-service teachers reflected by means of ad-hoc notes about what had happened during the implementation of their materials. Approximately three weeks after XMaSII, the students handed in a portfolio with a description of the mathematical background, the planned and actual schedule, tasks and explanations for their choice of tasks, and descriptions of critical events not anticipated in their planning as a group. Lastly, we asked the pre-service teachers to reflect individually on more personal aspects such as how they felt this teaching experiment had changed their perceptions of themselves as prospective teachers as well as of the discipline of mathematics or the school subject. For the portfolio, the pre-service teachers were explicitly asked to focus on aspects they deemed significant or momentous for themselves. Through that, we expected to minimise unwillingness to engage in reflection and to obtain valid answers of the pre-service teachers in terms of personal relevance.[5]

[5] A few interviews were collected to gain additional insight into the pre-service teachers' perspectives on the teaching format and their retrospective views on how they interlinked SMK and SMDK. However, for the mathematics part in this article, we only use data from the written reflections.

In "Varieties of English in Foreign Language Teacher Education", the first reflective assignment was a written language learning biography, which helps pre-service teachers reflect on and become aware of their own experiences with the English language and its varieties in and outside of educational contexts. Further assignments were two written reflections: One about the lesson planning process, including difficulties and solutions, and one to be written after the lesson focusing on the experience in class, what the pre-service teachers learned from it, and what they would change if they were to teach the lesson again. We added the reflection on the planning process in year three, because we assumed that it would shed more light on the process of bringing linguistics and language teaching pedagogy together. However, the obtained insights into students' interlinking strategies depended more on individual depth of the reflection than on the specific topic and time of the reflection. Other related descriptive elements, such as a description of the linguistic background and reasons for the choice of tasks and materials, are part of the detailed lesson plan ('Unterrichtsentwurf') the pre-service teachers handed in for assessment at the end of the semester. In addition, we conducted interviews with volunteering students after each cycle, in which we asked them about their opinions on the combination of linguistic content and teaching methodology in more detail.

Data analyses were carried out within and across subjects. First, we discussed the data within the two sub-project teams to identify aspects of the lectures and seminars to be improved as well as to identify critical sections relevant to our research questions – *how* interlinking

of the two knowledge areas occurred and *what conditions* fostered or hindered this interlinking. Second, we conducted analyses of these critical sections in regular weekly meetings across the two sub-project teams. For this to be done, we considered the pre-service teachers' reflections as interpretative "interactions with one's thoughts and actions, and their underlying conceptual frame" (Nguyen et al. 2014, p. 1182) with respect to one's own teaching (design) process. Following this interpretative paradigm (Scheiner, 2019), microanalyses were carried out. Thereby, we assumed that the pre-service teachers do not only answer the given questions but through that also tell us a story about themselves and their relation to the two knowledge areas, SMK and SMDK, following a sequential structure of meaning making, where one idea is built upon the previous one. Thus, we conducted our analyses sequentially, where we re-interpreted these narrations in the given critical segments (Jungwirth, 2003; Przyborski & Wohlrab-Sahr, 2014).

Each sequential analysis starts with embedding the critical sections into the data background of the particular case by the specific subject team. Next, we used the turn-by-turn analysis described by Jungwirth (2003) in that we traced episodes from the portfolios sentence by sentence to reconstruct possible linkages between SMK and SMDK and identified how these linkages are related to the experience of dovetailing as well as the conditions that foster or hinder interlinking. The full group of researchers raised presumptions and tested their evidence in the text by additional data, reflections of the lecturers as well as further analyses of the same case. Then, we compared and contrasted the results with other cases in the same as well as the other subject. The final step of the analysis procedure was structuring and typifying the results. Thus, we condensed conditions of dovetailing and interlinking into categories. In addition, we extracted the key ideas from cases of interlinking, idealised (Kluge, 1999) and translated them into interlinking strategies, which can be used in practical teaching and also transferred to other subjects.

6.0 Results on Design Level: The Final Design Principle *Boundary Crossing by Design(ing)*

The research questions are answered by a design research approach (Bakker, 2018; Gravemeijer & Cobb, 2006) in which a specific design principle is worked out (Euler, 2017; van den Akker, 1999). The design principle condenses design characteristics and guides teacher educators in the two university settings (mathematics and English linguistics) to design their own courses in which they aim to link SMK and SMDK.

Figure 5 shows the steps of the development of the design principle. In the first cycle, both sub-projects used a preliminary design principle, *linking SM and SMD through preparing and conducting teaching* for guiding the design of the lecture and seminars. As the linkage of contents appeared to be an extraordinary effort for pre-service teachers, the theoretical approach of boundary crossing has been worked out

resulting in the more sophisticated design principle of *boundary crossing by design(ing)* (Hanke & Bikner-Ahsbahs, 2019). This refined design principle has guided the redesign of the mathematics and English courses in the following two cycles explicitly, linking the two levels of investigation, dovetailing and interlinking (see subsections 3.2 and 3.3). On the lecture level, university teaching is *designed* to allow for dovetailing the two areas while on the pre-service teacher level, they interlink the two knowledge areas by *designing* and conducting their own teaching. This distinction helped us to identify conditions such as workload, for the course design at university level, which may affect the linkage of SMK and SMDK in pre-service teachers' thinking and acting, thus, served to reveal the final theoretical results, a *conditional model for dovetailing and interlinking* and *interlinking strategies*.
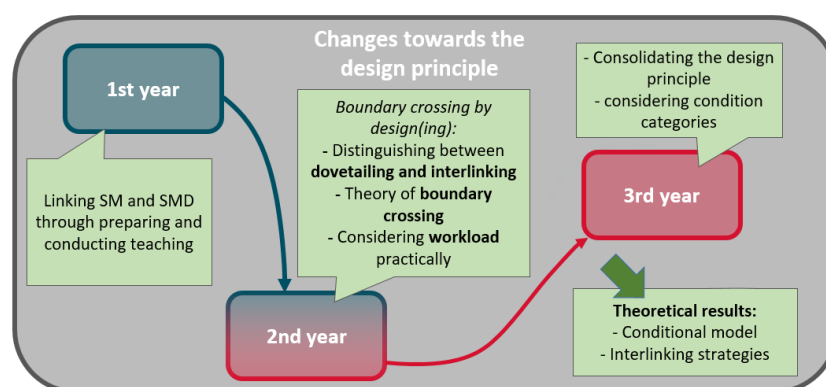

Figure 5: Changes towards the final design principle

The principle of boundary crossing by design(ing) addresses nested design cycles shaping the design process methodologically (see Figure 6; Prediger et al., 2012): A micro design cycle for the activities of the pre-service teachers (bottom) is embedded into the macro design cycle of our research project (top). Each cycle encompasses four steps on the lecture / seminar level: (1) (re-)structuring subject matter according to chosen teaching goals, (2) (re-)creating a design initiated by design principles to support teaching / learning, (3) exploring the design as an empirical teaching experiment, and (4) analysing the data to gain theoretical knowledge about the teaching and learning experiment which then informs the next cycle and the final theorising. The teaching experiment that takes place on the pre-service teacher level consists of four similar steps. Working in groups, the pre-service teachers choose a topic or phenomenon from the relevant academic content course to teach it to pupils according to goals they specify. Based on these decisions, the pre-service teachers transpose SMK to knowledge to be taught by re-structuring it for their teaching and preparing learning-teaching materials. The teaching experiment follows four steps: (1) structuring the content, (2) designing the mathematical group work for XMaSII or the English lesson at school, (3) conducting their teaching, and (4) analysing and reflecting on their teaching and planning based on what has been learned in courses in mathematics / English to learn

for future teaching and beyond. The pre-service teachers in each year can only undertake one cycle, whereas on the university level the cycles are revised and conducted each year, three times in total.
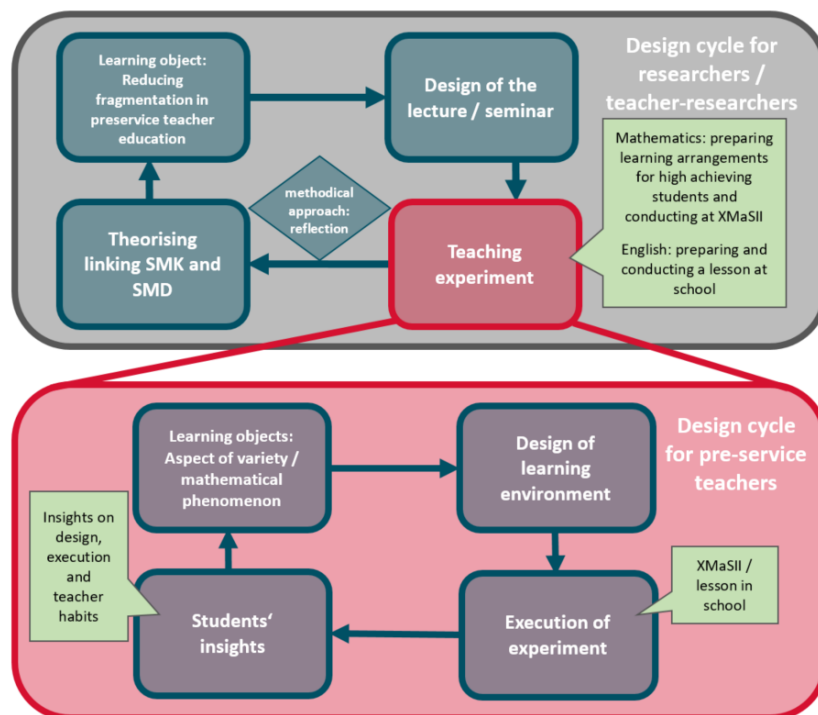

Figure 6: Nested design cycles of "Spotlights Lehre" (adapted and expanded version of Figure 1 in Hanke & Bikner-Ahsbahs (2019))

The initial task to identify a phenomenon from the mathematics lecture or the linguistics seminar respectively and to design teaching-learning materials functions as a catalyst to initiate boundary crossing because this forces pre-service teachers to use SMK and SMDK within the same task. Thus, *the task to create learning arrangements* for pupils on phenomena that ground in a university lecture or seminar functions as an *initial boundary object,* as we call it. It is intended as a catalyst for boundary crossing to happen in pre-service teachers' processes of designing and later on reflecting. The emerging materials that the pre-service teachers begin to produce and work on for the following weeks constitute a second type of task, the so-called *emerging boundary object*, as it provides a continuous opportunity to work with SMK and SMDK. Clearly, these two types of boundary objects are intertwined, as the latter does not exist without the former. However, the first one is a task we give to the pre-service teachers, while the second ones are tasks the pre-service teachers develop themselves.

7.0 Results on Conditions for Dovetailing and Interlinking

Already after the second cycle, our data indicated fostering and hindering conditions for linking SM and SMD. Based on these data, we will expound a *conditional model* ('Bedingungsgefüge') *for dovetailing and*

interlinking which condenses our reconstruction of these conditions. It serves to illustrate conditions that may affect interlinking and to organise dovetailing in such a way that unfavourable conditions can be reduced when planning courses or curricula for pre-service teacher training. We will then illustrate interlinking strategies by exemplary data, that is, characteristic ways in which pre-service teachers related SMK and SMDK (section 8).

We identified four categories influencing the twofold phenomenon of dovetailing and interlinking (see Figure 7). These categories are organised in two by two dimensions. The first dimension distinguishes between curricular and personal factors. The second dimension reflects the demand to link SM and SMD with respect to *potential fit* and *load*. The curricular factors consist of *curricular fit* as potential fit factor and *workload* as load related to curricular conditions. The personal factors with respect to potential fit contain *individual fit*, which are the attitudes of the actors (pre-service teachers, teacher educators, lecturers for courses on SM) towards the subject, the perceived relevance of study components as well as of the idea of linking SM and SMD in study programmes in general or in a specific course in particular. *Individual load* is about the amount of work for the individual in her or his personal living and working environment.
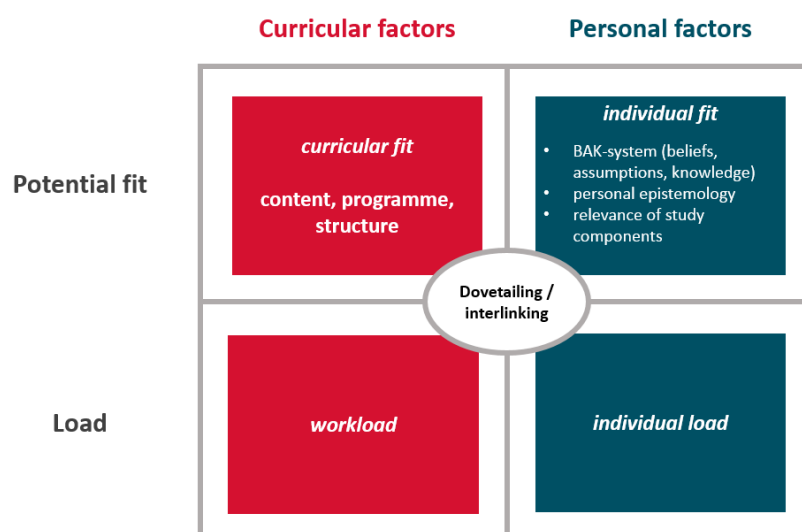
Figure 7: Conditional model for dovetailing and interlinking

The conditional model can be applied to both dovetailing and interlinking. On the level of dovetailing, the curricular factors refer to framework conditions given by study programmes and curricula. The personal factors on this level refer either to the university teachers or to the pre-service teachers. In this paper, though, we will restrict ourselves to the discussion of some examples of data for the conditional model on the level of interlinking.

7.1 Curricular Factors

Curricular factors cover structural components and their possible implications for the pre-service teachers and the teacher educators who coordinate their courses with other courses that either take place simultaneously or are supposed to be studied at some other point in the study programme.

7.1.1 Curricular Fit

Curricular fit on dovetailing level refers to the conditions given by study programmes and their curricula, but also other aspects such as cooperation with other institutions or staff resources. Dovetailing SM and SMD depends on the structure of the curriculum, for example, the sequence of the courses in the study programme. It also depends on the possibility to dovetail individual SM and SMD courses, when asking, for example, to what extent the content of the respective courses can be altered to achieve more coherence between courses. In turn, dovetailed courses provide opportunities for interlinking.

In the linguistics project, the opportunity for linking a linguistics seminar and a didactics seminar in one semester arose out of two conditions. First, the SMD seminar was relatively free in content; therefore, it could be linked to the linguistic seminar in terms of content. Second, the linguistic seminar does not necessarily have to be studied in a certain semester of the study programme. This flexibility makes it possible to shift the seminar to the semester in which the didactics seminar takes place.

In terms of interlinking, many pre-service teachers' statements support the hypothesis that dovetailed courses assist interlinking, as can be seen in the following example from a pre-service teacher of English:

> Also the connection, that we could see, we learn something linguistic and we see how we can actually use it later on in the classroom. Because we had many linguistics seminars that were comprehensive as they were, made sense to me, but I never knew exactly, WHAT can I do with it later on as a teacher. (Translated)

7.1.2 Workload

Even if this might seem obvious, a high curricular workload may decrease the efforts the pre-service teachers can invest as well as their motivation to complete the project work we implemented in our courses. Obstacles with respect to workload we encountered were collisions with the Bachelor thesis or the semester internship. In addition, perceptions of unequal workloads between the students in the different study groups according to the Y-model can decrease students' motivation.

To give an example from the transfer of the Y-model to the stochastics lecture, many pre-service teachers experienced a particularly high workload because in the respective stage of their study programme they are about to finish their Bachelor thesis, need to apply for their M.Ed. programme, and need to work for the learning arrangement during the non-lecture period.

7.2 Personal Factors

Personal factors are different for each individual student. Therefore, in comparison to curricular factors, their impact on interlinking processes is more difficult to trace and control.

7.2.1 Individual fit

In this conditional factor, the "fit" refers to how well SM and SMD fit from the point of view of the individual pre-service teacher.

Cognitions (such as beliefs and attitudes; Borg, 2006) which may be supportive for interlinking, frame the subject matter as relevant for teaching. Statements referring to the subject matter being experienced as relevant within the project can be seen as steps towards such supportive cognitions. "Negative" cognitions on the other hand, which we assume to hinder interlinking of SMK and SMDK, include seeing the specific subject matter at hand as abstract and not relevant for the school context, as in the following example taken from one of the written reflections of an English student:

> Abstract linguistic concepts just have no place in language teaching at schools. (Translated)

This indicates a content-independent belief about the nature of "linguistic concepts" as not being part of language teaching (and possibly a misconception of what linguistics comprises), pointing towards fragmented knowledge. The prevalent view of language has traditionally been a prescriptive view, distinguishing language production into right and wrong (Rose, Syrbe, Montakantiwong, & Funada, 2020), whereas the discipline of linguistics holds a descriptive view in which "right" or "wrong" forms of language use do not occur in absolute terms. This is illustrated by the following example, displaying a firmly held belief about language teaching which stands in contrast to a paradigm of the scientific subject (here: the approach of descriptive linguistics):

> So in the end in the classroom there is right and wrong. Even if that may not be accurate in scientific terms. But it definitely is what can legitimately be taught. That is my opinion. (Translated)

7.2.2 *Individual Load*

Individual load is the component which is not directly influenced by the circumstances of a course or curriculum but which depends on circumstances of the individual. Different aspects can affect individual load, such as:

- load of understanding: knowing clearly what the phenomenon to be presented to pupils is about and understanding the background of this SMK;

- workload of the personal curriculum: the individual pre-service teacher's workload which is not foreseen in the curriculum, for example, postponed or previously failed exams;

- transfer load: the increased demand which results from the fact that the pre-service teacher has to perform a transfer between SMK and SMDK on her or his own and which does not belong to usual, frequently practised assignments in SM or SMD courses;

- cognitive load (Plass, Moreno, & Brünken, 2010): the local component of the demands a pre-service teacher has to deal with while working on the preparation and implementation of the learning arrangement; and

- private load: burdening life situations.

Many pre-service teachers struggled with the mathematical content of the lecture and with the content of the phenomenon dealt with in their group work. Some of these pre-service teachers claimed in their reflection that they have intensified their understanding of the mathematical notions they worked on (see the first quotation in subsection 8.2). For example, one pre-service teacher showed in his reflection that he had to invest time and work to fully understand the content, and therefore had to increase his load of understanding (cf. Hanke & Bikner-Ahsbahs, 2019, p. 3051):

> So I find the problem to prepare a very complex and alien ('fremd') topic for pupils very interesting and instructive because I, myself, had to cope with this topic intensively once again.
>
> Unfortunately, I had to realize that exactly in this transformation very much time and work had to be invested which lacked for example for the precise planning and execution. At any time, the subject specific understanding ('das fachliche Verständnis') was the most important aspect of the planning. (Translated)

8.0 Results on Interlinking Strategies

Next, we identify three forms of interlinking by reconstructing interlinking activities present in selected pre-service teachers' reflections. We describe these as interlinking strategies, which we understand as ideal types (Kluge, 1999) of ways in which pre-service teachers (can

approach to) interlink SMK and SMDK in preparing a learning arrangement based on contents from a course on SM. These strategies are not meant to be prescriptive but rather idealised versions of how pre-service teachers produced relations between SMK and SMDK to be used as heuristic teaching tools in the future. They were identified and further explored throughout the three cycles. We label the strategies (1) "sensitising through analogy", (2) "epistemic pervasion", and (3) "using templates." In principal, these strategies can be used to analyse pre-service teachers' attempts to interlink SMK and SMDK or for scaffolding in dovetailed courses in teacher training to guide pre-service teachers' in their efforts to interlink SMK and SMDK. Note that using any of the interlinking strategies does not spontaneously lead to successful interlinking. The kinds of learning mechanisms that have taken place are individually rather than intersubjectively determined and mainly manifest themselves as reflection or coordination.

8.1 Sensitising Through Analogy

The first strategy is characterised by pre-service teachers' recognition of similarities. For example, these similarities may bridge their own and pupils' experiences or similar concepts within the subject matter. Analogies are understood here as a triple of source, target, and a description of the shared theme or idea that links the source and target (Bartha, 2019). Finding analogies results in a boundary crossing coordination mechanism if it mediates the two worlds of the subject matter and the subject matter didactics and explicates a connection through the shared theme in the analogy.

8.1.1 *Biographical Analogies*

This type of analogy appeared in different forms depending on the context of the subject and topic. In mathematics, biographical analogies referred to experiences in pre-service teachers' own schooling which they want to pass on to their learners or spare them. In English, these analogies referred to experiences which had been influenced (at least in retrospective perception) by knowledge from school or rather lack of it. For this reason, the pre-service teachers want to include certain elements in their teaching.

The following example shows a pre-service teacher's wish to teach learners how to deal with a specific variety because in their own experience they felt not prepared for it. The source is the pre-service teacher's own experience; the target is the anticipated experience of learners:

> *[...] in this case we put a lot of focus on teaching the pupils how the Australian English variety differs from the British or American standard variety and on the preparation of the pupils if they should ever meet somebody from Australia. The goal was to show the class the typical Australian intonation and make it easier for them*

to understand an Australian person talking. From my own experi-
ence this is quite a difficult task, because back in the day when I
finished school and traveled to Australia, I had problems to under-
stand the Australian people talk.

8.1.2 *Conceptual Analogies*

The next case shows that the learning of new content in a course at university can lead to a new perception of pupils' difficulties in their learning at school (Hanke & Bikner-Ahsbahs, 2019; Mehlmann & Bikner-Ahsbahs, 2018). One pre-service teacher's own learning in the lecture on complex analysis enabled her to build analogies on two layers. The source is her own learning of a specific aspect related to complex numbers, target is the anticipated learning of pupils of an element of school mathematics (cf. Hanke & Bikner-Ahsbahs, 2019, p. 3050):

> *The extension of number sets with the set of complex numbers is very demanding at first. Pupils who encounter negative numbers for the first time might feel similarly. The experiences I made in this course can help me to empathize with pupils and understand why the extension of numbers with the set of irrational numbers can be difficult for them and why they may not consider the number π as a number. (Translated)*

The common core of the analogy is the mathematical idea[6] of "extension of number sets" which leads to a comparison between her own learning experience in the lecture, where the field of real numbers is extended by complex numbers, and anticipated pupils' difficulties in school. The pre-service teacher values this insight as "especially important with respect to handling pupils ('Umgang mit Schülerinnen und Schülern')" (translated), thus providing profit for her as a future teacher. She continues to explain that she encountered difficulties in visualising complex-valued functions, hence assumes what it must be like for pupils who are unable to visualise functions in school. The mathematical objects in the pre-service teachers' experience in the complex analysis lecture and pupils' encounters in school are different, but the pre-service teacher regards the kind of difficulties as similar.

It is important to note that this pre-service teacher does not merely refer to ideas from SMD she might have encountered during her previous studies, but she offers concrete examples from her own learning biography that relate to fundamental ideas of mathematics. What we can learn from this for interlinking SMK and SMDK is that learning new mathematical content in their study programmes can sensitise pre-service teachers' views on pupils' learning and that they may achieve this sensitisation through retrospective reflection.

We also found conceptual analogies in English. In the following example, the pre-service teacher relates the main idea he wants the learners to grasp in the lesson, namely that American English has different varieties, back to previous knowledge of the pupils. The source is everyday knowledge the pupils have, the target is new knowledge they are supposed to gain:

[6] Mehlmann and Bikner-Ahsbahs (2018, p. 97) call this a "subject-epistemological principle (fachlich-epistemologisches Prinzip)".

[My teaching partner] had the great idea to relate American Varieties to German accents. We thought that it is quite likely that students have experienced some kind of other German accents and therefore might be able to see how English could be similar.

8.2 *Epistemic Pervasion*

We call the next strategy epistemic pervasion. Pre-service teachers following this strategy want to find and present the "heart of the matter". This means that they dismantle the content at hand and strive for identification of core ideas they can teach to pupils afterwards. This strategy resembles the boundary crossing learning mechanism "reflection", in particular "perspective taking": The didactic side of the assignment for the pre-service teachers to produce learning-teaching materials causes them to look at the content from a specific perspective, which is motivated by didactics, but the search for the core of the content is made from within the subject. Pre-service teachers following this strategy show their rootedness in the subject. They explicitly refer to topics from the lecture that they find interesting or refer to their own learning of the topic that they want to present in their learning arrangements. Then, they connect the topics to pupils' anticipated handling of the materials in their implementation.

In the next excerpts of another mathematics students' reflection, elements from SMD remain implicit, that is, he does not name or refer to concepts from SMD explicitly or apply an idea from SMD to the content at hand (his group dealt with power series expansions). However, preparing SMK for pupils is characterised on two levels of understanding. The pre-service teacher had to learn the content deeply (likely, deeper than during the lecture) but does not forget about the pupils who will have to work on it later:

Through the linking ('Verknüpfen') of pure mathematical content knowledge ('Fachwissen') with the task to prepare this in a fostering but demanding way ('fördernd und doch fordernd') for pupils, I could learn a lot. For one thing the most obvious: I had the possibility to occupy myself more with the core of the mathematical content ('Sachinhalt'). […] Even though the lecturer tried to describe these, it was still the better experience to work out these concepts once again for yourself and to transfer ('übertragen') these to something, which can also be understood by pupils. (Translated)

Ideally expressed in this strategy is a view towards the formation of knowledge to be taught, which is reconstructive rather than reductive. This pre-service teacher also recreates his view on contents usually taught in school (certain types of functions) while he connects it with in-depth insight he gained in the complex analysis course, believing that he has now recognised what is essential about this content:

Also, my view on the chosen elementary functions has once again changed while ('indem') I now know that they possess properties which are neither obvious at first sight nor intuitively accessible and which grant them a special position in analysis ('ihnen eine

besondere Stellung in der Analyse einräumen'). […] This enhances me in my role as prospective teacher since it gives me confidence that I can prepare complex topics of mathematics appropriately ('adressatengerecht') for pupils without overwhelming ('erschlagen') them with content knowledge ('Fachwissen') or having taught them something 'unnecessary' ('etwas 'Unnützes' vermittelt'). (Translated)

The choice of functions in the learning arrangement is justified with the personal perception of having understood the topic through the advanced lens of complex analysis. The interlinking in this part of the reflection is implicit and, ideal-typically, seems to be rooted in the wish for thorough understanding of SMK. The part of SMD in this strategy is not given by the usage of concrete models or ideas from SMD but by the attitude to root the development of learning arrangements on didactical reconstruction and fundamental ideas in mathematics didactics.

In the linguistics project, there seems to be a related phenomenon. The focus, however, is not on grasping the core idea and reflecting it from both perspectives but on appropriate exemplification of core ideas. An additional challenge is to bring several teaching goals together; as in language teaching, there are always two levels of instruction at play – the level of language learning and the level of content. The following example shows two levels of exemplification, which we found in several reflections of lesson planning. The more concrete level of the specific variety, where looking at exemplary features (phonological, grammatical, or lexical) is supposed to give learners an impression of the respective variety and is connected to the more abstract level on which the specific variety functions as an example for variation within the English language in general:

> *After the learners were able to hear the AAE [African American English] variety, we wanted them to know that there is a lot more about it than just the differences in pronunciation and vocabulary, because it has its own grammatical structure. In order to let them find out the differences, we provided a second worksheet with lots of sentences in AAE where the learners were supposed to find out differences and repetitions of grammatical issues. The main goal for the learners was to get in contact with other English varieties rather than the obvious ones such as British English and American English.*

8.3   Using Templates

Pre-service teachers who are using templates use structures of lessons or materials they already know, either from university or from their own time at school. This strategy seems to serve several purposes. For example, it can be used to shape content into a pedagogical form. At the same time, it can also possibly serve as a strategy to reduce workload or cognitive load. On the one hand, this strategy can enable pre-service teachers to fill a didactical concept (e.g., a method or an idea) with life and help to identify elements of the subject matter they want to treat. On the other hand, it could be a "coping strategy" to fulfil the

course requirements, or a "reflection strategy", in which the pre-service teachers refer to a template without actually having used it, because they think it will fulfil the expectations of the lecturers.

The next excerpts are from "Spotlight-Y". The first is from the reflection on the planning process of a group working on "differentiation as linearisation". The pre-service teachers argue that they found a vivid introduction and exercises in a mathematics education journal, which they used as a stimulus for their own development of a coherent worksheet. Their choice is also justified by the vividness of the example from (everyday) life, connecting the content of the learning arrangement with pupils' preconceptions:

> *We could find two articles in the journal [name omitted] that suggest tasks about the function microscope ('Funktionenmikroskop') following [name omitted]. […] The suggested tasks do not all seem equally meaningful with respect to our learning arrangement, therefore we adapted them for our purposes. Besides, we developed a consistent ('einheitliches') worksheet for all tasks in order to bring them into a meaningful context ('Zusammenhang') and offer concrete working material to the pupils. (Translated)*

This example shows pre-service teachers' usage of a template for the introduction of the notion of derivative, which they found elsewhere, but with partly justified adaptions.

Another group describes that they encountered a phase model for concept formation from mathematics education literature. Here, a methodical similarity is used to create the learning arrangement:

> *Our learning arrangement deals with the exploration ('Erschließen') of different phenomena in an idealised setting ('in einer idealisierten Umgebung'). It [the arrangement] is conceived as a double realisation ('doppelter Ausführung') according to the first four phases of concept formation ('Begriffsbildung') [footnote referring to a source omitted]: First, the learners experience the phenomenon without knowing it further. We take up the respective preconceptions ('an die jeweiligen Vorverständnisse angeknüpft') and create motivation through the context of airplane routes. The route of the airplane on the polystyrene ball is illustrated in everyday language […; further description of the other phases related to the mathematical context omitted]. (Translated)*

The pre-service teachers do not simply mention the steps of the model, but they also describe how they brought the content and the steps of the model together. One student from another group describes a similar procedure for his learning arrangement in response to the question, which elements from SMD his group used in the creation of their learning arrangement. However, none of the other group members described anything similar and the joint part in the portfolio on the planning process does not address this model either. We may thus assume that the strategy of using a template may as well be something a student comes up with to justify what she or he has done after the actual planning and implementation of the group work.

In the linguistics project, we observed a similar template use. In this case, using ideas and structures from existing materials is difficult, as little material exists for lessons on varieties of English. However, in some cases, the groups used elements from the seminar as templates for parts of their lessons. Another type of templates consists of lesson-plan templates introduced in the didactics course or earlier courses, similar to the example on concept formation from mathematics cited above. In contrast to the previous templates just described, these templates are basic knowledge pre-service teachers are expected to use. An example for this type is the structuring of lessons according to the phases of introduction ('Einführung'), elaboration ('Erarbeitung'), and securing ('Sicherung') of content.

9.0   Discussion and Conclusion

Our design research objective has been to reduce fragmentation in teacher education by developing course designs at university level that link subject matter and subject matter didactics. For this purpose, we distinguished conceptually between dovetailing and interlinking of subject matter and subject matter didactics. The design principle boundary crossing by design(ing) condenses these characteristics theoretically warranted, empirically tested, and explored in a design-based research approach; hence, it bridges theory and practice in our projects (Euler, 2017) and answers the first research question. The second and third research questions are answered with a conditional model and interlinking strategies. The conditional model consists of four key conditional categories, curricular fit, individual fit, workload, and individual load. It informs the quality of future course designs at university level with the same goal to reduce fragmentation. This model answers the second research question by framing a wide range of possible conditions to be considered in concrete design tasks. Our most innovative findings answer the third research question. They consist of three types of interlinking strategies found across both subjects but used in a subject-specific manner. These types are interlinking by analogy, by epistemic pervasion, and by the use of a given template. The interlinking examples are highly interesting because they indicate three interlinking dimensions. Interlinking by analogy draws on pre-service teachers' previous experiences. Interlinking by epistemic pervasion stresses the need of digging deeply into the epistemology of the subject to grasp the key idea underlying the school as well as the university level of the subject matter. The third strategy emphasises the wish to refine materials or formats already developed for teaching, and it reflects the need for orientation when teaching is prepared.

With our results, we have also contributed to a recent research programme on coherence in the study programmes of pre-service teachers (Brouër et al., 2018; Degeling et al., 2019; Glowinski et al., 2019; Hellmann et al., 2019). As research on coherence tends to focus more generally on the organisation of subject matter, subject matter didactics, and educational sciences, we have complemented this programme by a more local view on connecting courses by dovetailing

which, when implemented under suitable conditions, may evoke inter-linking between SMK and SMDK. Interlinking resonates with Diehr's (2018) idea of cognitive coherence, that is, "students' ability to relate the knowledge and proficiency acquired in all subfields of English studies autonomously to profession-related tasks and problems of teaching English [or other subjects; the authors]" (p. 84; own translation). Interlinking also goes beyond cognitive coherence as it covers the linkage of knowledge areas during the activity of teaching as well (see also Masanek, 2018).

The design principle boundary crossing by design(ing) (Hanke & Bikner-Ahsbahs, 2019) is a relevant result, too, as it serves as a heuristic to systematically dovetail subject matter and subject matter didactics at university level to initiate and foster interlinking, and it thus represents the double nature of linking subject matter and subject matter didactics in a unified way. Since the interlinking strategies and instances of the conditional model appeared in two very distinct subjects, mathematics and English linguistics, we assume that they may also appear in pre-service teachers' interlinking in other subjects. This suggests generativity (Bakker, Shvarts, & Abrahamson, 2019) of the design principle as a transfer characteristic.

Finally, to what extent did we achieve the aim to reduce fragmentation? Our course designs are a proof of principle for successful dovetailing that led to an interlinking of SMK and SMDK for many pre-service teachers and they provided the final design principle for transfer. To make this applicable for other subjects, practical hints for teacher educators are provided in a "transfer package" (Bikner-Ahsbahs, 2020). However, it remains to be investigated how far interlinking subject matter and subject matter didactics in one course affects pre-service teachers' experiences of fragmentation in their study programmes as a whole. Longitudinal effects on pre-service teachers' further education at university require additional research, for example, by conceptualising the four items of the conditional model in a more detailed way (e.g., in terms of belief-assumption-knowledge-systems; Bendixen & Feucht, 2010; Dunekacke, Jenßen, Eilerts, & Blömeke, 2016; Khine, 2008; Woods, 1996). In sum, there are at least three directions to be considered in subsequent research:

- The impact of dovetailing within study programmes, for example, asking: Which effects do dovetailed courses at one or various points in teacher education programmes have on pre-service teachers' experiences of fragmentation and their learning outcomes?

- The effects of interlinking experience for future teachers, for example, asking: How do interlinking experiences at university influence pre-service teachers' actual teaching at school in the future?

- Addressing transfer to other subjects, for example, asking: Which conditions and challenges do other subjects such as physics or political science face while implementing designs to dovetail subject matter and subject matter didactics in teacher

education programmes and initiate interlinking in students' thinking and acting?

Nearly all our students valued the experience of linking SMK and SMDK highly and many reported that explicit links between SM and SMD made the SM courses appear more relevant to them. Thus, our design approach seems to have reduced perceptions of fragmentation. Moreover, as shown above, our attempts to create learning opportunities that initiate boundary crossing and support interlinking have been (locally) successful. Nevertheless, much remains to be done to gain a more comprehensive understanding of the dual phenomenon of dovetailing and interlinking as an approach to reducing fragmentation in pre-service teacher education.

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