

Teacher Professionalization in Higher Education through Geographic Modeling Competence

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List of Acronyms

BMZ	Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung
BNE	Bildung für nachhaltige Entwicklung
CK	Content Knowledge
CoActive	Cognitive Activation in the Classroom: The Orchestration of Learning Opportunities for the Enhancement of Insightful Learning in Mathematics
CSCT	Curriculum, Sustainable development, Competencies, Teacher training
ECTS	European Credit Transfer and Accumulation System
ESD	Education for Sustainable Development
ETS	Educational Testing Service
KMK	Kultusministerkonferenz
KOM-BiNE	Kompetenzen für Bildung für Nachhaltige Entwicklung
OECD	Organisation for Economic Cooperation and Development
DGfG	Deutsche Gesellschaft für Geographie
PAM	Partition Around Medoids
PISA	Programme for International Student Assessment
PCK	Pedagogical Content knowledge
PK	Pedagogical Knowledge
ProPraxis	Das Projekt fokussiert die Weiterentwicklung des Studiengangs Lehramt für Gymnasien (L3) an der Philipps-Universität Marburg. Es wird im Rahmen der gemeinsamen Qualitätsoffensive Lehrerbildung von Bund und Ländern von 2015 bis 2023 gefördert.
SRI	Stanford Research Institute
UNECE	United Nations Economic Commission for Europe
WP	Working Package

1 Introduction

1.1 Motivation

The individual teacher is the most critical variable in students' success (Hattie, 2012). The general public received this statement as the conclusion of Hattie's large meta-study (Hemmer et al., 2020). It is discussed as abridged, and the danger is pointed out that it will unload all the problems on the teachers (Terhart, 2017). However, even if improving the school system is not the sole responsibility of the individual teachers, there is no denying that increased teacher performance will help improve it. Teacher performance can be enhanced by the individual or the educational system, for instance, by improving teacher education. In Germany, the quality campaign for teacher training was announced for this purpose (Bundesministerium für Bildung und Forschung - BMBF Qualitätsoffensive Lehrerbildung, 2022).

In Marburg, the project ProPraxis was funded within this campaign. It is focused on developing pre-service teachers' reflected disciplinary professionalism (Meister et al., 2020), an approach highlighting the need for deep disciplinary knowledge deduced from theory on professionalism (Overmann, 1996). The focus on reflected disciplinary professionalism also enables the integration of Hattie's empirical model for successful teaching, which considers the subject matter prominently (Hattie, 2012). Subject-specific considerations are, thus, necessary to improve teacher education.

The central element of geography education is a system perspective on spatial phenomena bridging natural and social sciences (DGfG, 2020). The interdisciplinary system perspective is shared by education for sustainable development (ESD) (UNESCO, 2020). Since modeling is the method to describe systems scientifically (Bossel, 2004), this dissertation focuses on pre-service geography teachers' ESD and modeling competencies. The next chapter will position the competence approach in developing pre-service teachers' reflected disciplinary professionalism and elaborate on the significance of ESD and modeling to geography education.

1.2 Theoretical Background

1.2.1 *Teacher professionalization in higher education*

The structure-theoretical approach defines teacher professionalism by analyzing the function teachers fulfill compared to other professions (Cramer 2020). According to

Oevermann's theory, the foundation of the German structure-theoretical approach (Cramer 2020), a professional teacher helps students overcome subject-specific crises in their understanding (Oevermann, 1996). The teacher's role is comparable to the role of a psychologist: the teacher has to evoke crises of understanding and help overcome them to help students with their learning process (Oevermann, 1996) instead of pushing such crises aside to promote reproduction (Helsper, 2014). The difference to a psychologist is that the teacher's job is delimited on the student's subject-specific crisis of understanding (Oevermann, 1996). The subject-specific element of this crisis of understanding was elaborated by Dressler's idea that different disciplines allow fundamentally different ways of understanding the world (2013). An educated human being can approach and reconstruct the world in different manners and select an approach appropriate to the specific situation (Dressler, 2013). A professional teacher can reflect on the discipline's practices; define and justify them (Blömeke et al., 2008; Laging et al., 2015)

ProPraxis applies the structure-theoretical approach to teacher education, to developing pre-service teachers reflected disciplinary professionalism (Meister & Hericks, 2020). To achieve reflected disciplinary professionalism, pre-service teachers must engage with topics, methods, guiding ideas, and the specific view on the world their future subjects entail (Meister & Hericks, 2021). They must experience crises in their understanding as their knowledge evolves from everyday life and school knowledge to a scientific understanding (Meister & Hericks, 2021). These crises are necessary to develop their thinking and are also part of the self-experience required to become professional teachers (Meister & Hericks, 2021).

While the structure theoretical approach is helpful to formulate the overall goal of university teacher training (Meister & Hericks, 2020), it does not offer methods to achieve reflected geographic professionalism. There is a need to define scientific understanding and a deep engagement with geography. In detail, knowledge of geographic topics, methods, and practices pre-service teachers must confront must be defined and assessed, and possible deficits in the pre-service teachers' understanding must be addressed. The competence-oriented approach (Baumert and Kunter 2006) is a methodological framework that allows set goals to be specified and promoted in a targeted manner. It, thus, offers an excellent supplement to convert the structure theoretical goals into an applicable education for pre-service geography teachers. The competence-oriented approach is introduced in the following chapter to prove its appropriateness to the cause.

1.2.2 Competence and Competence assessment

Competencies are constructs of emancipatory education in combining the individual development described by Humboldt's concept of education (*Bildung*), knowledge acquiesce, and vocational training (Klieme et al., 2008). The combination enables the individual to take responsible action, described as maturity (*Mündigkeit*) in the normative approach to competence (Roth 1971). The generic competence approach focuses on describing learning processes in an integrated perspective (Chomsky, 2006; Piaget & Inhelder, 1971). The differentiation between competence and performance, defined as visible competence in action (Chomsky, 2006), is the foundation of modern competence measurement, defining psychometrical models to mediate between competence assessment and competence model. The normative and generic approaches are bridged by Weinert's pragmatic approach focusing on what we need to indicate competence in defined contexts, acknowledging that cognitive dispositions, motivational aspects, and attitudes are included (Weinert, 2001). Klieme & Leutner applied this approach to develop competence frameworks for different subjects in German school education by defining dimensions and levels (2006). They developed Weinert's proposition to separate cognitive and motivational aspects for measurement and focused on cognitive factors (Klieme & Leutner, 2006).

The definition of competence in dimensions and level makes it assessable in standardized or non-standardized tests and observation of educational processes (Klieme et al., 2008). Competence assessment can be used to monitor individual progress, the effectiveness of an educational system or specific program, or research on competencies themselves (Klieme et al., 2008; Klieme & Hartig, 2007). This is the advantage of the competence compared to the structure-theoretical approach: competencies are theoretically well-founded and empirical verifiable at the same time (Baumert & Kunter, 2006). As competencies are always defined for a particular context, they are valuable to describe the specifics of subjects (e.g., geography) in teaching and suitable to define frameworks for cognitive aspects of competence for the context of ESD and modeling in geography. These frameworks can then be used to evaluate the effectiveness of the teachers' education program regarding ESD competencies and to gain knowledge on geographic modeling competencies.

1.2.3 Focusing teacher's competencies

The concept of competence can be applied to the specifics of any professional context. In the context of teachers, the concept of professional acting competencies is

prominent (An et al., 2004; Baumert & Kunter, 2006; Bromme, 1992; Shulman, 1986). It is grounded in a construct of Shulman (1986) and differentiates between cognitive aspects (knowledge), social and personal competencies, and organizational aspects. Shulman divided the cognitive aspects for teaching competencies into seven dimensions. The cognitive aspects of professional acting competence that prevailed are content knowledge, pedagogical knowledge, and pedagogical content knowledge (Baumert & Kunter, 2006).

Studies showed that pedagogical content knowledge has the highest impact on student performance (Krauss et al., 2008; Kunter et al., 2011; van Driel et al., 1998). Pedagogical content knowledge requires content knowledge (Hericks & Meister, 2020) because a broad and rich understanding of the subject matters enables a diverse repertoire for representation and explanation (Baumert & Kunter, 2006). Empirical evidence shows that teachers need deep and integrated knowledge to give good and flexible lessons rather than just a lot of knowledge (Hattie, 2012). The university can offer pre-service teachers deep subject knowledge as a central part of their higher education. Therefore, the development of pre-service teachers' competencies must be closely linked to geography, fostering deep and integrated geography knowledge that includes geographic practices and is not reduced to content knowledge.

1.2.4 *Geography education*

Developing a deep and integrated understanding of geography includes meeting the challenge of a discipline divided into the two subdisciplines, human- and physical geography, at the university level and, in contrast, an integrated perspective at the school level (Kanwischer, 2006; Peter & Nauss, 2020). This gap between the university and school level is also reflected in research on geography teacher education. On the one hand, many deficits in pre-service teachers' understanding regarding particular scientific concepts are described (Dove, 2016; Francek, 2013; Gregg, 2001; Nelson et al., 1992; Reinfried, 2006). On the other hand, intervention studies and course concepts focusing on teaching skills with geographic concepts that have little relation to scientific research are common (e.g., Favier et al., 2021; Jo & Bednarz, 2014; Reitano & Harte, 2016).

Addressing the deficits in scientific thinking among pre-service geography teachers systematically requires acknowledging the high complexity involved in an interdisciplinary approach connecting different spheres in complex systems. This task is described as system thinking in ESD (Schuler et al., 2018; UNESCO, 2017, 2020) and geography education (Mehren et al., 2016; Rieß et al., 2015; Viehrig et al., 2011). The system

perspective is central to geography school education. It connects the two primary attributes: its interdisciplinary approach bridging natural sciences and humanities, including human-environment interaction, and the spatial perspective (DGfG, 2020).

As the inherent interdisciplinary approach links geography education to education for sustainable development (ESD) (Bagoly-Simó, 2014; Chang & Kidman, 2020; Corney, 2006), ESD is increasingly important to and discussed as a central part of nowadays geography school education (IGU Commission on Geographical Education, 2016). Against this background, the well-defined competencies needed for broad ESD teaching can be used as a first reasonable estimate for the geographical teaching competence of pre-service teachers. A self-assessment within a framework defining ESD teaching competence dimensions (Hellberg-Rode & Schrüfer, 2016) will show the pre-service teachers' conception of their competence level. When applied within a cross-sectional design, the impact of the study course on the self-conception can be interpreted.

Although ESD provides some frameworks applicable in geography education, there is still a disciplinary perspective and methodological approach necessary to systematically reduce the complexity of systems, enabling reflected geographic professionalism and supporting the more complex task of system thinking. The geographical perspective is the spatial perspective, as space is the central concept in geography (Clifford et al., 2009; Peter & Nauss, 2020; Weichhart, 1999). The perception of the spatial relationality of physical-material things, bodies, and phenomena is also the main commonality shared by geographic research (Anthes et al., 2021; Massey, 1999; Weichhart, 1999). The appropriate method to scientifically describe spatial systems is modeling since modeling is key to scientific understanding in today's model-based research paradigm (Mahr, 2008) and is a well-established practice in geographic research (Chen et al., 2021). Thus, modeling space is key to geographic knowledge and system competence.

At least in the past two decades, modeling spatial systems usually involves computational work, as computers allow constructing powerful and complex models (Bossel, 2004). It is mandatory and beneficial to include this technological and scientific reality in educational contexts, even more as studies show that combining scientific inquiry with computer modeling is very effective (D'Angelo et al., 2014; Klahr et al., 2007; Smetana & Bell, 2012; Trundle & Bell, 2010). An inquiry-based learning course on computer-based spatial modeling seems thus to be suitable to engage both pre-service teachers in an authentic geographic research approach to meet the aims of reflected disciplinary professionalism. Because of the solid disciplinary focus, the course on computer-based

spatial modeling is not exclusively developed for pre-service teachers but is appropriate for B.Sc. students, also. Focusing on establishing authentic research skills as fundamental to teaching competencies connects to similar projects in geography teacher education research (Kim, 2020; Rosenkränzer et al., 2016).

In summary, the following desiderata were identified:

- 1) A comprehensive assessment of pre-service teachers' perceived disciplinary competencies framed by ESD.
- 2) A definition of the important disciplinary practice modeling that allows for a reflection needed for disciplinary professionalism.
- 3) Development of a concept for geographic modeling competence acquisition in higher education and evaluation of its results.

1.3 Research aims

Concludingly, to achieve reflected geographic professionalism, the structure theoretical approach of reflected disciplinary professionalism needs to be supplemented with competencies defining specific geographic knowledge. Insight surmounting individual course concepts is required at the subject level. At the same time, the competence acquisition at the individual course level focusing on geographic practices has to be monitored. For this purpose, a respective competence model is needed. In order to assess the development of reflected geographic professionalism comprehensively and allow immediate improvement of teacher education, the following three aims are targeted:

- 1) Assessment of how pre-service teachers see their preparedness to teach ESD related to modules taken as a proxy for their self-assessed competence development in the study course.
- 2) Derivation and definition of spatial modeling as a core geographic method and development of an appropriate competence framework suitable for assessment and orientation in course development.
- 3) Development and application of an open and flexible higher education course concept based on the competence model and assessment of the development of geographic modeling competence within the course.

1.4 Methods

A mixed-methods approach is an adequate framework for achieving the research objectives that target both confirmatory results from statistical analysis and deep structure explanatory description (Castro et al., 2010). Combining different methodological approaches is typical for subject didactic research (Cramer & Schreiber, 2018), which generally incorporates methods from psychology, social science, pedagogy to their research rooted in a reference discipline (Cramer & Schreiber, 2018; Schecker et al., 2014). These methods are to be used pragmatically in didactics research (Schecker et al., 2014). As an applied research branch, didactics call for research methods closely related to learning settings to develop and investigate the actual achievement towards a specific educational goal (Vollmer, 2014). Therefore, a naturalistic course context is most suitable to achieve tangible impact for application in an everyday educational environment and provide theoretical advancement (Barab, 2006). The different methodological approaches used, including theoretical and empirical work, allow for comprehensive results.

The dissertation consists of three parts integrated into a multiphase mixed-methods design (Cresswell, 2011). The rationale was process-oriented. The data was collected within a specific context, but many results can be generalized. The multiphase timing of the data collection and analysis allowed for the thorough integration of results and insights. The data was collected within a multi-level sampling strategy (Tashakkori & Teddlie, 2010). First, a quantitative survey was distributed to all enrolled pre-service geography teachers. The results of the quantitative analysis motivated the development of a competence model in the second step. The competence model integrated national and international empirical and theoretical research qualitatively. In the third step, the competence model informed a design-based research approach. The data were collected at the level of student groups within a course setting. The material contained was analyzed qualitatively and partly quantified.

The complex interaction of didactic research with educational goals is reflected in this research approach. On the one hand, educational goals must be considered in didactic research by developing concepts (e.g., competence models) helping to achieve educational goals and measure student performance according to these goals (Klieme & Rakoczy, 2008). On the other hand, didactic research shapes educational goals (Klieme & Rakoczy, 2008; Vollmer, 2014), investigating which educational goals should be deducted from the subject matter (Klieme & Rakoczy, 2008). The chosen research approach considered

important educational goals towards ESD and school geography to define competence models explicitly. Nevertheless, the competence model for geographic modeling competence also surmounted these existing goals by integrating concepts from science education and a geographic research perspective. The development of a course and analysis of the students' performance adds empirical perspective on the goals formulated in the model and proves its validity for assessment.

1.5 Thesis Structure

The thesis is structured in three working packages (WP) to investigate and develop the disciplinary knowledge of pre-service teachers: (1) measuring the status quo, (2) developing a competence framework to define educational goals, (3) developing a course framework to reach these goals and evaluating both suitability of the competence model and pre-service teachers' progress in achieving competencies (see Figure 1.1). The working packages are being published separately. Except some format adjustments, they are included in their original versions. Since WP 2 was published in German, it is included in its original German version here.

The first package provided an overview of pre-service teachers' competencies to teach ESD. Since frameworks for professional acting competence regarding ESD exist, these frameworks could be adapted and used. In this setting, a quantitative approach is reasonable because it allowed inviting all pre-service teachers enrolled in Geography to participate in the study and process a large sample ($n=100$). Overall, the results were very high, suggesting an overestimation by the pre-service teachers and revealing a weakness in personal competencies necessary for scientific thinking and a positive impact of active learning environments on competence self-assessment.

The second package filled the gap existing in frameworks for geographic modeling. Because theoretically grounded frameworks are needed in competence measurement, I deduced a theory-based competence model for geographic modeling. The nomological network, theoretical and empirical research, and the prescriptive framework were included in this process. This framework shall clarify a scientific approach to geographic problems and help develop and measure geographic modeling competence.

The third package focused on fostering modeling competence alongside the competence model in a design-based research approach in two classes, one in the teacher program and one in the B.Sc. program. A multimethod approach was applied, an inductive strand allowed insight into the learning process, and a deductive approach evaluated the

final competence level of the participating groups ($n = 15$). The results yield four learning types for geographical modeling and provide an empirical base for teaching geographic modeling. Finally, all studies and results are summarized, and the overall results for geography teacher education are discussed and concluded.

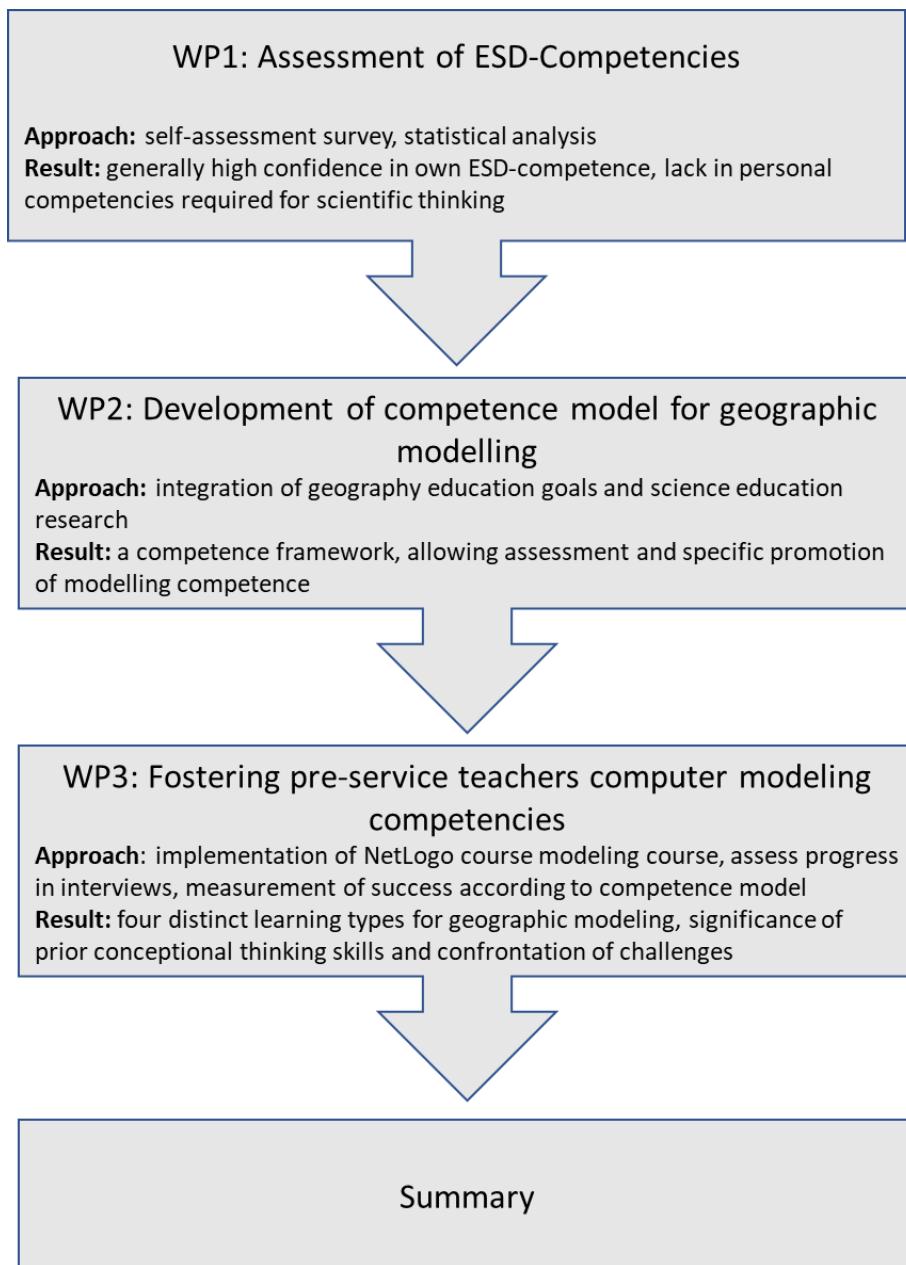


Figure 1.1 Dissertation structure

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2 Pre-Service Geography Teachers' Professional Competencies in Education for Sustainable Development

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Abstract

The professional competencies pre-service geography teachers acquire in university influence their contribution to education for sustainable development (ESD) in their future school careers. We assessed pre-service geography teachers' ($n = 100$) competencies and attitudes towards the official, German ESD orientation framework to determine the specific need for higher education action. The results are a high competence assessment and even higher importance assigned to the ESD-related professional competencies. In the context of ESD, pre-service teachers are most confident in their content knowledge and social and personal competencies and least confident in their pedagogical knowledge. The cross-sectional analysis shows the perceived competence level rising with the semester number and a strong positive influence of the school practice module.

Keywords: teacher education; ESD; competencies; higher education

2.1 Introduction

Amid a global crisis, the need for education for sustainable development (ESD) is more apparent than ever (UNESCO, 2020). As ESD “empowers learners with knowledge, skills, values, and attitudes to make informed decisions and take responsible actions for environmental integrity, economic viability and a just society empowering people of all genders, for present and future generations, while respecting cultural diversity” (UNESCO, 2020). To reach the goals defined by the UNESCO models, defining competencies needed for sustainable development were developed (Barth et al., 2007; Bormann & Haan, 2008; Brundiers et al., 2021; Giangrande et al., 2019; Wiek et al., 2011). The ESD competence models stress the importance of interdisciplinary thinking and holistic competencies. It is essential to integrate ESD into teachers' education to equip teachers with the necessary skills to integrate ESD into their work and become change agents (Bagoly-Simó et al., 2018; Braßler, 2018; Rieckmann & Holz, 2017; Sprenger & Nienaber, 2018). As holistic ESD aims require disciplinary expertise to become meaningful (García-González et al., 2020) and most educational systems are organized by subjects, integrating ESD into subject didactics is vital for quick integration in schools. Since geography is inherently ESD-related (Bagoly-Simó, 2014; Chang & Kidman, 2020; Corney, 2006; Smith, 2002) and geography education is committed to ESD (IGU Commission on Geographical Education, 2016), we assume that geography education contributes to ESD. However, the question arises as to how exactly geography education contributes to professional ESD teaching. We assessed pre-service teachers' ESD competencies within a professional acting competence model because knowing the status quo allows us to successfully connect new approaches to the present teachers' education. We thereby connected to studies assessing the interdisciplinary competence level (Azapagic et al., 2005; Birdsall, 2014; Cebrián & Junyent, 2015; Dahl, 2019; Zamora-Polo et al., 2019) but set the focus on geography students only.

2.2 Theoretical Background

2.2.1 *Professional Acting Competence*

To connect to the teachers' education in place, we acknowledge the perspectives present on professionalizing teachers in Germany: (1) structural theory, discussing the interaction between student and teacher within inherent conflicts in a theoretical approach (Helsper, 2004; Oevermann, 1996), (2) professional biography, studying the professional development of teachers within the challenges of the first years of practice (Hericks et al., 2018), and (3) the competence-oriented approach, defining and measuring competencies

needed for teaching (Baumert & Kunter, 2006). The structural theory and professional biography approach pursue a holistic perspective on teaching. For subject didactics, it is necessary to focus on subject-specific issues. Thus, the competence-oriented discourse is advantageous as it divides subject-specific competence from other competence dimensions (Klieme & Rakoczy, 2008). The competence-oriented approach is grounded in the work of Shulman (Shulman, 1987), who classified the various forms of knowledge required for successful teaching. The knowledge dimensions, which were best replicated in (Blömeke, 2005; Borko & Putnam, 1996; Helmke, 2007; Lipowsky, 2006; Munby et al., 2001), were integrated by Baumert and Kunter (2006) into a competence model for professional acting competence. The competence model thus comprises the following dimensions: pedagogical knowledge, content knowledge, and pedagogical content knowledge. Motivational and personal aspects supplement the model. This model allows the modeling of subject-specific professional teaching competencies, e.g., in the COACTIV project (Kunter et al., 2011).

2.2.2 Professional Competence and ESD

Multiple approaches model teaching competence regarding ESD; four are most prominent (Rieckmann & Holz, 2017): (1) the UNECE model (UNECE, 2012), (2) the CSCT model (Sleurs, 2008), (3) KOM-BiNE (Rauch & Steiner, 2012), and (4) the approach by Bertschy et al. (2013). The UNECE model promotes a holistic approach aiming at envisioning change and achieving transformation of education and the educational system. It describes educators' competencies regarding the four spheres: learning to do, learning to know, learning to live together, and learning to be (UNECE, 2012). While the UNECE model is visionary, compact, and calls for engagement for fundamental change, the CSCT model is a detailed and comprehensive approach. It integrates the curriculum, sustainable development, competencies, and teacher training and describes five competence domains important for teaching ESD: knowledge, system thinking, emotions, ethics and values, and action (Sleurs, 2008). KOM-BiNE refers to the CSCT model and focuses on competencies needed to implement ESD projects. It divides competence into three levels, one describing individual aspects, one the integration in society, and one the competencies bridging both. It subdivides individual aspects into the four fields: knowing, acting, valuing, and feeling (Rauch & Steiner, 2012). Bertschy et al. (2013) also refer to the CSCT model and develop a competence model for the individual elementary school teacher, applying the professional acting competence model by Baumert and Kunter.

(2006). We connected to the approach by Bertschy et al. because measuring ESD competencies within the frame of professional action competence best allows for the discussion of the contribution of existing geography teacher education to ESD.

2.2.3 Competence Model for ESD Teaching in Secondary Geography Education

To investigate secondary school teaching, we grounded our model in a Delphi study by Helberg-Rode and Schrüfer on competencies for secondary school ESD teaching (Hellberg-Rode & Schrüfer, 2016). The experts participating in the study named and ranked different competencies relevant to ESD teaching in secondary schools and assigned them to one of the competence dimensions: professional knowledge (PK), content knowledge (CK), professional content knowledge (PCK), or social and personal competence (Hellberg-Rode & Schrüfer, 2016). We integrated the four competence dimensions according to the competencies in our competence model (see Figure 2.1). Since the national context and its standards are vital to school education and ESD (Haan, 2008), we supplemented the model with topics demanded by the national standards (Schreiber & Siege, 2016). We included all topics from the national standards declared as geographic by a panel of experts ($n = 21$) (see Figure 2.1) because geography teachers must be knowledgeable in these subject areas to welcome them to their teaching.

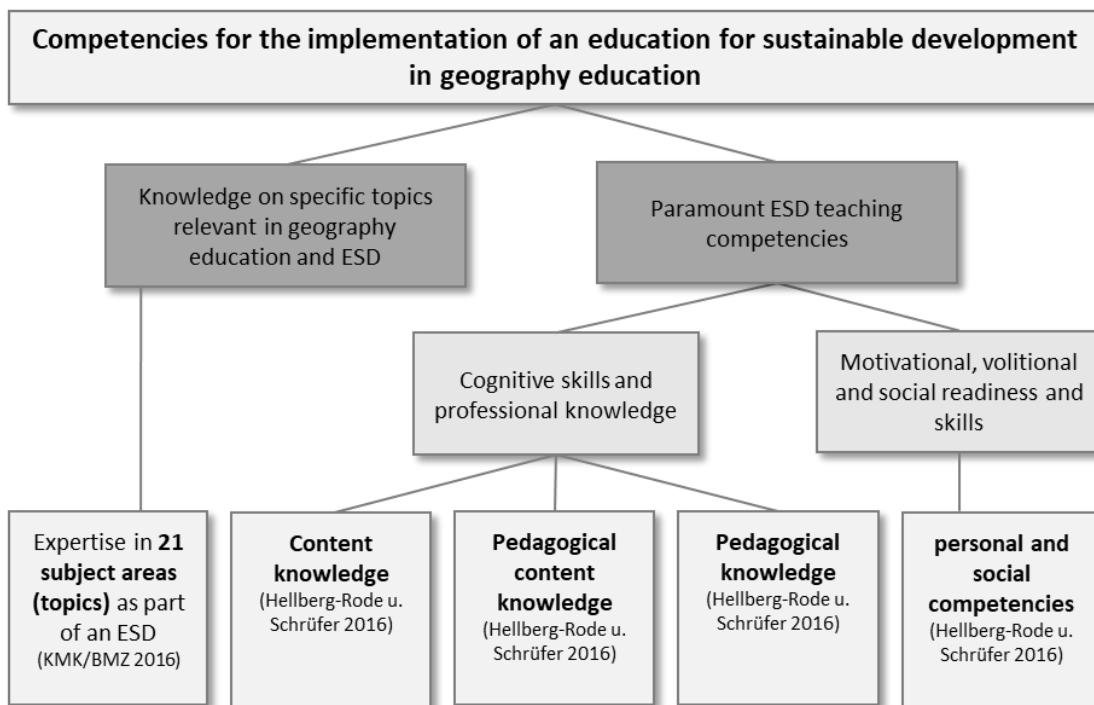


Figure 2.1 Competence model

2.2.4 Higher Education Geography's Impact on ESD

Knowledge and interest in geographic subdisciplines might correlate differently to professional competence in ESD since teachers' understanding of sustainable development differs between social and natural science backgrounds (Corney & Reid, 2007; Konrad et al., 2021; Philipps-Universität Marburg, 2018). Geography didactics, field, and school practice might impact competence patterns distinctively (Corney & Reid, 2007). Since studies show that activating methods raise students' ESD competency level and interest successfully (Corney, 2006; Konrad et al., 2021), we expected a positive school and fieldwork impact. The importance of the curricular integration of ESD was discussed (Bagoly-Simó et al., 2018; Braßler, 2018; Rieckmann & Holz, 2017; Sprenger & Nienaber, 2018). Modules with explicit ESD reference should, therefore, impact the competence level significantly.

2.2.5 Research Questions and Scope of this Study

This study aims to assess the status quo of pre-service geography teachers' ESD competencies to help identify the specific need for action in promoting ESD competencies in pre-service teachers' higher geography education. We assessed pre-service teachers' self-conception of their ESD competencies cross-sectionally to evaluate the geography teacher education's impact on ESD competence, asking:

- How confident are pre-service geography teachers in their professional competence regarding ESD?
- How important are the specific competencies to them?
- How does the course of studies connect to self-assessed competence?

2.3 Methods

2.3.1 Research Design

This study presents our results from a cross-sectional full survey study on ESD competencies and interest in ESD among pre-service geography teachers at the University of Marburg. Before carrying out the survey, we ensured its quality by the following steps (for illustration, see Figure 2.2):

(1) We defined a competence model within which we measured the pre-service teachers' level for each competency, considering scientific literature and normative frameworks. (2) We designed items following the Delphi study by Hellberg-Rohde and Schrüfer (Hellberg-Rode & Schrüfer, 2016) and illustrated the 21 topics from the orientation framework [40] by examples. (3) Experts (geography teachers ($n = 4$) and

professors in geography (education) ($n = 3$) validated both the selected competencies and the item testing on it in a qualitative pre-testing. (4) We then designed a survey. (5) The qualitative pre-test with pre-service teachers from different semesters and genders ($n = 8$) showed that the items were understood as intended; the survey improved its structure. (6) To reach all students enrolled in geography education, the survey was carried out in the winter term of 2018/2019 and summer term of 2019 in all geography education modules at the University of Marburg. (7) All complete surveys ($n = 100$) were included in the quantitative analysis.

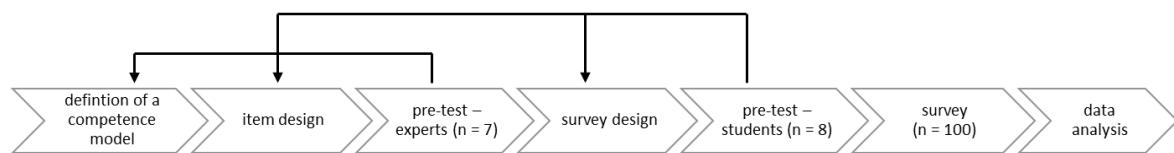


Figure 2.2 Research design

2.3.2 Survey

The survey measured the pre-service teachers' self-assessed ESD competencies and knowledge in ESD-specific topics and the subjective importance they assigned to the sub-competencies and topics (see Box A1 in Appendix) and the socio-demographic factors: semester number, modules finished, sex, level of geography school education, second subject (a necessity in German school education). It relied on a Likert scale from 1 (not at all) to 5 (to a very high degree) with a can't judge/don't know option (-1) for the competence and interest measurements. It was distributed online using SoSci Survey.

2.3.3 Sample

We distributed the survey to all 375 pre-service teachers enrolled in geography at the University of Marburg and included only complete and plausible surveys ($n = 100$) in the analysis. Our sample represented gender adequately with a slight female bias: 42% of the pre-service geography teachers were female (Philipps-Universität Marburg, 2018) and 46% of the study participants. A total of 58% of the pre-service geography teachers were male (Philipps-Universität Marburg, 2018) and 52% of the study participants. The university statistics only classified male and female students, whereas 2% of the study participants were diverse. Students from all semesters participated in the study (see Figure 2.3). The teacher education program is designed for nine semesters; thus, those above were summarized. All pre-service geography teachers were enrolled in one or two

subjects next to geography because all teachers need at least two subjects in Germany. In the sample, 19% also studied another social science (history, politics and economy, ethics), 24% studied natural sciences (biology, chemistry) or mathematics, 27% studied physical education, and 41% studied a language (German, German as a second language, English, Spanish). Two-thirds of the participating pre-service teachers took geography in their advanced high school education (Oberstufe).

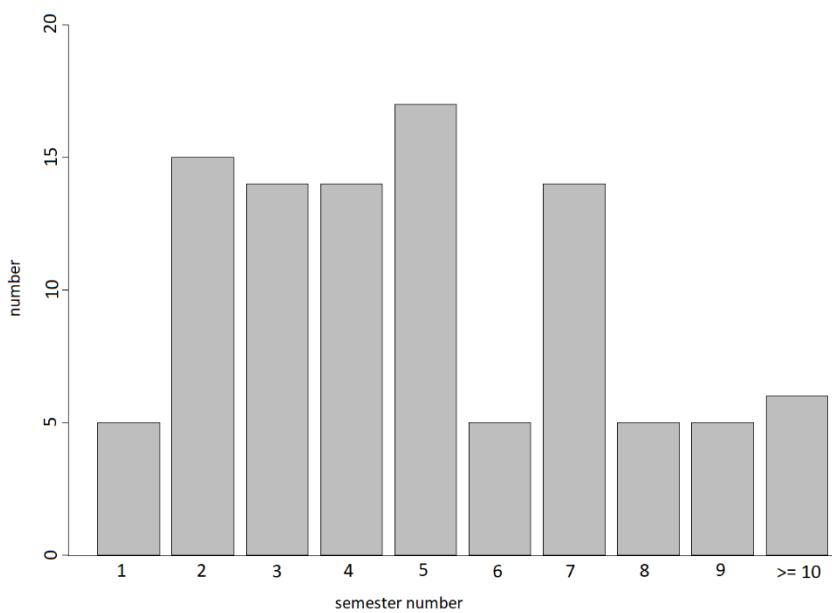


Figure 2.3 Students by semester number

2.3.4 Analysis

We analyzed the data with the statistic software R (R Core Team, 2020) and relied primarily on the ‘PerformanceAnalytics’ package (Peterson & Carl, 2020). All correlations were calculated with the Spearman rank correlation. We analyzed the development of the competence levels cross-sectionally. The correlation between finished modules and competence level was calculated for every module, subdimension, and item. Modules with literal reference to sustainable development in the module description were included as such.

2.4 Results

2.4.1 Overall Results

Overall, pre-service geography teachers assessed themselves as having a high ESD competence. The median lay between 3 and 4 for all subscales with the highest results in social and personal competencies (see Figure 2.4). All subscales correlated with

each other (see Figure 2.6); thus, the pre-service teachers regarded their competence level generally, over the different subscales, as higher or lower compared to their peers. The importance pre-service teachers assigned to the ESD competencies was even higher than their competence level; the median was four or above for all measured subscales (see Figure 2.5). The pre-service teachers' interest correlated significantly with their competence ($p < 0.05$).

Socio-demographic factors did not affect the overall competence assessed; we saw no gender impact and no significant impact of high school geography education or second subject. Effects were only found in the importance pre-service teachers assigned to competencies: Females generally gave higher importance to ESD competencies than males ($p < 0.01$). We will now discuss the different subscales in more detail.

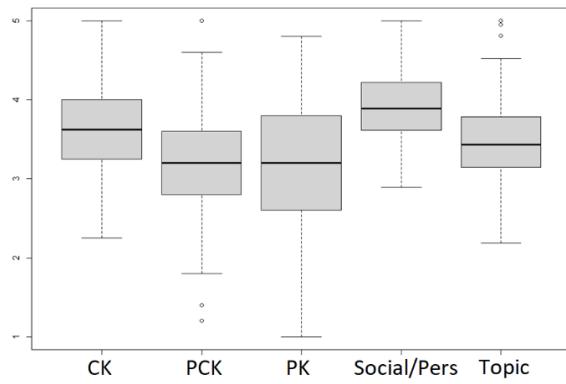


Figure 2.4 Competence by subscale

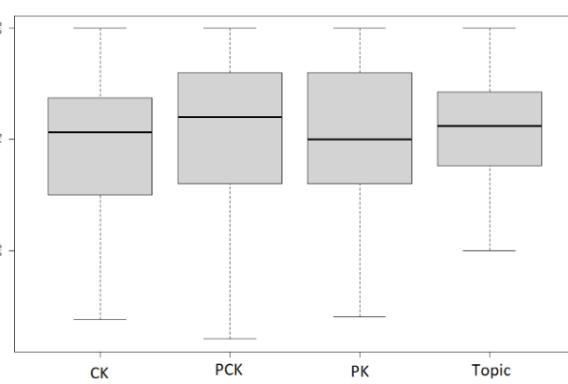


Figure 2.5 Importance by subscale

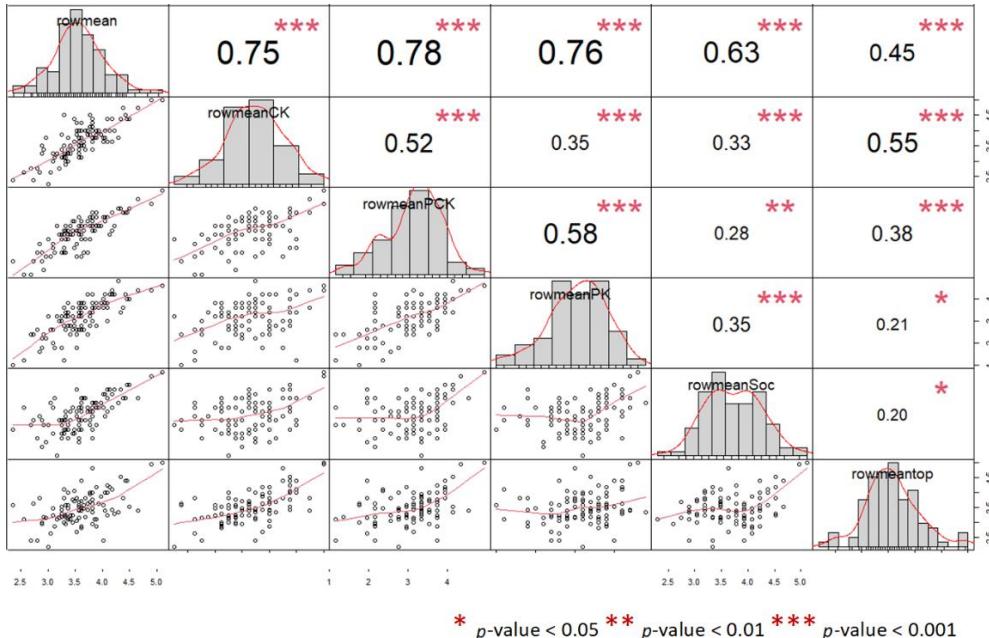


Figure 2.6 Correlation between subscales

2.4.2 Content Knowledge

The pre-service teachers assessed themselves homogenously high on ESD-related content knowledge; the median was 4 for all items (see Figure 2.7). They felt most competent in system thinking (CK2) (see Figure 2.7 and Box 1). The importance assigned to the items correlated to the assessed competence ($p < 0.01$), but it was more heterogeneous and slightly higher (see Figure 2.8). The median was four for all items, but dynamics and interdependencies of global processes (CK5) were rated the most important (median = 5).

Content knowledge correlated by 0.27 with the semester number ($p < 0.01$) and by 0.34 with the school practice ($p < 0.001$). Content knowledge was thereby the dimension that was impacted by semester number and school practice the most. There was no gender effect to the competence assessment, but females significantly assigned higher importance to the CK ($p < 0.01$) than males. Pre-service geography teachers overwhelmingly expected to gain competence in CK during their higher education. They expected to foster only their competence in system thinking and global solving strategies in their later careers.

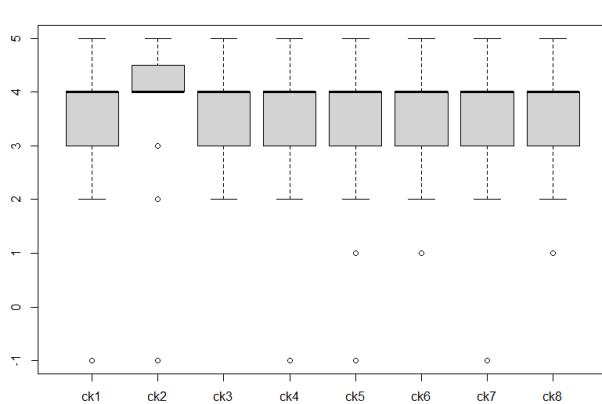


Figure 2.8 Content knowledge competence level by item

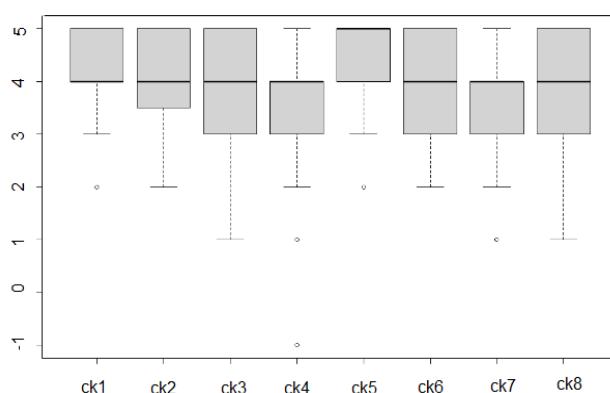


Figure 2.7 Content knowledge importance by item

Box 1 Items for content knowledge

- CK1 = critical reflection and assessment of global change
- CK2 = system thinking
- CK3 = interdisciplinary analysis
- CK4 = sustainable development concept
- CK5 = dynamics and interdependencies of global processes
- CK6 = discourse on ethics
- CK7 = ecological systems
- CK8 = global problem-solving strategies

2.4.3 Pedagogical Content Knowledge

The pre-service teachers assessed themselves as having medium ESD-related pedagogical content knowledge; the median was 3 for all items but problem-solving-oriented thinking (PCK1), which the pre-service teachers felt more competent in (median = 4) (see Figure 2.9 and Box 2). The importance of the items was rated higher than their own competence; only the importance of the repertoire of methods for ESD was rated with a median of 3 (see Figure 2.10).

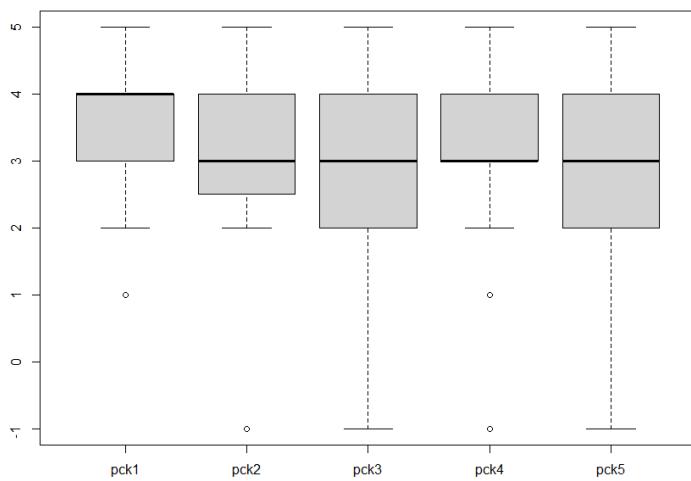


Figure 2.9 Pedagogical content knowledge competence level by item

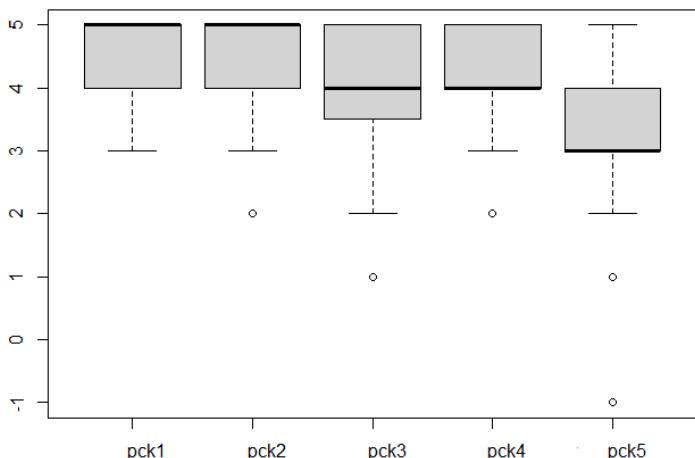


Figure 2.10 Pedagogical content knowledge importance by item

There was neither a correlation between the importance and competence nor the semester number and competence level. The school practice correlated by 0.20 ($p < 0.05$) to the competence. There was no gender effect to the competence assessment, but females significantly assigned higher importance to the PCK ($p < 0.01$) than males. Pre-service geography teachers expected to develop all five competencies during higher education.

Box 2 Items for pedagogical content knowledge

PCK1 = problem-solving-oriented thinking

PCK2 = development of assessment skills among learners

PCK3 = the sustainability triangle or square as a structuring principle for lesson planning

PCK4 = promote design skills

PCK5 = repertoire of methods for ESD

2.4.4 Pedagogical Knowledge

The pre-service teachers assessed themselves as having medium ESD-related pedagogical knowledge. Still, their assessment varied between the different items, with the median ranging between three and four (see Figure 2.11). They felt most competent in the change of perspective (PK1 see Figure 2.11 and Box 3). The importance of the PK items was rated higher than the competence and more homogenously (see Figure 2.12). This difference resulted in a gap between the median of importance (= 4) and assessed competence level (= 3) for the items on dealing with complexity and uncertainty (PK2), participation and co-creation in terms of Agenda 21 (PK3), and open schools to cooperating with external partners (PK5).

There was neither a correlation between the importance and competence nor the semester number and competence level. The school practice correlated by 0.23 ($p < 0.05$) to the competence level. There was no gender effect to the competence assessment, but females significantly assigned higher importance to the PK ($p < 0.001$) than males. Pre-service teachers expected to develop their overall PK during their later careers and only expected to develop the competencies change of perspective (PK1) and open schools to cooperate with external partners (PK5) during higher education.

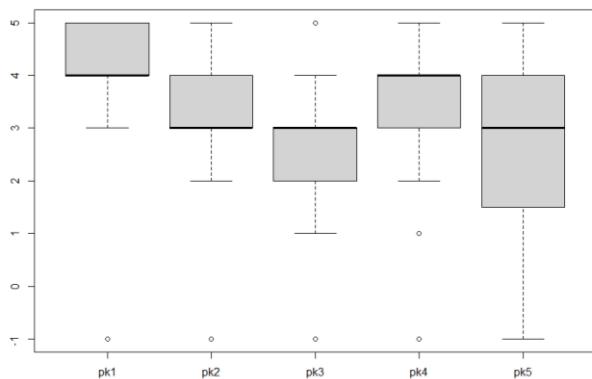


Figure 2.11 Pedagogical knowledge competence level by item

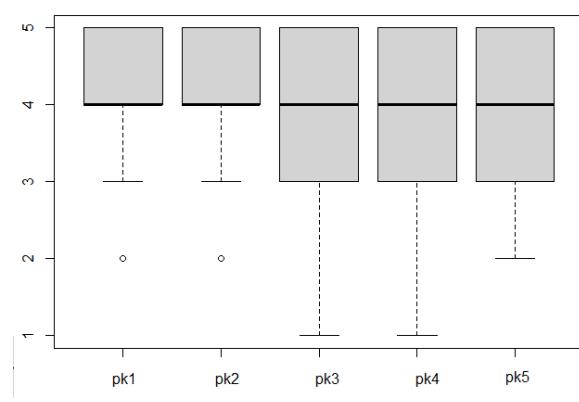


Figure 2.12 Pedagogical knowledge importance by item

Box 3 Items for pedagogical knowledge

PK1 = change of perspective

PK2 = dealing with complexity and uncertainty

PK3 = participation and co-creation in terms of Agenda 21

PK4 = to act as a learning companion/learning coach

PK5 = open schools to cooperating with external partners

2.4.5 Social and Personal Competence

The pre-service teachers assessed themselves as having a high social and personal competence (see Figure 2.13). They felt extremely empathetic (S1) (median 5). It is noticeable that the social competencies were assessed higher than the personal (see Figure 2.13 and Box 4). Tolerance of ambiguity and frustration (S6) and visionary thinking (S9) were assessed as the lowest (median = 3). There was no correlation between the semester number and competence level. The school practice correlated by 0.22 ($p < 0.05$). There was no gender effect to the competence assessment.

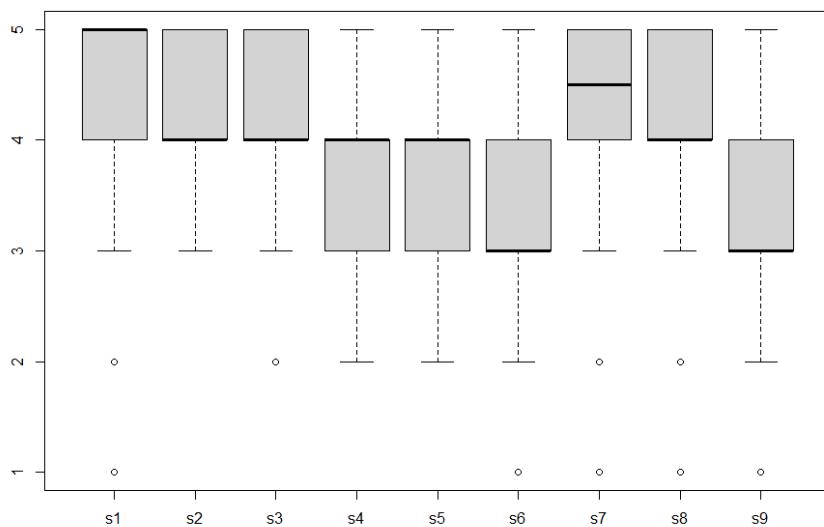


Figure 2.13 Social and personal competence level by item

Box 4 Items for social and personal competence

- S1 = empathy
- S2 = communication competence
- S3 = competence in cooperating
- S4 = critical ability
- S5 = willingness to innovate
- S6 = tolerance of ambiguity and frustration
- S7 = open-mindedness
- S8 = competence in acting solitarily
- S9 = visionary thinking

2.4.6 ESD Topics

The pre-service teachers assessed themselves as having a medium-high competence regarding ESD topics; the median ranged between 3 and 4 (see Figure 2.14). They felt most competent in demographic structures and developments (T14) and least qualified in global topics (the history of globalization (T3), peace and conflict (T16), development cooperation and its institutions (T19), and global governance (T20)). Each ESD topic's importance was ranked highly with medians between 4 and 5 (see Figure 2.15). A rather diverse set of topics reached the highest level of importance: agriculture and food (T5), education (T7), protection and use of natural resources (T9), global environmental change (T11), and peace and conflict (T16) (see Figure 2.15, Box 5). Comparing competence and importance, we saw a gap in peace and conflict (T16) between a high

importance and low competence level. The assigned importance correlated highly with the assessed competence ($p < 0.001$) despite this item. However, there was neither a correlation between the semester number and competence level nor the importance. The school practice correlated by 0.25 ($p < 0.05$) with the assessed competence. There was no gender effect to the competence assessment or the importance.

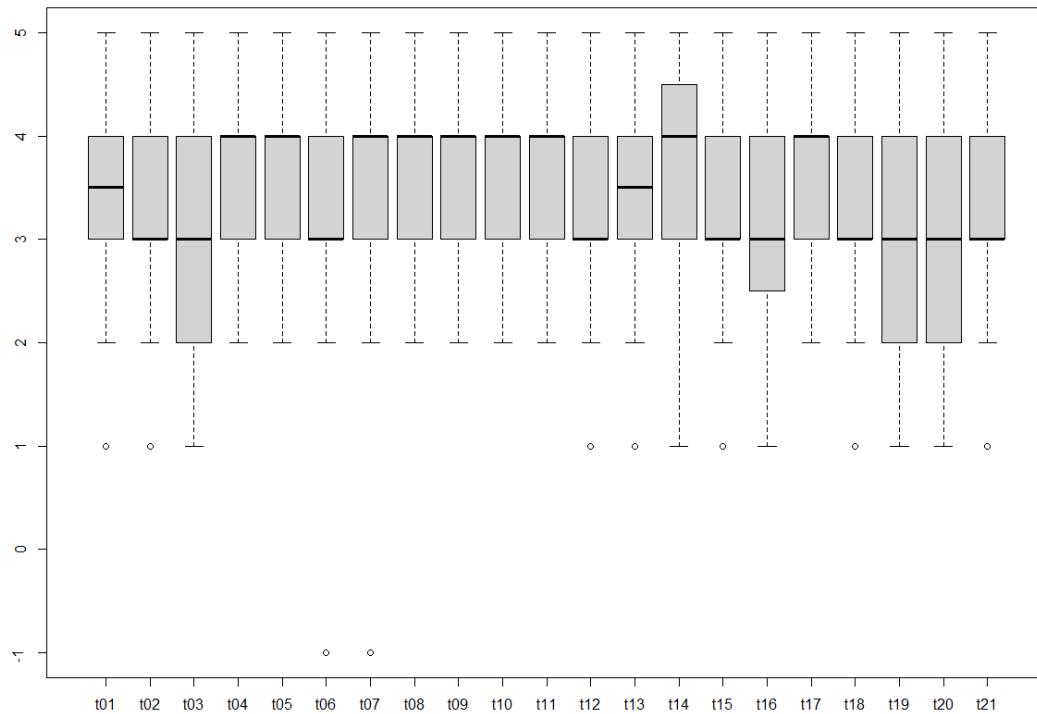


Figure 2.14 Competence for topics by item

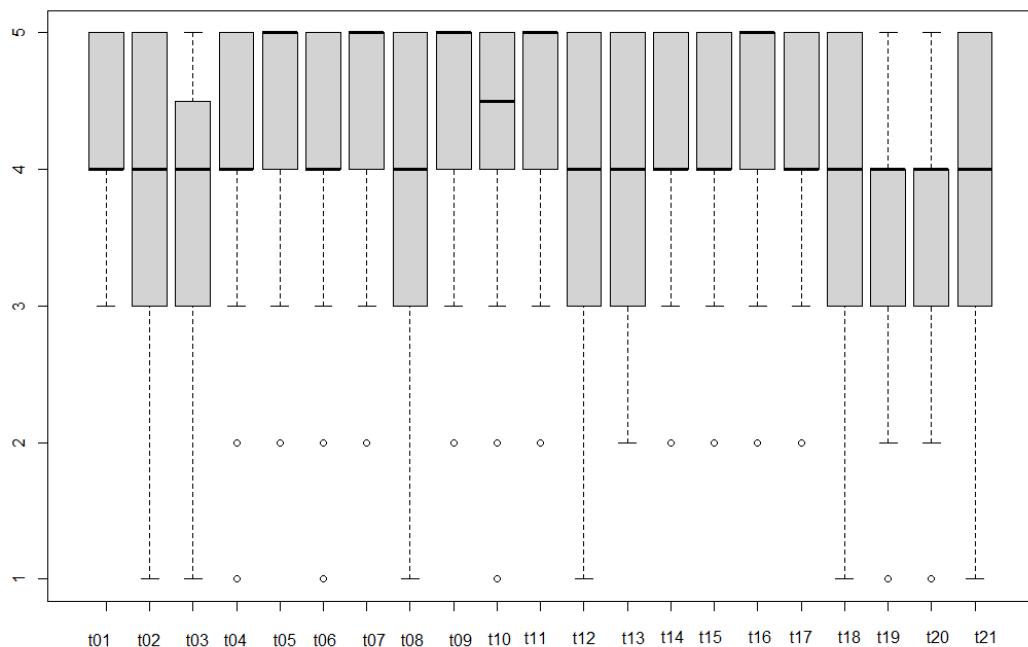


Figure 2.15 Importance for topics by item

Box 5 Items for topics.

- T1 = diversity of values, cultures and living conditions
- T2 = globalization of religious and ethical models
- T3 = history of globalization
- T4 = goods from all over the world
- T5 = agriculture and food
- T6 = health and disease
- T7 = education
- T8 = globalized leisure
- T9 = protection and use of natural resources
- T10 = opportunities and dangers of technological progress
- T11 = global environmental change
- T12 = mobility and urban development
- T13 = globalization of economy and work
- T14 = demographic structures and developments
- T15 = poverty and social security
- T16 = peace and conflict
- T17 = migration and integration
- T18 = good governance
- T19 = development cooperation and its institutions
- T20 = global governance
- T21 = communication in a global context

2.4.7 Study Course and ESD Competencies

Overall, ESD competencies were assessed more highly by more advanced pre-service teachers. A U-curve characterizes the correlation between semester number and competence (see Figure 2.16). Students enter university with high confidence in their

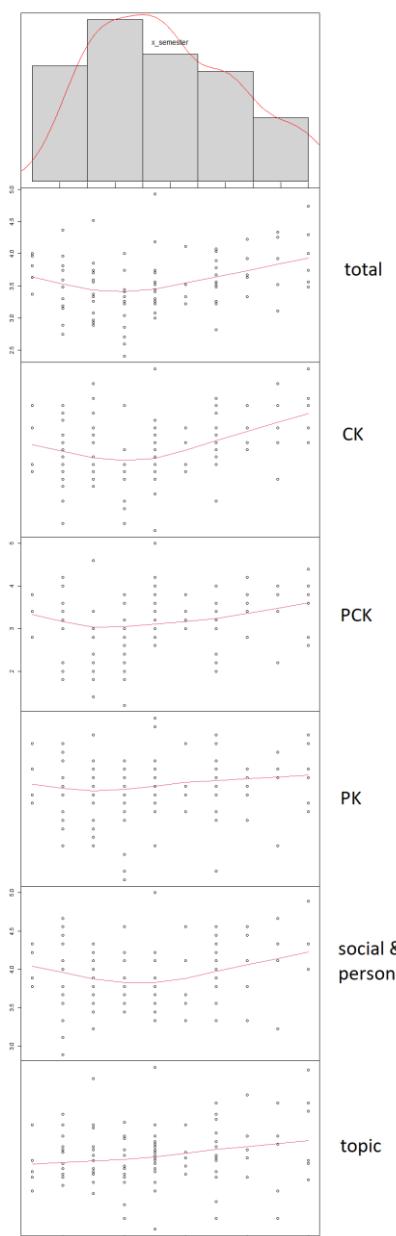


Figure 2.16 Semester course

modules with ESD reference, and fieldwork, but also correlated to physical geography, nature-society, and school practice. PCK, PK, and social and personal competence linked to fewer modules. PCK was influenced by didactics, field, and school practice only. PK correlated to the school practice and the human geography modules taken. The social and personal competencies were impacted only by the practical experience in school.

competencies, get less confident during the first semesters, and then gain confidence again, finally exceeding the entrance level. There was neither a correlation between assigned importance and semester number nor between importance and individual modules.

General ESD competence correlated only with some individual modules (see Table 2.1). Out of all modules, the school practice had the most significant impact on ESD competence ($p < 0.001$); the fieldwork also correlated significantly ($p < 0.01$). Its correlation (0.33) underlines the importance of the school practice to the assessed competence, which was higher than the correlation between semester number and competence (0.21). The modules with explicit ESD references (e.g., nature-society) did not relate to general ESD competence.

The individual competence dimensions were correlated differently to the different modules. CK was impacted most strongly and correlated to all modules but nature-and-society and modules with ESD reference (see Table 2.1). In detail, didactics and school practice impacted CK most significantly and physical geography and fieldwork more significantly than human geography. On the other hand, the ESD topics were more robustly correlated to human geography,

Table 2.1 Subdiscipline's correlation with ESD competence * p-value < 0.05 ** p-value < 0.01 *** p-value < 0.001.

	Human	Physical	Nature-Society	Didactics	ESD Reference	Fieldwork	School Practice	Semester Number
Total	**	*		**		**	***	*
CK	*	**		***		**	***	**
PCK				**		**	*	
PK	**						*	
Social and Personal							*	
Topic	**	*	*		**	**	*	

2.5 Discussion and Conclusions

2.5.1 How Confident are Pre-Service Geography Teachers in their Professional Competence Regarding ESD?

Pre-service geography teachers are generally very confident in their ESD competencies. These results align with previous research, attesting that geography teachers are highly familiar with all ESD dimensions (Summers et al., 2004). The competencies with the highest marks (system thinking, problem-orientated thinking, change of perspective, and empathy) are ranked as very important by most experts (Hellberg-Rode & Schrüfer, 2016).

Regarding the dimensions, the pre-service teachers are most confident in their CK and social and personal competencies and least satisfied with their PK. CK is reflected in a knowledge dimension included in many ESD models (Brandt et al., 2021; Cebrián et al., 2019; García-González et al., 2020; Malandrakis et al., 2019; Rauch & Steiner, 2012; Sleurs, 2008; UNECE, 2012). Surveys on the ESD competence of pre-service teachers from different disciplines show lower results in the knowledge dimension (Brandt et al., 2021; Brockmüller & Siegmund, 2020; Maidou et al., 2019; Sass et al., 2021; Viehrig et al., 2011). Our high results in the content knowledge assessment connect to intervention studies results (Brandt et al., 2021; Cebrián et al., 2019; García-González et al., 2020) and

suggest an impact of higher education in geography on the pre-service teachers' ESD competence assessment.

2.5.2 2. How Important are Specific Competencies to Them?

Pre-service geography teachers assign very high importance to ESD competence. The given importance is above the competence level but correlates. This connects to empirical findings (Maidou et al., 2019; Sass et al., 2021). Nonetheless, problem-solving-oriented thinking is the only competence pre-service teachers feel highly competent in and rank with the highest importance. These results reflect the central role system thinking has in German geography education (Brockmüller & Siegmund, 2020; Mehren et al., 2016; Schuler et al., 2018; Viehrig et al., 2011). The other competencies with the highest level of importance assigned (dynamics and interdependencies of global processes, agriculture and food, education, protection and use of natural resources, global environmental change, peace and conflict, problem-solving-oriented thinking, and development of assessment skills among learners) have high and medium competence levels assigned. All dimensions are similarly highly ranked in importance. Women assign higher importance to ESD competencies than men. This result connects to previous findings (Stukalo & Lytvyn, 2021).

2.5.3 How Does the Course of Studies Connect to Self-Assessed Competence?

The course of studies is positively connected to the self-assessed ESD competences. The importance pre-service teachers assign to ESD competence is constantly high, independent of semester number and modules finished. Our results show that active learning environments in a disciplinary setting affect the competence assessment more strongly than formally integrating ESD into the curriculum. The modules with an explicit SD reference in the module description only affect the assessed competence level regarding the ESD topics; the practical modules, school practice, and fieldwork correlate positively in general. The didactic modules yield higher impacts on CK than human and physical geography, which might be explained by the integrated perspective on the subject the didactics of Marburg pursue (Peter & Nauss, 2020).

Regarding the competence dimensions, we see that the semester number only impacts the assessed CK and ESD topics strongly and, possibly due to this influence, streamlines the assessment of these competencies. Intervention studies show that PCK and PK are more difficult to promote in a purely academic setting (Brandt et al., 2021; Cebrián et al., 2019). In our study, the PCK assessment is influenced by didactics, fieldwork, and

school practice only. PK assessment is only positively correlated to school practice and, surprisingly, to human geography. As social science teachers promote the social dimension of ESD more strongly than natural science teachers (Borg et al., 2014), pre-service teachers with a solid connection to human geography might feel more engaged with pedagogical ESD tasks. Overall, PK was assessed very heterogeneously, and we assume that these results reflect pre-service teachers' prerequisites from outside the university (Römer et al., 2018). Regarding the social and personal competence assessment, we see an impact of practical experience only, highlighting the importance of the practical experience described in the literature (Brandt et al., 2021; Cebrián et al., 2019; Corney, 2006).

The U-curve describing the competence assessment over the semester number can be explained by pre-service teachers overestimating their competencies in the beginning of their studies. After experiencing challenges and possibly failures, they adjust their competence assessment. Finally, when they become established, the assessed competencies rise and exceed the entrance level.

2.5.4 *Limitations*

To ensure a coherent analysis, we included complete questionnaires only. This proceeding might have led to a bias toward positive results by selecting the more motivated students. Unfortunately, the incomplete questionnaires were too fragmented for well-founded statements as to whether a bias exists.

The students self-assessed their competencies. This method is valid for comparative statements as students can usually tell which part they are more competent in and which part they are less competent in (Baer et al., 2007). It is questionable whether the pre-service teachers' competence is as high as experts would assess (Birdsall, 2014). Rothland argues that pre-service teachers overestimate their competence at the beginning of the school practice and their development during the practice (2018). Their self-assessment is driven by an illusionary self-concept that is perceived as ideal (Rothland, 2018). Under this argumentation, the competence assessment in this study might depict the pre-service teachers' idealized self-concept.

Our analysis of the impact of the modules is based on the formal module description only. The module descriptions have been in place for some time: long enough to surpass different instructors. We did not assess how much ESD is included in the syllabus of practical teaching by the individual instructors. Neither did we assess the attitudes the individual instructors have towards ESD.

2.5.5 *Conclusions*

Our results show an impact of geography education on professional ESD teaching competence assessment. However, this impact is neither very high nor does it encompass all competence dimensions. We see a connection to the importance the pre-service teachers assign to the competencies. How the pre-service teachers want to be might, thus, be a factor in the competence assessment. However, the pre-service teachers integrate some dimensions of ESD competence more strongly into their self-concept than others. This study revealed the blind spots of geography teacher education regarding ESD: PK, PCK, and social and personal competencies.

The claim that higher education should foster all ESD teaching competencies alike might be too strong. A differentiation of PCK according to the consensus model (Carlson et al., 2019) might help develop a hierarchy of skills that must or can be developed during higher education. While we can argue that PK and PCK are left to be developed in the practical phase of teacher education, that higher geography education has no general impact on social and personal competencies, not even in the self-concept, is not satisfying.

Exploring the potential of different geography modules to meet this need shows the benefit of practical modules. Adjusting specialized theoretical modules smoothly to foster competencies to teach ESD thus seems challenging. A strong focus on research and project-based learning might be critical to integrate ESD adequately into geography education. Such methods successfully improve geographic (Walkington et al., 2011) and ESD competence (Braßler, 2018; Kalsoom & Khanam, 2017; Konrad et al., 2021). Scientific and research skills are also the most mentioned learning skills in geographic ESD concepts (Yli-Panula et al., 2020).

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Box A 1 Survey structure

- | | |
|-----|--|
| (1) | ESD-specific competencies |
| a. | self-assessment of competence level |
| b. | importance assigned to competencies |
| c. | classify items to CK, PCK, PK |
| d. | expected phase to gain proficiency level (higher education / ongoing career) |
| e. | self-assessment of social and personal competencies |
| (2) | ESD-specific topics KMK/BMZ (2016) |
| a. | self-assessment of knowledge |
| b. | importance assigned to knowledge |
| c. | self-assessment of capability to prepare a lesson for topic |
| (3) | socio-demographic data |

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3 Geographische Modellierkompetenz – Modellierung von Raum konzeptualisieren

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Abstract

In diesem Beitrag wird basierend auf theoretischer und empirischer Forschung sowie den Bildungsstandards der Deutschen Gesellschaft für Geographie ein Kompetenzmodell für das Modellieren im Kontext einer geographischen Bildung entwickelt. Die Stufung des Modells wird aus den Systemkomponenten Struktur, Funktion, Prozess abgeleitet. Modellieren umfasst auf jeder Stufe die vier Modellierpraktiken Entwerfen, Anwenden, Evaluieren und Revidieren, die zyklisch eingesetzt werden und die Dimensionen des Modells bilden.

Key Words: Modellieren, Wissenschaftsverständnis, Modellkompetenz, Geographieunterricht, Kompetenzmodell

Abstract

Based on recent international research on modelling in science education and geographical concepts a competency model for geographic modelling is presented in this article. Within this model three consecutive levels are being modelled: structure, function and process. These levels mark the difficulty in the competence model. Within each level four modelling practices are deployed in a cyclic manner: draft, use, evaluate and revise. Each of these practices forms one dimension within the competency model.

Key words: Modelling, scientific literacy, model competencies, geography

3.1 Einleitung

„The history of man [...] is the history of model building“ (Rivett, 1972): 2). Die große Bedeutung von Modellen liegt in der Breite des Begriffs begründet. Aufbauend auf dem Modellbegriff von Mahr (2008) ist alles ein Modell, was dazu erklärt wird und gleichzeitig Modell von etwas für einen Zweck ist (Mahr, 2008). Ein Modell muss also keine gegenständliche Nachbildung sein, vielmehr kann auch etwa das Erdenken von graphischen Abbildungen, mathematischen Gleichungen und Computersimulationen modellieren bedeuten, solange dabei Interessensgegenstände zweckgerichtet abgebildet werden. Die Modellierung hilft uns die Welt durch Reduktion verständlicher zu machen (Stachowiak, 1973), sie wird interpretier-, prognostizier- und gestaltbar. Diese Eigenschaften verleihen der Modellierung und den Modellen, traditionell auch in der Geographie und den geographischen Bildungskontexten, eine besondere Bedeutung, sind doch Globen, Karten, Stadtmobile, Klimamodelle etc. reduzierte Abbildungen. Dies wird auch mit Blick auf die Bildungsstandards der Deutschen Gesellschaft für Geographie (DGfG, 2017) für das Schulfach Geographie deutlich, in denen konkret der Operator Modell entwerfen aufgeführt wird. Der Annahme folgend, dass die Modellentwicklung zur Strukturierung der komplexen Welt maßgeblich beiträgt (vgl. Rivett 1972), nimmt sie auch im Zusammenhang mit räumlichem Denken (spatial thinking) eine zentrale Rolle ein und sollte im geographischen Bildungskontext forciert werden. Modellieren kann daher als ein vielgestaltiges Konstrukt betrachtet werden, dem auch in geographischen Bildungskontexten eine hervorgehobene Bedeutung zukommt. Damit Modellieren im Bildungsprozess operationalisier- und somit anwendbar wird, wird in diesem Artikel ein Kompetenzmodell zur Modellierkompetenz theoretisch abgeleitet und das Potenzial der Komplexitätsreduktion durch Modellierung für die geographische Bildung eruiert.

Die theoretische Voraussetzung das Modellieren für den Geographieunterricht zweckdienlich zu konzeptualisieren, erfordert die Synthese der Grundlagen von Geographieunterricht und Modell- und Modellierkompetenz. Beide Ebenen werden im Folgenden betrachtet und in das Kompetenzmodell überführt. Aufbauend auf der Modelltheorie, insbesondere von Mahr (2008), wurde das reflektierende Verständnis von Modellen in der Biologiedidaktik als Modellkompetenz gefasst und umfassend evaluiert (Grünkorn & Krüger, 2012; Krell & Krüger, 2013; Upmeier zu Belzen & Krüger, 2010), für die Naturwissenschaftsdidaktik verallgemeinert (Kauertz et al., 2010; Krüger et al., 2018; Upmeier zu Belzen et al., 2019) und aktuell in der Geographiedidaktik vorgestellt (Bette et al., 2019).

Bette et al. bauen damit auf die Entwicklung innerhalb der Geographiedidaktik auf, die Modellentwicklung ausgehend von einer Beschreibung von Modellen im Unterricht zur Veranschaulichung (Wiktorin, 2013; Wirth, 1979) hin zu einer Nutzung insbesondere auch zur Herleitung von wissenschaftlicher Erkenntnis (vgl. Brucker, 2016; Otto & Mönter, 2015; Peter, 2018; Raschke, 2018; Wiktorin, 2014) betrachtet. Vor allem in der deutschsprachigen Rezeption bedingte die Reflexion bestehender Modelle und eines modellbasier-ten Wissenschaftsparadigmas Forschungsansätze aktives Modellieren durch die Schüler/innen selbst und somit das Schaffen eigener Modelle zu beschreiben (vgl. Krell et al. 2019; Krüger et al. 2018; Upmeier zu Belzen et al. 2019). Zu dieser prozessbezogenen Modellierkompetenz liegen erste theoretische und empirische Arbeiten aus Biologie, Physik und allgemeinem naturwissenschaftlichen und technischen Unterricht vor (Krell et al., 2017; Mislevy et al., 2017; Nicolaou & Constantinou, 2014; Marios Papaevripidou et al., 2014; C. V. Schwarz et al., 2009). In diesen wurden unter anderem Kompetenzmodelle entwickelt und im naturwissenschaftlichen und technischen Unterricht getestet (Louca et al., 2011; Tsivitanidou et al., 2018). Die aus diesen Arbeiten resultierenden unterschiedlichen Be- grifflichkeiten, Betrachtungsebenen und fachliche Fokussierungen werden in diesem Auf- satz übereingebracht und auf eine geographische Herangehensweise angewendet, da der fachliche Kontext im Umgang mit Modellen essentiell ist (Krell et al., 2015; Krüger et al., 2018), für die Geographie aber diesbezüglich noch keine fachspezifischen Konzepte vor- liegen.

Einen Rahmen für den Geographieunterricht definieren die Bildungsstandards der Deutschen Gesellschaft für Geographie (DGfG 2017), laut denen sich das Fach zum einen „zentral mit der Kategorie Raum beschäftigt, zum anderen verbindet es natur- und gesell- schaftswissenschaftliches Wissen und ist somit Brückenfach zwischen diesen Wissen- schafts- und Bildungsbereichen“ (DGfG 2017: 5). Die resultierende Problematik hinsicht- lich der fachlichen Fokussierung und Einordnung sei exemplarisch durch Uhlenwinkel skizziert: „[...] interdisciplinary in itself [is] opening the door for an undifferentiated vari- ety of contents that may be derived from all sorts of other subjects [...], but very often is simply taken from the everyday experience of the teacher [...]“ (Uhlenwinkel, 2018). Wird jedoch die Brückenfunktion nicht neben die Raumbetrachtung gestellt, sondern werden zur Beantwortung von räumlichen Fragestellungen Wissenschafts- und Bildungsbereiche zweckgerichtet verbunden, erwächst aus der Anwendung von räumlichem Denken (spatial thinking) geographisches Denken (geographical thinking) (Metoyer & Bednarz, 2017). Diesen Zugang modellierend zu gestalten ist ein Ziel des Artikels. Dabei werden sowohl

Orientierungskompetenz, die die Raumwahrnehmung sowie die Raumdarstellung umfasst, als auch darauf aufbauend Fachkompetenz geschult. Diese wird laut Bildungsstandards als die Fähigkeit beschrieben Räume als Systeme zu betrachten und auf verschiedenen Maßstabsebenen auf Funktion, Struktur, Prozess hin zu analysieren (DGfG 2017).

Systemdenken wurde in der Geographiedidaktik umfassend beforscht (Brockmüller, 2019; R. Mehren et al., 2016; Mehren, R., Rempfler, A. et al., 2018; Rieß et al., 2015; Schuler et al., 2018; Viehrig et al., 2011; Viehrig, 2017). Die räumliche Dimension im Systemdenken wurde vor allem von Viehrig et al. (2011) explizit als eigenständig benannt. In diesem Artikel kommt hingegen der räumlichen Perspektive, eine fundamentale und integrierende Rolle zu, auf der jedes Modell fußt. Zur Modellbildung muss ausgehend vom Realraum Komplexität systematisch reduziert werden. Dazu werden laut der Systemtheorie z. B. nach Bossel (2004) Systemgrenzen gezogen und Systemelemente dem Modellzweck nach auf die wesentlichen Elemente reduziert, um darauf aufbauend funktionale Zusammenhänge zu definieren, die nach einer Quantifizierung für [Prozess-]simulationen genutzt werden können (Bossel, 2004). In einer systemtheoretisch fundierten Modellierungspraxis muss die ethische Dimension (vgl. M. Mehren et al., 2015; Meyer, C. Felzmann, D., 2011) auf der fachlichen Modellierung aufbauend diskutiert werden. Diese Handlungsdimension ist jedoch nicht Teil der hier diskutierten Komplexitätsreduktion. Stattdessen liegt der Fokus dieses Beitrags auf der Tätigkeit des Modellierens, die als methodischer Zugang zu verstehen ist und sowohl für die Darstellung von Raum als auch für die Analyse von Systemen (vgl. Viehring 2011; Wiktorin 2014; Rieß et al. 2015; Brockmüller 2019) genutzt wird. Sie liefert so die Grundlage einer darüberhinausgehenden Beschäftigung mit Komplexität.

Auf diesem Gedankengang aufbauend kann ein Desiderat abgeleitet werden: Es bedarf eines geographiedidaktischen Konzepts, das Modellierpraktiken nutzt um die notwendige Komplexitätsreduktion zur Bearbeitung räumlicher Fragestellungen zu erreichen. Wir konkretisieren das Ziel dahingehend, dass ein Konzept des geographischen Modellierens unter Integration geographischer Basiskonzepte hergeleitet und methodisch begründet werden soll. Unter Rückgriff auf theoretische und empirische Arbeiten zum Modellieren wird daraus ein Kompetenzmodell zur Modellierungskompetenz theoretisch abgeleitet.

3.2 Methodisches Vorgehen

Um geographische Modellierkompetenz differenziert betrachten zu können, ist ein Kompetenzmodell zu erstellen, das die Operationalisierung von Tests und die gezielte Förderung der Kompetenz ermöglichen wird. Kompetenzmodelle dienen dazu Kompetenzen in verschiedene Dimensionen, also in Teilbereiche, zu strukturieren (Mayer & Wellnitz, 2014) und die Schwierigkeit bzw. Niveaus durch aufeinander aufbauende Stufen zu gliedern (Hartig & Klieme, 2006; Klieme & Leutner, 2006).

Geographisches Modellieren ist nach Weinert (2001) eine Kompetenz, da es einen fachdidaktischen Bildungsbereich darstellt, innerhalb dessen sich Könnerschaft zurückführen lässt auf „kontextspezifische kognitive Leistungsdispositionen, die sich funktional auf bestimmte Klassen von Situationen und Anforderungen beziehen. Diese spezifischen Leistungsdispositionen lassen sich als Kenntnisse, Fertigkeiten oder Routinen charakterisieren.“ (Definition nach Hartig & Klieme 2006: 126, vgl. Weinert 2001: 57 in englischer Sprache). Die Förderbarkeit der Modellierpraktiken lässt sich aus empirischen Befunden ableiten (Papaevripidou et al. 2007; Tsivitanidou et al. 2018). Diese Erkenntnis stützt das Vorhaben, das geographische Modellieren als Kompetenz zu modellieren.

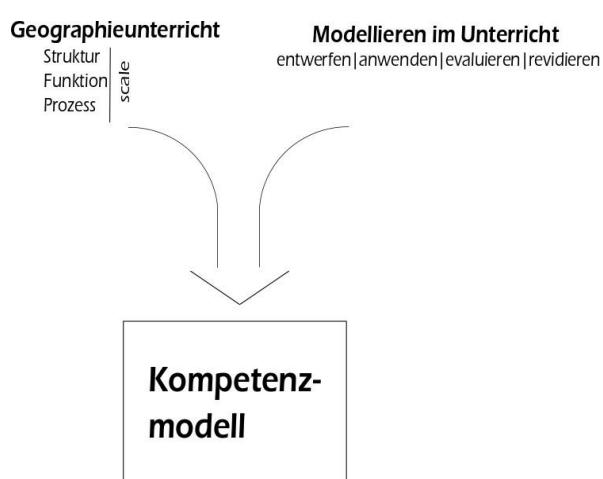


Figure 3.1 Grundlage des Kompetenzmodells

Für eine theoriebasierte Entwicklung müssen grundsätzlich das nomologische Netzwerk, theoretische und empirische Forschung, sowie der präskriptive Rahmen einbezogen werden (vgl. Mayer & Wellnitz 2014). Es werden deshalb die Ergebnisse didaktischer Forschung zu modellierender Tätigkeit und geographische Bildungsziele innerhalb des diskutierten Forschungskontextes (Kapitel 1) vereint (s. Figure 3.1). Für eine möglichst breite

Grundlage der didaktischen Herleitung modellierender Tätigkeit, werden verschiedene Forschungszugänge integriert. Es wird hierzu an didaktische Studien angeschlossen, die theoretische Konzepte umfassend empirisch umgesetzt haben (Schwarz et al. 2009; Papaevripidou et al. 2014). Diese werden verknüpft mit psychometrischer Expertise zur Messung von Modellieren (Mislevy et al. 2017) und den Erkenntnissen zur Modellierpraxis von Krell et al. (2019), die eine erste empirische Studie auf der Grundlage des Konzepts

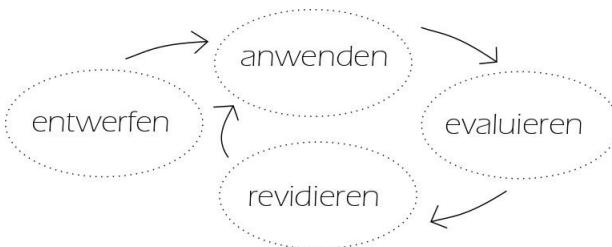
zur Modellkompetenz von Upmeier zu Belzen und Krüger (2010) darstellt. Auf dieser Grundlage werden strukturierend die vier Dimensionen entwerfen, anwenden, evaluieren und revidieren abgeleitet. Die zugrunde gelegten geographischen Bildungsziele sind durch die Bildungsstandards (DGfG 2017) definiert. Die dort beschriebenen Basiskonzepte Struktur, Funktion, Prozess werden in drei aufeinander aufbauende Stufen modellierender Tätigkeit untergliedert. Diese Einteilung lässt sich mit den Komplexitätsabstufungen in bestehenden Arbeiten zum Modellieren übereinbringen (Papaevripidou 2014). Im Folgenden wird die theoretische Herleitung ausgeführt und das Kompetenzmodell vorgestellt.

3.3 Didaktische Konstruktion des Modellierens

Die Struktur des Modellierens kann als zyklisch aufgefasst werden, wie sich aus didaktischer Forschung fachunabhängig ableiten lässt (Gilbert et al., 2000; Mislevy et al., 2017; Oh & Oh, 2011; M. Papaevripidou et al., 2007; C. V. Schwarz et al., 2009). Die Arbeitsschritte beziehen sich dabei iterativ aufeinander, daraus ergibt sich die Schwierigkeit einen Arbeitsprozess zu strukturieren, der weder linear ist noch in

Figure 3.2 Modellierkreislauf

aufeinander aufbauenden Stufen beschrieben werden kann. Als geeignete Grundlage erscheint der von Schwarz et al. (2009) entwickelte Ansatz einer Charakterisierung des Prozesses durch Modellierpraktiken, die sich aufeinander beziehen und im Arbeitsprozess wiederholt eingesetzt werden, der in empirischer Forschung vielfach Verwendung findet (Baumfalk et al., 2019; Bierema et al., 2017; Forbes et al., 2015; Hokayem & Schwarz, 2014; C. V. Schwarz et al., 2009; C. Schwarz, 2009; C. V. Schwarz & Gwekwerere, 2007; Zangori et al., 2017). Auf diesem Ansatz aufbauend wird von der Forschungsgruppe um Papaevripidou empirisch weitergearbeitet, allerdings unter einer leichten inhaltlichen Abwandlung (siehe Tab. 3.1) der einzelnen Praktiken (Louca et al. 2011; Papaevripidou et al. 2007, 2014, 2015; Nicolaou & Constantinou 2014; Papaevripidou & Zacharia 2015; Tsivitanidou et al. 2018). Um zu einer eigenen Nuancierung der Modellierpraktiken zu gelangen, wurde auch die davon unabhängige aus psychometrischer Perspektive entstandene Arbeit von Mislevy et al. (2017) hinzugezogen, die im US-Kontext unter Kooperation von ETS (Educational Testing Service) und SRI International (Standford Research Institute) design pattern zur Modellierfähigkeit entlang der



Next Generation Science Standards formuliert, und sich ebenfalls in Modellierpraktiken einordnen lässt (siehe Tab 1). Zur Integration der deutschen Diskussion wurden die jüngeren Arbeiten von Krell und Krüger hinzugezogen, die modellierende Tätigkeit qualitativ mit Hilfe eines Kategoriessystems beschreiben (siehe Tab. 3.1) (Krell et al. 2019; Krüger et al. 2018). Aus diesem Forschungsstand werden vier Modellierpraktiken zusammenfassend abgeleitet (siehe Tab. 3.1): entwerfen, anwenden, evaluieren, revidieren (siehe Figure 3.2).

1. *Entwerfen* ist die Setzung des Rahmens und Konstruktion oder Formulierung eines initialen Modells. Die kleinschrittigeren Kategorien Wahrnehmung des Phänomens und Aktivierung von Analogien und Vorwissen von Krell et al. (2019) werden in diese Praktik integriert (siehe Tab. 3.1). Modelle werden auch genutzt (Stufe2), um zu erklären (vgl. Schwarz et al. 2009; Papaevripidou et. al 2014; Mislevy et al. 2019 und
2. *Anwenden* ist die deduktive Ableitung von Aussagen bzw. Daten aus einem Modell, das Modell wird hierzu genutzt.
3. *Evaluieren* ist das Vergleichen dieser Aussagen bzw. Daten mit Externem, d. h. sowohl mit anderen Modellen und Theorien als auch mit empirisch erhobenen Daten. Der Modellvergleich (siehe Tab. 3.1), den Papaevripidou et al. (2014) nennen ist Teil dieser Praktik.
4. *Revidieren* ist die Integration neuer Erkenntnisse in ein bestehendes Modell.

Table 3.1 Modellierpraktiken in bildungswissenschaftlicher Literatur

	Papaevripidou et al. 2014	Schwarz et al. 2009	Mislevy et al. 2017	Krell et al. 2019
Modellier-praktiken				
Entwurf	Modellkonstruktion	Konstruieren	Modell-formulierung	Wahrnehmung des Phänomens, Aktivierung von Analogien und Erfahrungen, Modellentwicklung
Anwendung	Modellnutzung	Benutzen	Modellnutzung	Ableitung von Vorhersagen
Evaluierung	Modellvergleich	Evaluieren	Modell-evaluierung	Evaluierung der Konsistenz und Repräsentativität, Evaluierung

				der Prognosefähigkeit, Manipulation des natürlichen Systems, Datenerhebung
Revision	Modellrevision	Revidieren	Modellrevision	
Bezugnehmend und transformierend			Modellelaboration, Modellartikulation	
Metaebene				
Reflexiv und organisierend	Metamodellierungs-wissen, Metakognitives Wissen des Modellierprozess		Modellbasierte Untersuchung	

Die Modellelaboration und -artikulation von Mislevy et al. (2017) werden nicht explizit mit aufgenommen (siehe Tab. 3.1), da sie keine wiederkehrenden Modellierpraktiken beschreiben, sondern Fähigkeiten, die im gesamten Prozess hilfreich sind. Die Modellelaboration beschreibt die Fähigkeit zur Weiterentwicklung von Modellen und den Umgang mit dem Zusammenhang zwischen Modellen eines Gegenstands auf verschiedenen Maßstabsebenen. Diese Fähigkeit kann sowohl bei der Modellentwicklung als auch Evaluierung und Revision eine Rolle spielen, sie wird daher bei der Entwicklung der Stufung des Kompetenzmodells berücksichtigt. Die Modellartikulation beschreibt die Fähigkeit zwischen verschiedenen Darstellungsformen wechseln zu können und ist ebenfalls für die Stufung relevant. Die reflexive Metaebene wird z. T. ebenfalls als reflexiv organisierende Praktik aufgefasst (vgl. Papaevripidou 2014; Mislevy et al. 2017). Die Unterscheidung zwischen prozessorientiertem Vorgehen und reflexiver Metaebene wird nicht nur speziell in der didaktischen Forschung zum Modellieren (vgl. Schwarz et al. 2009; Papaevripidou et al. 2014), sondern auch allgemein in der Kompetenzforschung (vgl. Weinert 2001) als grundsätzlich begriffen. Es liegen umfassende Konzepte zum reflexiven Modellverständnis vor (z. B. Upmeier zu Belzen & Krüger 2010), diese könnten ergänzend hinzugezogen werden, wenn das Zusammenspiel beider Bereiche untersucht werden sollte (vgl. Krüger et al. 2018; Krell et al. 2019). In dieser Arbeit wird darauf verzichtet das Metaverständnis als eine Praktik aufzunehmen, da sie Teil der Modellkompetenz ist und nicht der Modellierkompetenz.

Nachfolgend werden auf Grundlage geographiespezifischer Merkmale Schwierigkeitsstufen erarbeitet, die in der Zusammenführung mit den vier Praktiken als Dimensionen die Formulierung des Kompetenzmodells zulassen.

3.4 Drei Stufen geographischen Modellierens

Für die Modellierung von Raum werden in diesem Artikel die drei Basiskonzepte Struktur, Funktion, Prozess (vgl. DGfG 2017) als hierarchische Ebenen betrachtet. Die Wahrnehmung und Erfassung des Realraumes ist Fundament für die aufeinander aufbauenden Abstraktionen. Ausgehend von einer Ebene wird die darüber liegende modelliert

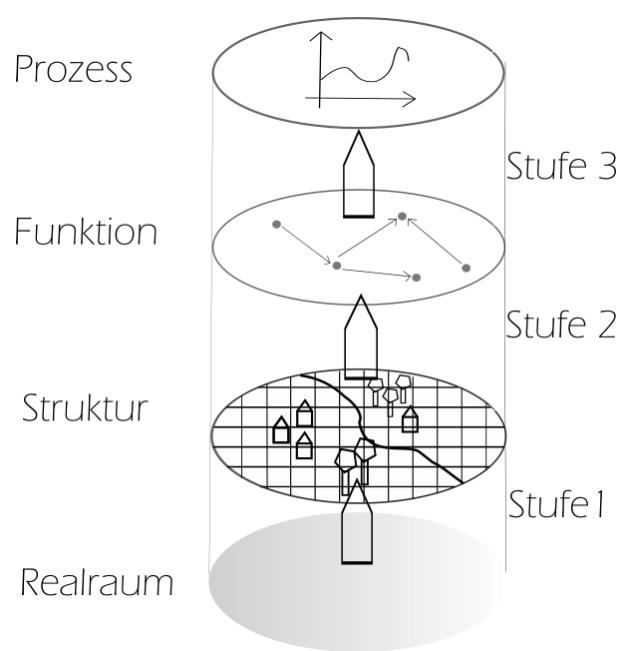


Figure 3.3 Modellierpraktiken in bildungswissenschaftlicher Literatur

(siehe Figure 3.3). Also erfolgt Modellieren im Übergang zwischen den Ebenen. Die Modelle der verschiedenen Ebenen beziehen sich dabei aufeinander, was die Fähigkeit der Modellelaboration nach Mislevy et al. erfordert, die das Herstellen von Zusammenhängen sich überschneidender Modelle (hier räumlicher) und die Ergänzung von generellen Modellen mit der Erkenntnis aus detaillierten Modellen beschreibt (vgl. Mislevy et al. 2017). Da die Objekte und ihre Funktionen der unteren Ebene für das Verhalten des Systems auf höherer Ebene auf komplexe Weise verantwortlich sind, ist

das Konzept Scale, das den Umgang mit verschiedenen Maßstabsebenen bezeichnet (Burt, 2009; Lambert & Morgan, 2010), hierbei von herausragender Bedeutung (Goldstone & Wilensky, 2008; O'Sullivan, 2004).

Die grundlegende Ebene ist der Realraum und die erste Stufe geographischen Modellierens ist die Erfassung der Struktur des Raumes (siehe Schritt 1 in Figure 3.3). Die Komplexität des Realraumes wird durch eine homomorphe Abbildung reduziert, die den Realraum z.B. in einer Karte abbildet (Harvey, 1969). Das Modell des Realraumes gibt Auskunft über die Struktur seiner explizit abgebildeten Objekte. Ist der Raum derart erfasst, wird eine Analyse räumlicher Muster und Zusammenhänge möglich (vgl. Metoyer & Bednarz 2017), was eine Erklärung von Funktionen zulässt (Holt-Jensen, 2018), die in Stufe 2

modelliert werden (siehe Figure 3.3). Die Modellierung kann in Modellobjekten, wie etwa Flowlinemaps, Wirkungsdiagrammen, Flow Charts oder mathematischen Gleichungen ausgedrückt werden. Die Modellierung des Raumes hinsichtlich Struktur und Funktion kann genutzt werden, um im dritten Schritt Prozesse im Raum zu modellieren (siehe Schritt 3 in Figure 3.3) (vgl. O'Sullivan 2004). Hierfür können für den Schuleinsatz geeignete Simulationsprogramme z. B. netlogo (Wilensky, 1999) Verwendung finden.

Die Ebenen werden in einem spiralförmigen Modellierprozess aufbauend durchlaufen (siehe Figure 3.4). Aus der Anwendung der Modellierung der unteren Ebene ergibt sich der Modellentwurf der darüber liegenden. Essentiell ist dabei stets eine Reflexion über die Güte und Tragweite der zugrunde gelegten Modelle (vgl. O'Sullivan 2004). Eine Kartenanalyse kann z. B. für den Entwurf eines Funktionsmodells genutzt werden. Dabei sollte die Güte und Intention der Karte reflektiert werden, da sie das auf ihr fußende Funktionsmodell beeinflusst. Dies gilt insbesondere auch dann, wenn nicht alle Ebenen spiralförmig durchlaufen werden, sondern sich der Modellzweck auf eine Ebene beschränkt und auf bestehenden Modellen aufgebaut wird. Evaluation und Revision sollten deswegen immer auch die darunterliegenden Ebenen mit einbeziehen.

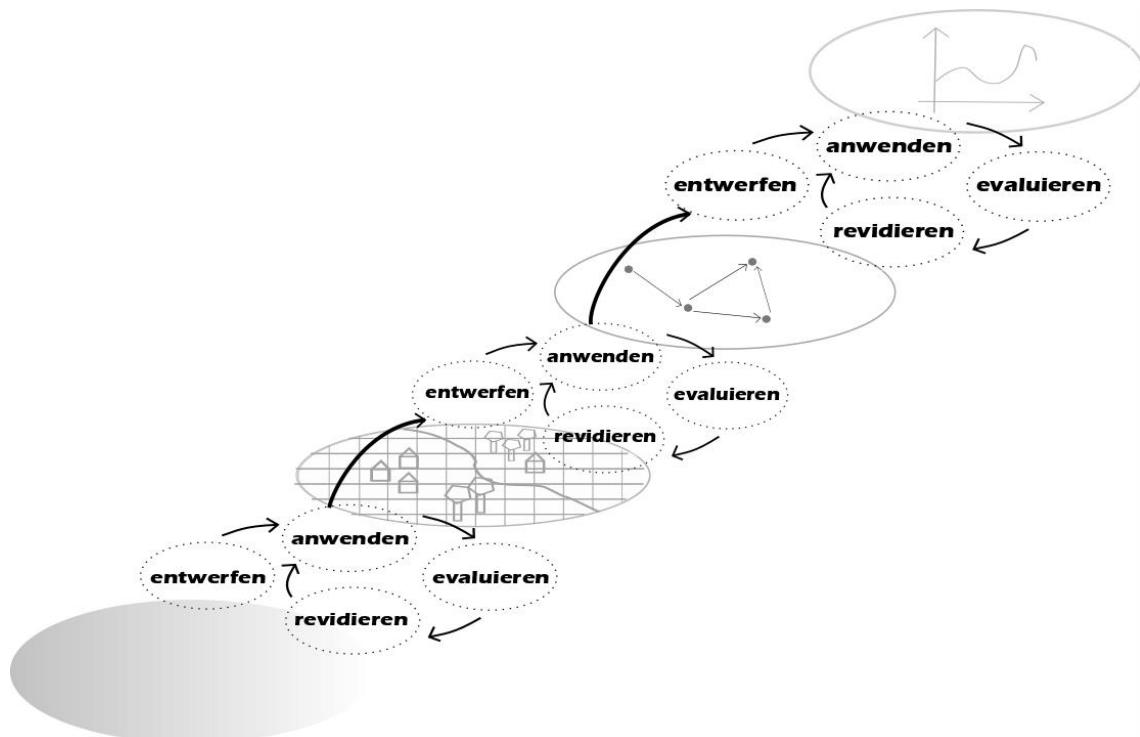


Figure 3.4 Modellieren zwischen den Ebenen geographischer Abstraktion

Ein einfaches Beispiel der räumlichen Ausbreitung eines Waldbrandes soll diesen Prozess illustrieren (vgl. Wilensky, 1997); Mithilfe des Modellierungsframeworks NetLogo

wird die Ausbreitung eines Brandes in Abhängigkeit von der Dichte des Baumbestandes modelliert und kann dann simuliert werden. Hierzu muss zunächst der Wald auf der Strukturebene modelliert werden. Dafür wird die Fläche in gleich große quadratische Felder unterteilt, die entweder als Baumfeld oder als baumloses Feld definiert werden. Das Verhältnis zwischen baumlosen und baumbestandenen Feldern wird über die Baumdichte bestimmt und in der Standard-Einstellung wird die Verteilung als zufällig angenommen. Das Feuer wird an der linken Kante des Gesamtfeldes verortet und breitet sich von dort aus. Die Ausbreitung des Feuers wird als räumlich-funktionaler Zusammenhang modelliert, indem das Feuer sich von Baumfeld zu Baumfeld, nicht jedoch über baumlose Felder hinweg ausbreiten kann. Dabei kann es sich in alle vier Himmelsrichtungen, d. h. im Modell über jede der vier Seiten des Baumfeldes, ausbreiten. Durch die Simulation des Modells wird der Prozess der Feuerausbreitung visualisiert. Dabei kann prognostiziert werden, ab welcher Baumdichte unter diesen Modellannahmen die gesamte Fläche abbrennen würde. Das Modell kann elaboriert werden, etwa indem Wind als Faktor hinzugenommen werden kann, dieser lässt das Feuer im Modell einzelne freie Felder überspringen und sorgt so für eine großflächigere Ausbreitung des Feuers oder indem die Bäume nicht zufällig, sondern in festgelegten Mustern auf der Fläche verteilt werden. Die Anpassung des prädiktiven Simulationsmodells kann also durch eine Abänderung der darunterliegenden Ebenen erfolgen. Soll das Modell für einen konkreten Realraum genutzt werden, muss seine Gültigkeit für den Raum reflektiert und ggfls. die Modellvorstellungen angepasst werden.

3.5 Geographische Modellierkompetenz

Aus den zusammengestellten Erkenntnissen zum Modellieren (siehe Tab. 3.1) und den geographischen Basiskonzepten (s. Abbildung 3) wird nun das Kompetenzmodell (siehe Tab. 3.2) abgeleitet. Integriert werden dazu die vier Praktiken, die die Strukturierung des Modells in Dimensionen ausmachen und die drei Stufen, die die Schwierigkeitsstufung definieren.

Da die Struktur von Modellen, z. B. in der Biologie (vgl. Krell et al. 2014), schwierigkeitsgenerierend im Umgang ist, erscheint es auch für die Geographie plausibel die Schwierigkeitslevel über die Struktur des erstellten Modells zu definieren. Die Struktur eines Modells lässt sich anhand von Zweckkategorien definieren. Das hat für den Prozess der Modellierung den Vorteil, dass das Schwierigkeitslevel einer Modellieraufgabe festgesetzt und nicht erst rückwirkend anhand des erstellten Modells das Niveau der zuvor erbrachten Leistung abgelesen werden kann. Der Modellzweck lässt sich danach

kategorisieren, ob ein Modell illustriert bzw. repräsentiert, erklärt oder vorhersagt (vgl. Schwarz et al. 2009; Upmeier zu Belzen & Krüger 2010; Oh & Oh 2011; Mislevy et al. 2017). Papaevripidou et al. (2014) nutzen das Vorhandensein dieser Kategorien im Endprodukt für die Bewertung von Modellierprozessen, indem sie diese als aufeinander aufbauende Ebenen begreifen (vgl. Papaevripidou et. al 2014). Die drei Zweckkategorien lassen sich mit den drei Stufen geographischen Modellierens parallelisieren: Auf unterer Ebene wird der Realraum in einem Modell repräsentiert und dabei illustriert. Werden räumliche Funktionen daraus abgeleitet, entsteht ein Modell, das erklären kann (= interpretative Ebene). Werden aus diesen funktionalen Zusammenhängen Prozesse modelliert, entsteht ein Modell, das vorhersagen kann. Das Schwierigkeitsniveau der Praktiken wird über die drei Ebenen hinweg als zunehmend angenommen, die im Kompetenzmodell die drei aufbauenden Schwierigkeitslevel ausbilden (siehe Tab. 3.2). Die Ausprägung der Schwierigkeit in der jeweiligen Modellierpraktik wird im Folgenden dargestellt.

Table 3.2 Geographische Modellierkompetenz

		Entwerfen	Anwendung	Evaluation	Revision
1	Repräsentativ - Struktur	einen Space als Target definieren und daraus Komponenten in ein Raummodell abbilden	aus einem Modell Information-en über Lagebeziehungen auslesen	ein Modell durch Beobachtung und direkte Messung im Raum prüfen	das Modells durch Integrieren, Verschieben oder Streichen von Komponenten optimieren
2	Interpretativ - Funktion	räumlich funktionale Zusammenhänge zwischen den Komponenten in ein Modell abbilden	durch ein Modell argumentativ einen Zusammenhang erklären	Zusammenhänge in kontrollierter Umgebung oder durch Stichproben statistisch prüfen	funktionale Zusammenhänge optimieren
3	Prädiktiv - Prozess	räumliche Prozesse und Interaktionen in ein Modell abbilden	einen Simulationsprozess ausführen und Daten generieren	Grenzen eines Modells durch Variation der Simulation erproben	Zusammenstellung der zu Grunde liegenden Strukturen und Funktionen optimieren

Das **Entwerfen** eines Modells ist gleichbedeutend mit dem Formulieren von Hypothesen (vgl. Schwarz et al. 2009): für die Wahrnehmung eines Phänomens und spontane

Analogiebildung ist eine Eingrenzung und Konkretisierung des Modellgegenstandes (Targets) zwingend (vgl. Mislevy et al. 2017; Krell et al. 2019). Dafür muss eine passende Maßstabsebene und Betrachtungstiefe festgelegt werden (vgl. Mislevy et al. 2017). Im geographischen Kompetenzmodell finden diese Vorüberlegungen bei der Definition des Space, d.h. des Raumausschnittes und der Betrachtungsweise, statt. Die Kompetenzdimension des Modellentwurfens wird in drei Stufen strukturiert:

1. Ein einfaches Modell (Stufe 1) wird zur Repräsentation entwickelt (vgl. Schwarz et al 2009; Papaevripidou et al. 2014; Mislevy et al. 2017), es werden hierfür die relevanten Objekte als Modell abgebildet (vgl. Papaevripidou et. al 2014; Mislevy et al. 2017).
2. Ein interpretatives Modell (Stufe 2) soll erklären können (vgl. Schwarz et al. 2009; Papaevripidou et. al 2014; Mislevy et al. 2017): es werden zusätzlich zu Objekten auch Funktionen abgebildet (Mislevy et al. 2017).
3. Ein elaboriertes Modell (Stufe 3) formuliert Prozesse und ist dadurch prognosefähig (vgl. Schwarz et al. 2009; Papaevripidou et al. 2014; Mislevy et al. 2017): es werden dafür Modelle der unteren Ebenen miteinander kombiniert, was eine Transformation der Darstellungsform und ein Erstellen von Zusammenhängen über unterschiedliche Modelle hinweg erforderlich macht (vgl. Mislevy et al. 2017).

Die **Anwendung** umfasst das sichere Bewegen im Raum des abstrakten Modells, was ein Durchdringen der verwendeten Symbolik einschließt und durch Vertrautheit mit dem Target des Modells erleichtert wird (vgl. Mislevy et al. 2017). Die Modellanwendung wird in drei Stufen strukturiert:

1. Niederschwellig (Stufe 1) bedeutet dies ein Modell zu nutzen, um etwas zu beschreiben (vgl. Schwarz et al. 2009; Papaevripidou et. al 2014).
2. Modelle werden auch genutzt (Stufe2), um zu erklären (vgl. Papaevripidou et. al 2014; Schwarz et al. 2009; Mislevy et al. 2017) und
3. (Stufe 3) um Vorhersagen abzuleiten (vgl. Schwarz et al. 2009; Papaevripidou et. al 2014; Mislevy et al. 2017; Krell et al. 2019) bzw. Daten zu generieren (vgl. Mislevy et al. 2017).

Um Vorhersagen ableiten zu können, bedarf es einer spezifischen Initialisierung des Modells (vgl. Krell et al 2019). Schließlich ist die Anwendung von Modellen notwendig für die Konstruktion, Evaluation und Revision von Modellen (vgl. Mislevy et al. 2017), da durch die Anwendung die innere Konsistenz geprüft wird und Aussagen generiert werden, die auf ihre Richtigkeit bezgl. der modellierten Realwelt hin prüfen lassen.

Die **Evaluierung** bedeutet einen Vergleich zwischen dem Modell und empirischen Daten oder den Vergleich mit anderen Modellen sowie die Überprüfung der inneren Konsistenz (vgl. Schwarz et al. 2009; Mislevy 2018; Krell et al. 2019). Dieser Vergleich erfordert den Umgang mit einem Messmodell (vgl. Krüger et al. 2018). Es wird hier davon ausgegangen, dass die Schwierigkeit mit dem Abstraktionsgrad des Messmodells zunimmt. Drei Stufen strukturieren die Kompetenzdimension Modellevaluation:

1. Auf erster Stufe werden Modellkomponenten mit realweltlichen Referenzen verglichen (vgl. Mislevy et al. 2017), dies kann ausmessen, auszählen oder klassifizieren bzw. bestimmen im Gelände bedeuten.
2. Die Zusammenhänge der zweiten Stufe sind nicht direkt beobachtbar, jedoch können sie beobachtbare Phänomene bedingen (vgl. Mislevy et al. 2017; Krell et al. 2019). Zur Evaluierung von Zusammenhängen muss deshalb auf Experimente oder die Analyse von Stichproben zurückgegriffen werden (vgl. Krell et al. 2019). Durch statistische Messmodelle können Ergebnisse aus Experimenten und Stichprobenanalysen mit Modellaussagen unter Ausschluss von Zufallsergebnissen verglichen werden (vgl. Krüger et al. 2018).
3. Auf dritter Stufe ist die Gültigkeit von Simulationsmodellierungen zu beurteilen. Nach Oreskes et al. (1994) bleiben diese Modelle immer heuristisch, da es unmöglich ist Vorhersagekraft zu validieren. Geprüft werden können lediglich interne Konsistenz und Passung mit vergangen Daten (vgl. O'Sullivan 2004) sowie ein Vergleich der Simulationsergebnisse mit etablierten Modellen (vgl. Schwarz et al. 2009). Die Reflektion der zu Grunde liegenden Ebene ist somit auf dritter Ebene essentiell (vgl. O'Sullivan 2004).

In der **Revision** werden Erkenntnisse aus der Evaluierung in das Ausgangsmodell integriert (vgl. Schwarz et al. 2009; Mislevy et al. 2017). Dies kann ein Erweitern, Kürzen oder Umstrukturieren des Modells bedeuten und fordert sowohl ein gutes Verständnis des Ausgangsmodells mit seinen Grenzen, als auch der Erkenntnisse aus anderen Modellen und empirischen Untersuchungen und verlangt eine strenge Fokussierung auf den Zweck des Modells, d. h. das Modell darf nur beinhalten, was für den Zweck relevant ist (vgl. Schwarz 2009; Mislevy et al. 2017). Die Hauptschwierigkeit liegt in der Syntheseleistung. Drei Stufen strukturieren die Kompetenzdimension Modellrevision:

1. Auf der ersten Stufe werden hierzu Objekte gestrichen oder hinzugefügt, ggf. auch räumlich verschoben.

2. Auf der zweiten Stufe muss die erste Stufe mitbedacht werden, zusätzlich müssen die funktionalen Zusammenhänge optimiert werden.
3. Auf der dritten Stufe wird die Kombination der zu Grunde liegenden Strukturen und Funktionen überarbeitet.

3.6 Fazit

Durch Modellierung von Raum auf Ebenen aufeinander aufbauender Abstraktion lässt sich Komplexität mit Schüler/innen methodisch kontrolliert systematisch reduzieren. Das systematische und strukturierte Vorgehen ist geleitet durch einen iterativen, die drei Ebenen des Modellierens übergreifenden Prozess. Die jeweilige Ebene wird zyklisch modelliert, indem der erste Entwurf durch Anwendung und Evaluation geprüft und durch Revision verbessert wird. Bei höherer Abstraktionsebene sind die darunterliegenden Ebenen stets mit zu prüfen. Theoretisch kann ein perfektes Modell nicht erreicht werden. Eine zweckgerichtete Validität kann hingegen durch das vorgeschlagene Vorgehen zureichend abgebildet werden. Dieses Verständnis von Modellierung ordnet sich in den systemwissenschaftlichen Zugang nach Bossel (2004) ein. Das Konzept baut damit auf der gleichen Grundlage auf, wie die verschiedenen Arbeiten zur Systemkompetenz (Viehrig et al. 2011; Rieß et al. 2015; Schuler et al. 2018; Brockmüller 2019) und ist an diese anschlussfähig. An die Arbeit von Viehrig et al. (2011) besteht durch eine analoge Stufe in der Dimension „Systeme erfassen und analysieren“ (vgl. Viehrig et al. 2011) besondere Anschlussfähigkeit.

Die Besonderheit dieses Beitrages liegt darin, dass auf eine Wissens- und Handlungsebene verzichtet, hingegen der Prozess der Modellierung detailliert strukturiert wird und in einer geographischen Perspektive der Räumlichkeit steht. Auf diese Weise wird ein dezidiert geographisches Modellieren konzeptualisiert.

Die Strukturierung des Kompetenzmodells in Teilkompetenzen und Schwierigkeitsniveaus baut auf theoretischer und empirischer didaktischer Forschung zur Modellierung auf. Sie unterliegt jedoch noch gewisser theoretischer Unsicherheit und muss, ebenso wie ihre Nützlichkeit, empirisch untersucht werden. Hierzu muss die Struktur des Kompetenzmodells hinreichend konkret sein, um eine Operationalisierung für eine spätere Testung zuzulassen (vgl. Upmeier zu Belzen & Krüger 2010). Für diese Operationalisierung bildet diese Arbeit die Grundlage.

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4 Developing geographic computer modeling competencies in higher education

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Abstract

Modeling is a key scientific practice and is usually computer-implemented, but it is challenging to teach because it seems high on presuppositions, for example, coding. This design-based research study presents a geography course offered during the 2019/20 winter semester in computer modeling, with no prior coding knowledge. It was implemented in two elective classes: one in the Bachelor of Science program and one in the teacher program. Interviews were conducted to monitor the students' development, and the final reports showed their competencies at the end of the course. Since there were no noticeable differences between the Bachelor of Science students and the teacher trainees in terms of competence acquisition, four learning types could be described based on analysis of the interviews and final reports, which are important for the planning and adaptation of the course concepts. In summary, our results show four key findings: (1) mere reproduction of learning content is of no value for the development of geographic modeling skills; (2) the ability to access conceptual thinking patterns is crucial; (3) process-level understanding is a fundamental prerequisite for advanced geographic modeling understanding; and (4) poor programming skills hinder but do not prevent at least basic modeling understanding.

Keywords: scientific thinking; NetLogo; teacher education; computational thinking; modeling competencies

4.1 Introduction

For decades, computer modeling has been highly relevant in geographic research (Burt & Butcher, 1986; Chen et al., 2021; Moffatt, 1986). Both geographers (Etherington, 2016; Muller & Kidd, 2014) and teachers (Vasconcelos & Kim, 2020) need related computer skills. Therefore, geography and teacher education are combined in this design-based research approach to teaching computer modeling. The combination reflects Marburg's initiative in teacher education (Meister et al., 2020), demanding that pre-service geography teachers develop geographic skills before teaching them (Anthes et al., 2021; Peter & Nauss, 2020). The specific needs of both groups are briefly discussed.

In geography education, technical skills are considered essential (Etherington, 2016; Muller & Kidd, 2014), but unfortunately, there seems to be a risk of geography students losing access to computer fundamentals due to the prevalence of touch screens (Muller & Kidd, 2014). Geography educators are confronted with students' anxiety about approaching technology (Muller & Kidd, 2014; Rickles & Ellul, 2015). Bowlick et al. (2017) called for research on classroom teaching in programming to assist geographers in overcoming these challenges. Corresponding research has shown that coding, the transformation of instructions into a code a computer can read, within the frame of authentic scientific inquiry is suitable for acquiring coding skills in a geographic setting (Tian et al., 2020).

On the other hand, geography teacher education should prepare pre-service teachers for educational standards. Geography education standards call for geographic inquiry and thinking skills (German Geography Curriculum [DGfG], 2020; Heffron & Downs, 2012; Schell et al., 2013), and the Next Generation Science Standard (NGSS, 2013) makes modeling a core scientific practice. However, teachers lack a scientific understanding of models (Justi & Gilbert, 2003) and seldom use modeling as a scientific practice (Gray & Rogan-Klyve, 2018; Ke & Schwarz, 2021). Therefore, pre-service teachers need training in modeling (Bybee, 2014; Krell et al., 2019).

While Bachelor of Science (BSc) geography education focuses on more technical skills, teacher education focuses on conceptional skills. Combining BSc students' and pre-service teachers' foci in a one-course concept incorporates the merits of the scientific and educational perspectives, respectively. While the trainee teachers benefit from authentic inquiry-based research, BSc students can profit from the epistemological modeling frameworks teacher education provides (e.g., Krell et al., 2019). This approach of combining

computer modeling and scientific inquiry is not only generally considered to be effective (D'Angelo et al., 2014; Klahr et al., 2007; Smetana & Bell, 2012), it is also in high demand among and supported by geography educators at all levels (Bush et al., 2019).

The developed course concept provides a simplified research setting connected to inquiry-based learning (Aditomo et al., 2013), in which students model a spatial simulation of the emergence of humans' unplanned paths with NetLogo. The course was offered during the 2019/2020 winter term once weekly for one semester (3.5 months) as two separate elective classes weighted at three points in the European Credit Transfer and Accumulation System (ECTS): one in the BSc program (taught by the second author) and one in the teacher program (taught by the first author). The students worked in groups of two to three, as programming novices benefit from peer scaffolding (Vasconcelos et al., 2020) ($n = 15$ groups, BSc $n = 7$, pre-service teachers $n = 8$). We captured the students' learning processes by interviewing the groups after each block. The groups' final reports were used to evaluate the competence level at the end of the course. Specifically, the following research questions were investigated:

1. Which geographic modeling competencies do student groups show at the end of the course?
2. What are the characteristics of the learning process during the course?
3. Are there interconnections between the learning process and competence patterns?
4. Regarding the first three questions, are there differences between pre-service teachers and BSc students?

4.2 Course framework

Vasconcelos and Kim (2020) provided a framework for educating teachers in coding through scientific modeling lessons based on theoretical considerations and empirical evidence. Our course design reflects their four guidelines: (1) combining simulation coding with authentic scientific inquiry, (2) tailoring coding activities to a scientific modeling framework, (3) promoting the creation and development of self-made simulations, and (4) designing scaffolds for engagement in coding and scientific modeling (Vasconcelos & Kim, 2020).

The emergence of unplanned paths in public areas, such as walkways, lawns, and points of interest, is a common spatiotemporal phenomenon that is easily observable almost everywhere and has been the target of scientific inquiry (e.g., Alexander, 1975; Helbing et al., 1997; Vahidi & Yan, 2016). It is an engaging topic in modeling class because (1)

distinctive system boundaries can be drawn; (2) the path system can be structurally mapped (Alexander, 1975); (3) the underlying functions of optimizing walkways can be analyzed by observing, reflecting, and abstracting human behavior (Henderson, 1974); and (4) simulation can predict emergent optimization (Helbing et al., 1997).

Our course design was tailored to a competence model for geographic modeling (Ammoneit et al., 2019). It maps three levels of modeling activity described in science education literature, namely depict, explain, and predict (Papaevripidou et al., 2014; C. Schwarz, 2009; Upmeier zu Belzen & Krüger, 2010) onto the three components of the main geographic concept "systems," structure, function, and process, provided by the DGfG (2020), which facilitate the modeling of human and physical systems over time (DGfG, 2020; Heffron & Downs, 2012). The competence model differentiates the modeling practices on each level—drafting, applying, evaluating, and revising—and connects to research in science education (Ammoneit et al., 2019; Chiu & Lin, 2019; Mislevy et al., 2017; Papaevripidou et al., 2014; C. V. Schwarz et al., 2009).

We worked with NetLogo (Wilensky, 1999), which was initially developed for educational use and is ideal for students who are new to programming (Bodine et al., 2020; Wilensky, 1999; Xiang & Passmore, 2015). Among other geographical issues, it is also explicitly used for the spatial simulation of pedestrian movements in relation to trampling paths (Hassanpour & Rassafi, 2021; Pluchino et al., 2014; Procházka & Olševičová, 2014). NetLogo allows for the manipulation of variables on an interface and the visualization of the simulation using sliders and bottoms and can be customized as desired by switching to the underlying code. Furthermore, NetLogo allows for the construction of models from scratch and the use or customization of models from an extensive code library.

NetLogo has a basic model of paths integrated into its library (Grider & Wilensky, 2015). It simulates the emergence of paths on green lawns. Sliders allow users to change and investigate the underlying variables. We introduced this model to provide an expert model as a scaffold, as Sins et al. (2005) proposed. Learning material covering NetLogo and modeling was offered, and counseling was provided in class, via mail, and during designated consultation hours upon request. We fed the intermediate results at different time points individually.

The course on modeling paths with NetLogo consists of three blocks and a final report (see Table 4.1). The three blocks are as follows: (1) conceptional modeling, (2) introduction to NetLogo, and (3) an individual student research project reflecting the

simplified research approach in which (1) a research interest is identified, (2) a methodological approach is chosen, and (3) the research is conducted.

Table 4.1 Course structure

Block	Content	Modelling practice	Geographic concept
1: Introduction & conceptional modeling	<ul style="list-style-type: none"> - Brief introduction to modeling and NetLogo - Classifying paths and formulating wording models (for information on wording models see Bossel, 2004) 	<ul style="list-style-type: none"> - Draft classification and wording model - Apply classification - Evaluate own work in classroom discussion - Revise 	<ul style="list-style-type: none"> - Model structure of path classes in sketch - Model function and process in wording model
2: Computer model	<ul style="list-style-type: none"> - Introduction to NetLogo's paths - Manipulating code - Integrating streets and barriers into NetLogo model 	<ul style="list-style-type: none"> - Apply NetLogo's paths - Evaluate against own conception - Revise by integrating streets and barriers 	<ul style="list-style-type: none"> - Model structure in NetLogo's world - Model function in turtle behavior - Model process by running the model and interpreting the results
3: Research project	<ul style="list-style-type: none"> - Reading research literature - Developing own research question - Adjusting the NetLogo model - Running the model and interpreting and discussing the results 	<ul style="list-style-type: none"> - Draft own research question - Revise NetLogo model - Apply NetLogo model - Evaluate own research 	<ul style="list-style-type: none"> - See Block 2
Final report			

In the final report, students must support their hypothesis with a theoretical background, explain the methods and procedures, and present, interpret, and discuss the NetLogo simulation results. The instructors provided an example report and a detailed evaluation guide (see <https://github.com/ammrie/ModelingCompetence>) based on the competence model (Ammoneit et al., 2019) that guided the course design to a specific task.

4.3 Inquiry methods

The study was conducted as a design-based study using a concurrent multimethod approach that combines two qualitative threads (Creamer, 2018), one deductive and one inductive, to describe learning processes and outcomes (see Fig. 4.1). In the deductive approach, the students' final reports were scored to measure their final modeling performance. In the inductive approach, the learning process was recorded in interviews conducted after each block about difficulties and key moments. Merged interpretation of the deductive and inductive approaches allows for the identification and description of types of learners, considering both their objective learning outcomes and subjective learning experiences. These learner types provide the basis for answering our research questions and are helpful tools for guiding future course development to better meet learners' needs. Description of the learner types will help to meet learners' demands through course development (Ferguson & Clow, 2015).

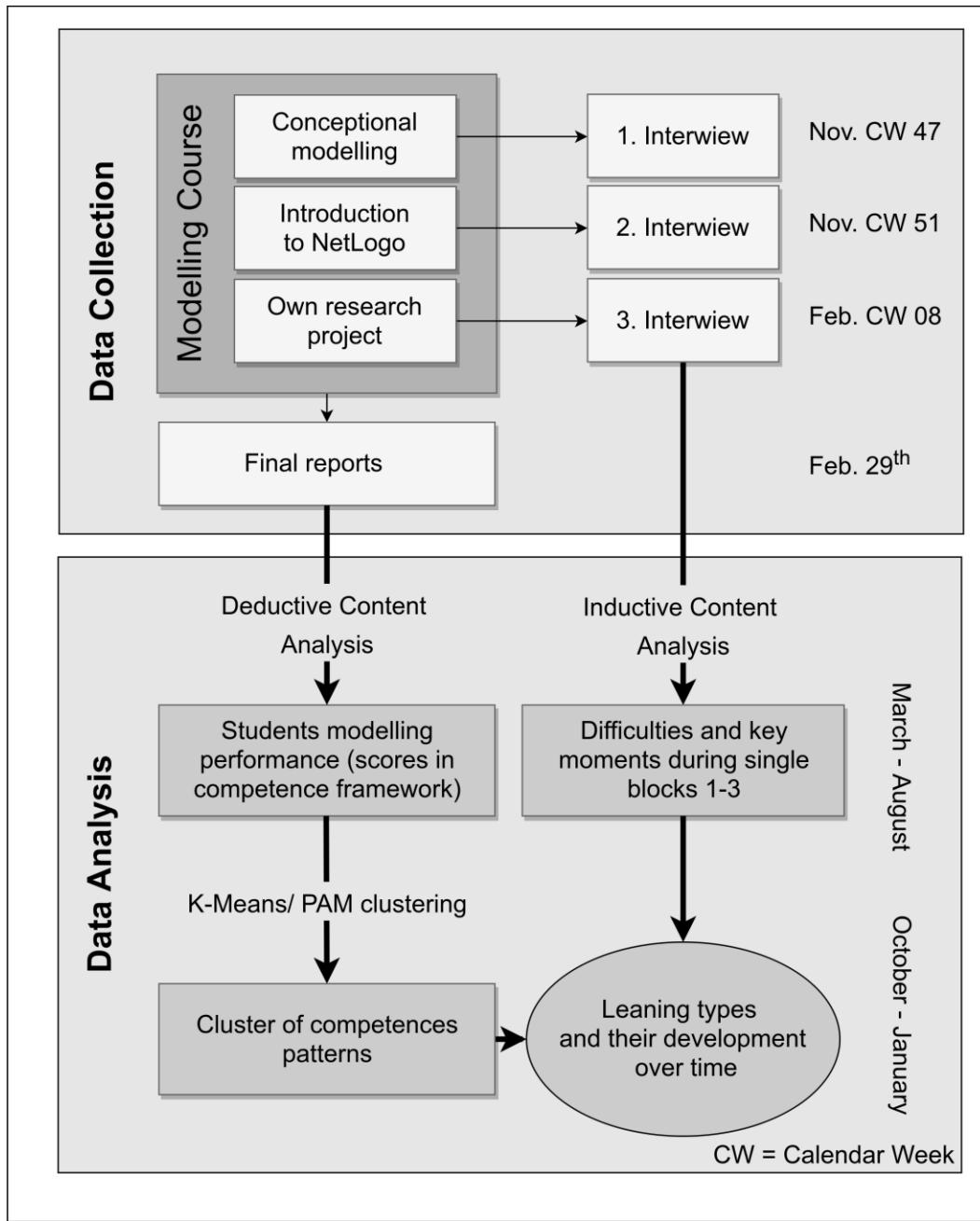


Figure 4.1 Research design

4.3.1 Assessment of modelling performance: deductive approach

To assess the students' modeling performance, we conducted deductive content analyses on the 15 final reports using the competence model for geographic modeling (Ammoneit et al., 2019) as a coding matrix (see Appendix 1 for details). We followed Gläser and Laudel's (2013) framework and selected the chapters of the reports that are connected to a dimension of the matrix for our analysis first: Introduction and Hypothesis for "draft," Model Alteration for "revise," Results for "apply," and Discussion for "evaluate." The first two authors then ranked the sections independently according to the levels

of the matrix (Cohen's kappa = 0.87) and resolved the few conflicting cases through discussion. To classify results that the competence model did not depict correctly, an additional competence level of zero, which lies outside the competence model, was added.

The content analysis results were then used to identify distinct result patterns using a clustering approach. The computerized approach limited subjective influence and increased reproducibility. Clustering is a well-known technique that partitions data into clusters according to their features or values by minimizing the distance of data points belonging to the same cluster. The crucial task of a priori identification of an adequate number of clusters is performed using R-package NbClust, which varies by 30 indices to determine the best number of clusters (Charrad et al., 2014; R Core Team, 2021) and concurs with the standard elbow method (Kodinariya & Makwana, 2013). Both approaches suggest dividing the data into four clusters (see Figure 4.2). The R software facilitated the k-means and PAM algorithms (R Core Team, 2021).

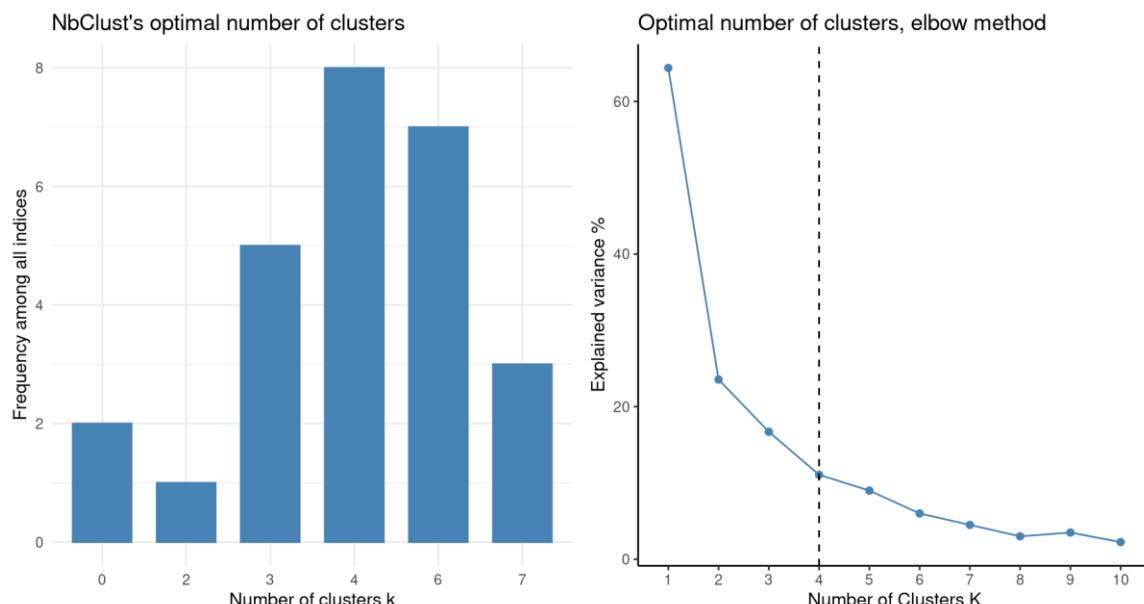


Figure 4.2 Determining the best number of clusters

4.3.2 Describing students' development over time: inductive approach

Semi-structured interviews were held immediately after each block to ascertain the groups' authentic learning situation and understand the groups' development trajectory (see Figure 4.1). The interviews focused on difficulties and key moments during each course block because these indicated what the students were working on the most intensively. The first author conducted all interviews in person. Each interview had a duration

of approximately 15 minutes. All 15 groups were interviewed individually, but unfortunately, some groups missed single interview dates for various reasons (field trips, sickness, unexcused). However, per the qualitative analysis approach, we included all interviews in the analysis (see Appendix 2 for an overview). The interviews were transcribed and analyzed inductively (Elo & Kyngäs, 2008).

To guarantee a transparent and reproducible analysis, we proceeded in five steps: (1) extracted all segments to answer a question focusing on difficulties and key moments, (2) eliminating all fillers, (3) highlighting difficulties and key moments, (4) coding difficulties and key moments, and (5) categorizing the codes (see Appendix 3). Finally, we compared the groups' categorized codes to the competence clusters to merge the data for interpretation.

4.3.3 *Limitations*

It must be emphasized that the research approach presented works with authentic materials obtained from real, everyday course environments. The aim is to provide results with high validity in educational settings. In comparison to a more standardized approach, there are some limitations that we will discuss now.

We did not measure the level of competence before starting the course, as the course concept does not require any specific previous education. Since the students worked in teams and were monitored over time via interviews, the level of competence achieved can be reliably assessed, and learning development shows the relative dynamics of this developmental trajectory. Under real course conditions, it is impossible for students to participate in a pre-course individual competence assessment. Therefore, the final report was chosen as a valid source for competence assessment (Koh et al., 2010; Werner et al., 2012) and is the only data point.

However, the interviews revealed many prerequisites. We monitored the learning process based on the difficulties and key moments the students reported. This has the limitation that students might not report problems due to social desirability. However, due to the confidential interview setting and the students' willingness to give feedback, interviewees reported problems revealing misconceptions far beyond our expectations.

4.4 Results

4.4.1 Achievements in the final reports

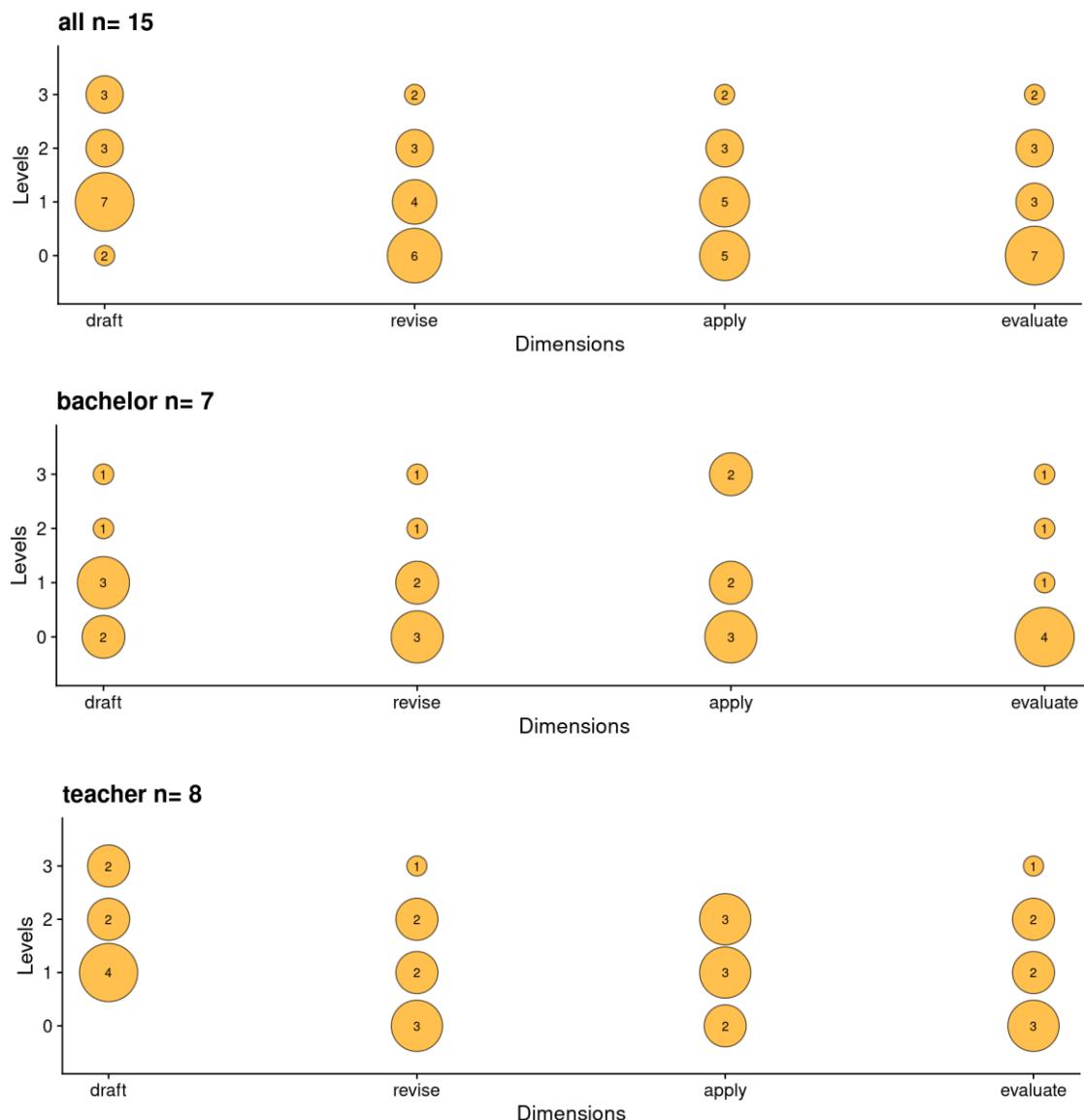


Figure 4.3 Deductive content analysis results

An overview of the distribution of the achieved modeling competencies is shown in Figure 4.3. The circles represent the number of groups that scored at or outside the three levels in the respective dimensions. While in “draft,” only two groups are classified outside the matrix, and three groups reach the highest level, the situation is almost inverse in the dimensions “revise,” “apply,” and “evaluate.” Here, most of the results are classified as Level 0 (outside) or Level 1. Only two groups reached the highest levels.

4.4.2 Distinct competence patterns

To distinctly describe the groups' competence patterns, we used the results above as a data basis for clustering, using the k-means and PAM algorithms. Both algorithms resulted in almost identical clusters (see Figure 4.4): one big cluster ($n = 7$) with results at Level 1 or below and three smaller clusters differentiating between the more successful groups. The algorithms differ only in assigning group T4 to a cluster. However, as shown in the cluster silhouette plot (Figure 4.4), none of the groups were mismatched (< 0); in both cases, T4 has the least fit to the respective cluster, which will be discussed later.

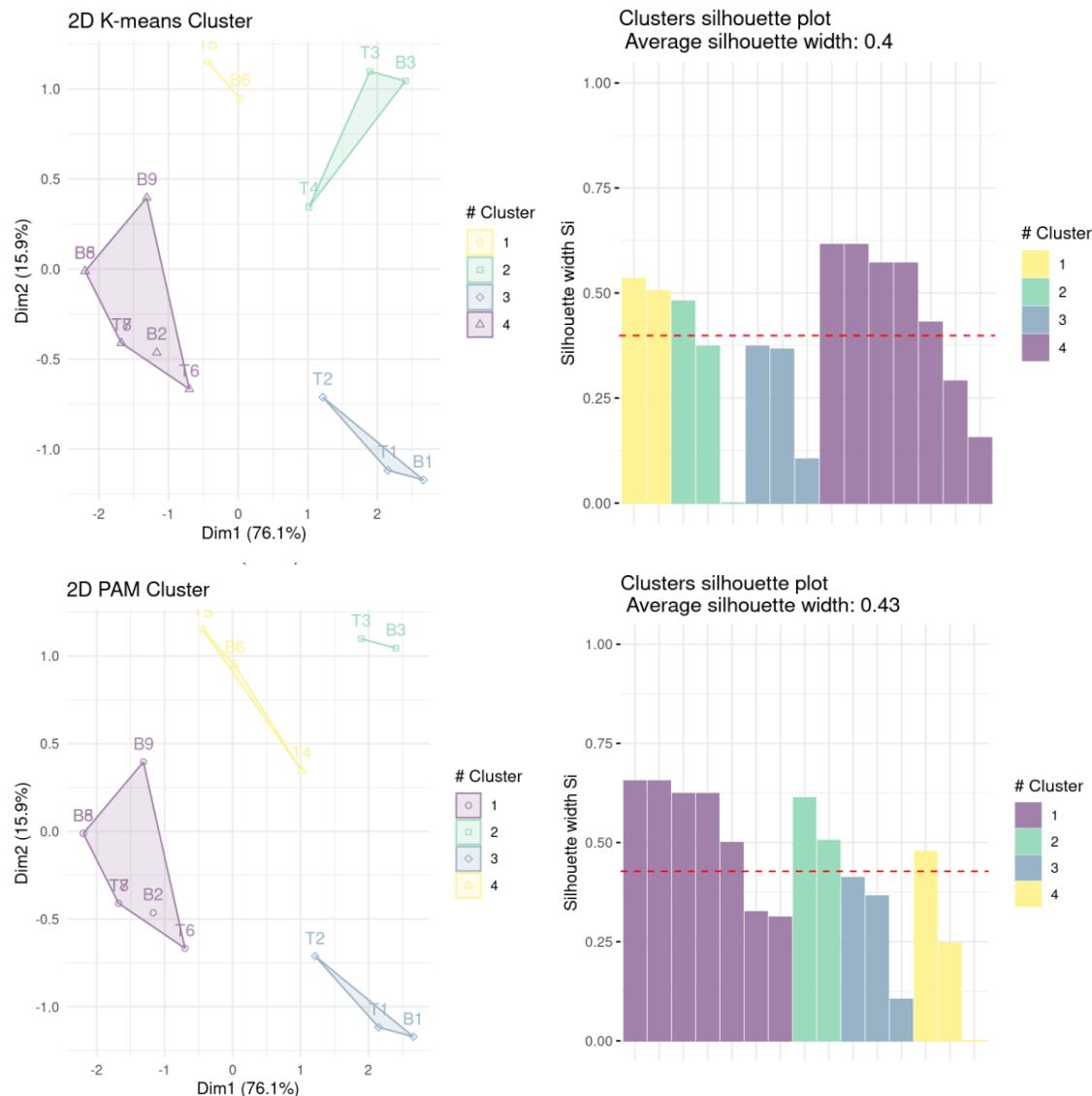


Figure 4.4 Clusters by k-means and PAM

We can see that the performance pattern between clusters differs considerably in terms of the four dimensions (Figure 4.4); the clusters' highest-ranking dimension differs.

Within clusters, we see that the levels vary for some dimensions within neighboring levels. We will now discuss each cluster and supplement the data from the qualitative analysis of the reports.

Learner Type 1: reproductive

Seven groups (T8, T7, T6, B9, B8, B5, and B2) were Type 1. All groups stuck closely to the classroom discussion, and none developed a particular research question. Five groups (T8, T7, T6, B8, and B5) did reproductive work consistently and clearly, reaching Level 1 in the first dimension. Only one group (B8) reached Level 1 in the second dimension by slightly changing the model; the others left the model unchanged (Level 0). In application (Dimension 3), two groups (T6 and B5) reached Level 1 by describing emerging patterns; the other groups either made severe logical mistakes or set the wrong focus (Level 0). No group discussed the results thoroughly (Dimension 4, Level 0).

Learner Type 2: engineering

Two groups (T5 and B6) belonged strictly to Type 2. These groups focused on implementing and testing technical variations in the code. Their motivation was framed too broadly for the particular hypothesis (Level 1) in the first dimension. They implemented the tools in NetLogo code (Dimension 2, Level 2). The result was not replicated and was stated plainly, without explanation (Dimension 3, Level 1). B6 discussed the technical outcome (Dimension 4, Level 1); in both cases, the conceptual meaning of the variation was not discussed.

Group T4 implemented a technical variation within this type range; application was similar, but in the report, the motivation was less focused on implementation itself. Consequently, the results were discussed for practical use.

Learner Type 3: rebuilding

Two groups (T3 and B3) belonged strictly to Type 3. The groups created a particular setting for their study, within which they wanted to observe path formation (Dimension 1, Level 2). To produce these settings, the groups made elaborate changes to the code (Dimensions 2 and 3). The groups described their proceedings comprehensively, T3 qualitatively (Dimension 3, Level 2), while T4 replicated and quantified the results (Level 3).

In conclusion, both groups discussed how their results can be transferred into reality (Dimension 4, Level 2).

Group T4 started with the same approach but changed the code less extensively. The presentation of results was more superficial, but the results were discussed within this type's scope. For pragmatic reasons, T4 is included in Type 3 in all the figures.

Learner Type 4: conceptional

Cluster 4 comprised three groups (T1, T2, and B1). The groups used the model to investigate a specific idea about the emergence of paths based on observation in reality (Dimension 1, Level 3). All three integrated their research settings into the NetLogo interface and modified the model slightly (Dimension 2, Level 1). They quantified and replicated the results yielded: B1 did so very comprehensively (Dimension 3, Level 3), while T2's results were not well structured (Level 2), and T1 provided too much detail (Level 2). Two groups (B1, T1) determined and discussed the threshold of variables for specific path patterns (Dimension 4, Level 3), and one group (T2) discussed the hypothesis qualitatively (Level 2).

4.4.3 Learning process

To understand how the groups developed their modeling competencies over time, we analyzed three interviews focusing on students reporting the difficulties they encountered and the key moments that pushed their understanding. The results shown in Figure 4.5 indicate that all groups identified coding as the main difficulty throughout the individual interviews because no group had substantial prior experience coding in any language. In addition, the interviews reflected unique approaches to the modeling task. There was more correspondence between the groups' challenges than between the key moments. Some groups advanced and overcame the difficulties they encountered, whereas others stagnated, naming the same difficulties repeatedly or failing to experience key moments to which they could refer during the interview. We found correspondence between the types of learners and the learning progress reflected in the interviews, which we will elaborate on now.

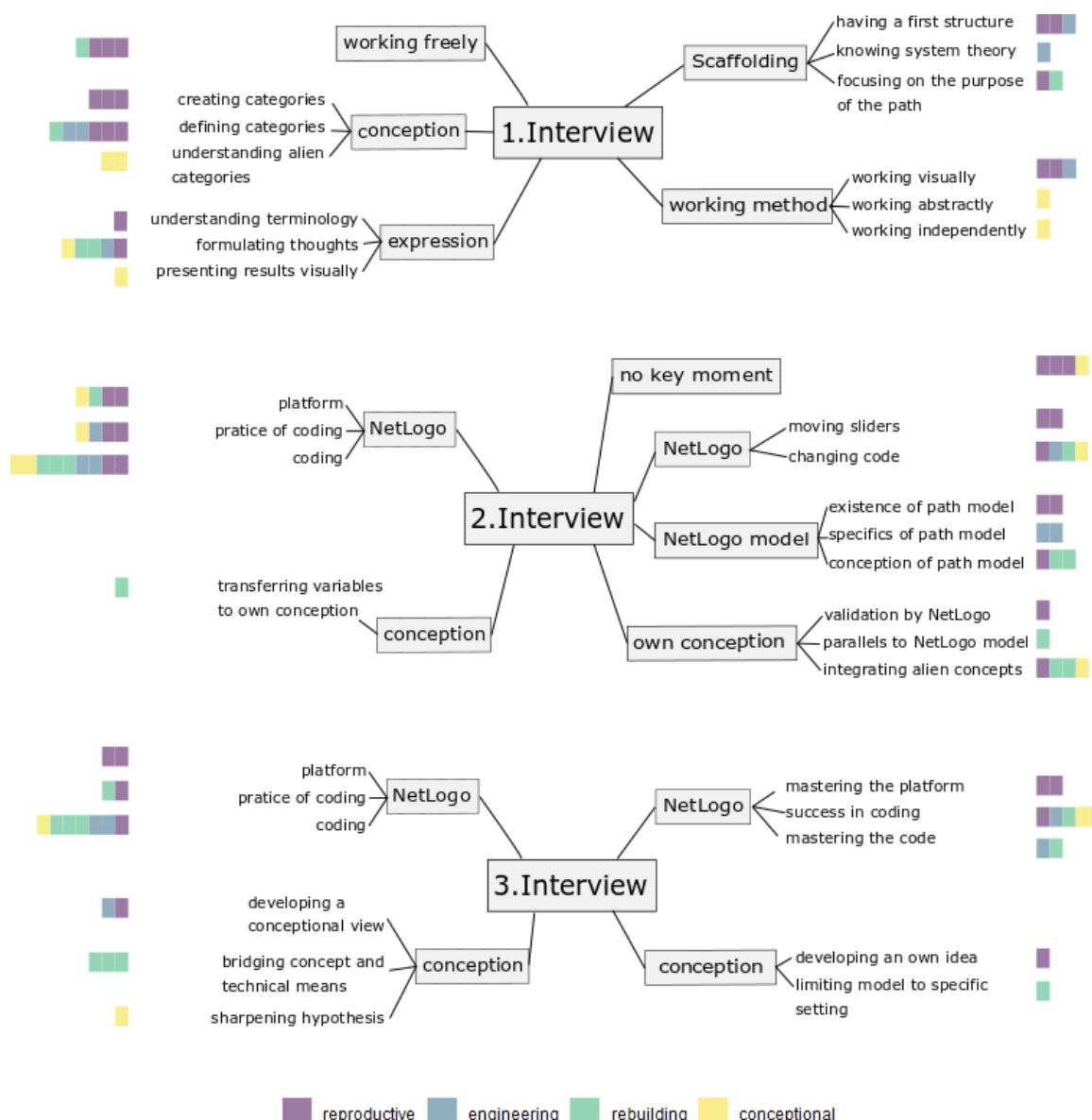


Figure 4.5 Inductive content analysis results

4.4.4 Interconnections between learning fields and competence patterns: progression over time

In the first interview, the students addressed difficulties concerning conceptualization and expressing their thoughts. Scaffolds and working methods induced the key moments. Students who were conceptual learners (Type 4) were singled out the most visibly in the first interview. Structuring their work processes and performing conceptual work were not challenging. We also found that it was primarily reproductive learners (Type 1) who found it difficult to structure their thinking in the context of an open task and who had trouble taking the first steps, for example, creating categories as the first structure of a conception.

In the second interview, NetLogo and conceptional thinking challenged the students. Key moments were diverse; some students reported no key moments, while others reported key moments related to NetLogo as a tool or model and their conceptional thinking. NetLogo posed a challenge to all groups. We found a wide range of problems across types. While some struggled with handling the platform, others reported coding problems. Four groups also struggled to understand the general logic of codes, that is, that the computer can only understand specific words. These problems reflect that no learner had the advantage of prior coding experience.

Regarding key moments, reproductive learners stood out: None of the reproductive groups experienced key moments during coding. In addition, groups without any key moments overwhelmingly belonged to Type 1. The reproductive type of learner (Type 1) is, thus, generally less involved in acquiring NetLogo skills for modeling than the other types of learners. Rebuilding learners (Type 3), on the other hand, were singled out for their greater engagement in conceptional thinking.

In the third interview, difficulties and key moments were condensed into NetLogo and conceptional thinking. We noted that some Type 1 groups (reproductive) were still concerned with handling the platform, while groups from other clusters reported key moments related to mastering coding in NetLogo. The existence of problems with conceptual thinking was reflected in the results derived from the final reports. Groups classified as reproductive and engineering learners (Types 1 and 2) cited conceptual ambiguity, while groups categorized as rebuilding learners (Type 3) reported methodological ambiguity in bridging concept and technical means, and a group of conceptional learners (Type 4) cited adequate hypothesis formulation.

4.4.5 A comparison of BSc students and trainee teachers

Figure 4.6 provides an overview of the study program and the semester number. All four types were found in both study programs, but Type 1 was overrepresented in the BSc program. The semester distribution explains this difference. All groups with semester numbers below five and seven belong to Type 1. Thus, the semester number influences modeling competence. Notably, there were no students with a semester number below five in the teacher course.

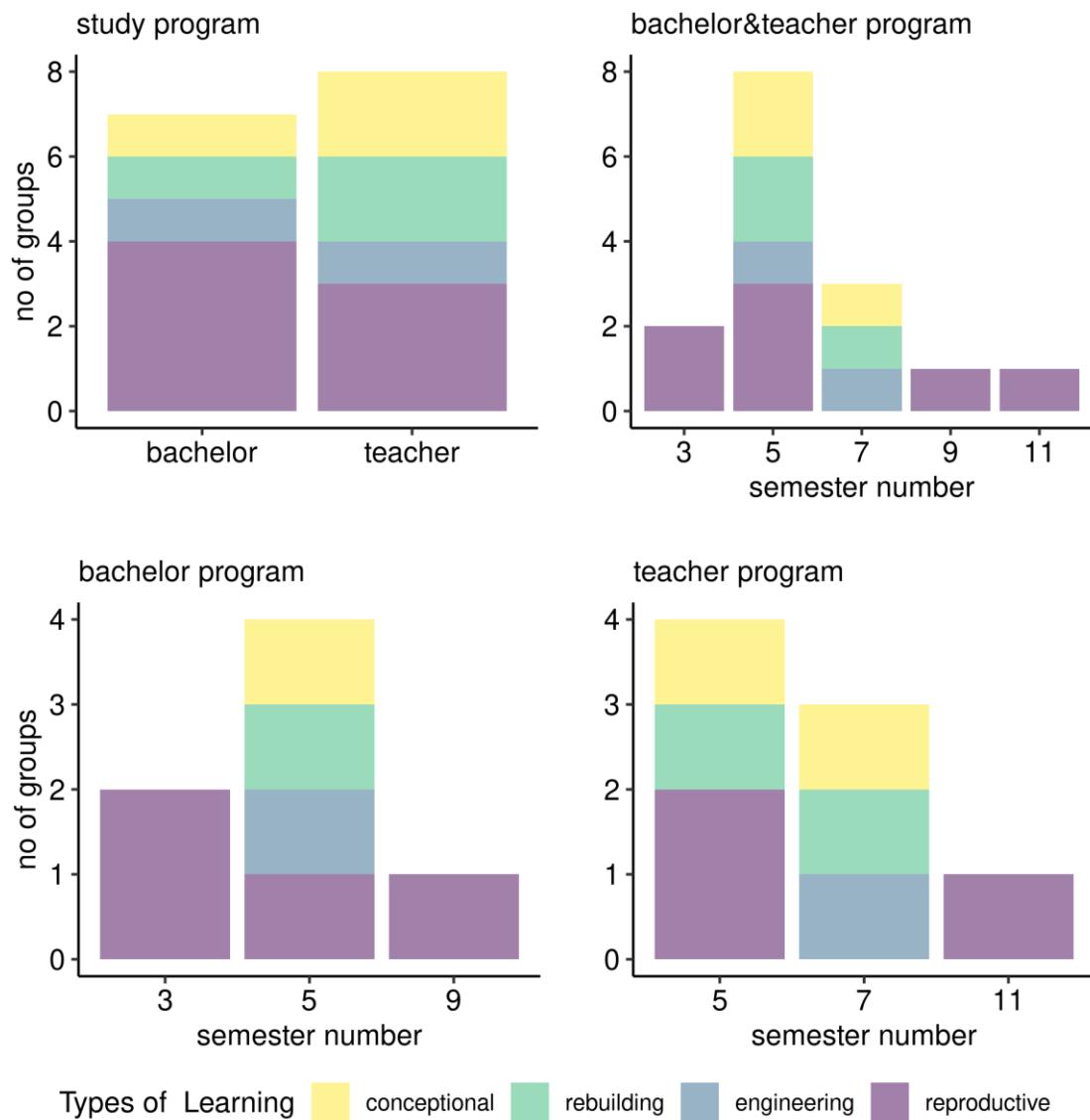


Figure 4.6 Learner types' socio-demographics

4.5 Findings

4.5.1 Which geographic modeling competencies do student groups show at the end of the course?

Looking at the cohort as a whole, the students achieved all the dimensions and levels per the competency model's requirements. However, at the level of the individual groups, there were significant differences in their competence patterns. Strikingly, the underlying geographical concepts of "structure," "function," and "process" were not consistently linked to the competencies, but the competence levels in relation to the four dimensions did not present clear patterns; rather, they described mixed learning types.

4.5.2 What are the characteristics of the learning process during the course?

To describe the learning process, we asked the students to identify the major difficulties and key moments they encountered during each block. Notably, the students neither specifically referenced geographical concepts nor modeling practices; instead, they described general technical and conceptual problems and key moments on different levels that can be understood as a propaedeutic learning experience.

4.5.3 Are there interconnections between the learning process and competence patterns?

We conclude that the competence types were shaped by the learning process. Only by combining the results derived from the final reports and the interviews was it possible to meaningfully describe four learner types: reproductive, engineering, rebuilding, and conceptional (Table 4.2).

Table 4.2 Modeling proceedings by learning type

	Draft	Revise	Apply	Evaluate
Type 1 reproductive	The task is to create a model	No revision	Superficial application of the given model	No insight is yielded
Type 2 engineering	The model is a technical tool.	Technical variation is the aim.	Testing technical variation against undefined ideas	Purposeless schematic
Type 3 rebuilding	The model is a tool to reproduce real-world scenarios.	Substantial integration of variables into the model	Generating model output for a specific setting is the aim	Discussing model's limitations to represent the target
Type 4 conceptional	The model is a tool to investigate a conceptional idea.	Pragmatic revision of the world	Concentrating on research setting and presenting results	Prove that a conceptional idea is the aim

4.5.4 Regarding the first three questions, are there any differences between pre-service teachers and BSc students?

Unexpectedly, there were no differences between BSc students and trainee teachers concerning the four types of learners, neither with regard to the competence pattern nor the learning process. Computer modeling is suitable for both BSc and teacher training programs. The clarity of this result suggests the robustness of the course concept since neither study group dynamics nor different lecturers had any detectable influence on the results.

4.6 Discussion

Surprisingly, we found that the geographic concepts of function, structure, and process are hardly uniform and were even less mastered in the four modeling dimensions of drafting, applying, evaluating, and revising. Moreover, according to our findings, the dimensions are by no means hierarchical: Some groups demonstrated the ability to draft a process, while others could revise one but not draft it. Obviously, geographical concepts are too complex to be learned and taught along a hierarchical matrix; an individual learning process based on conceptual thinking skills is needed. This combination determines the level of geographical modeling competence that can be achieved and is closely linked to general research competencies. We can conclude that these specific geographic modeling skills are, at least at this level, a subset of general research skills. Thus, the four learning types identified in this study (Table 4.2) are in good agreement with the results of previous research on teaching modeling and coding in non-specific geographic science education, which we will now discuss in more detail.

Among Type 1 learners (reproductive), we replicated the finding that students who do not revise the given model do not discuss their conceptions either (King et al., 2019). As previously described (Bundy, 2007; Vasconcelos et al., 2020), coding helps formulate thoughts consistently; among Type 1 learners (reproductive), we found that students who did not code generally did not succeed at the task. The modeling results should reflect the students' epistemological views of the models (Cheng & Lin, 2015; Sins et al., 2009; Upmeier zu Belzen et al., 2019). Type 1 is the only one that does not reveal any specific epistemological view of models but rather treats them as a self-contained world.

Despite the necessity of being capable of learning how to code, modeling cannot be reduced to this skill. As Sins et al. (2005) previously noted, the engineering type of learner (Type 2) sees computer modeling as an engineering problem without conceptional

motivation. This type of learner reaches Level 1 in epistemological model competence (Upmeier zu Belzen et al., 2019): Changes to the model are made to correct defects. By not discussing the original, the engineering type of learner (Type 2) implicitly tries to copy it.

The rebuilding type of learner (Type 3) demonstrates that combining coding in modeling is beneficial when intensive work with the NetLogo model improves conceptional thinking. In sharing this core characteristic, we assign the disputed group T4 to this type of learning. Type 3 is in line with the research finding that students who engage in model construction demonstrate deeper reasoning than students who simulate a pre-constructed model (King et al., 2019). This type reaches Level 2 in epistemological model competence (Upmeier zu Belzen et al., 2019), which is an idealized representation of the original used to explain it.

The conceptional type of learner (Type 4) reaches the highest level (3) of model competence (Upmeier zu Belzen et al., 2019): the model is a theoretical reconstruction to test a hypothesis about the original in order to make a prediction. Against this background, this type clearly represents a typical scientific approach and combines it with the expertise of the geographical domain.

4.6.1 Conclusion

It is apparent that scientific inquiry and modeling are challenging for higher education students (Cheng & Lin, 2015; Crawford & Cullin, 2004; Walkington et al., 2011), especially when connected to coding (Sins et al., 2005; Tian et al., 2020). Overall, the interviews show that success is independent of prior coding experience, which is encouraging because students with no coding experience prior to entering higher education seem to constitute a global issue (Lin et al., 2021; Liu & Xia, 2021; Tian et al., 2020; Vasconcelos & Kim, 2020).

In terms of geographical concepts, the interviews suggest that students are increasingly facing challenges. While many groups succeeded at modeling a spatial structure, at least in some modeling dimensions, fewer groups succeeded at modeling spatial functions, and only a minority succeeded at modeling a process. No group succeeded at capturing all the modeling dimensions at the process level. These results show that even simple geographical concepts are so complex that we cannot assume that students can model at the process level without exceptional qualifications.

In line with previous research (Göhner & Krell, 2020; Sins et al., 2005), our study shows that groups of students undertaking a challenging modeling task may follow

significantly different developmental paths. Therefore, it is necessary to supervise individual projects carefully and closely (Livingstone & Lynch, 2002; Spronken-Smith et al., 2008). Over time, we see a major difference between the development of Type 1 learners versus the other types of learner. The essential characteristic of Type 1 learners (reproductive) was to reject the challenges all the groups faced in favor of stagnating regarding reproducing the classroom discussion. It is possible that this type regards failure as termination rather than as an epistemic chance and therefore tries to avoid it (Schiefner-Rohs, 2019).

Since learners classified as Types 2, 3, and 4 confronted these challenges, albeit to different degrees, it can be concluded that active and reflective responses to challenging situations combined with a commitment to realize them are particularly important for acquiring modeling competence. However, while Type 2 learners generally only sought to correct “deficiencies” without reflecting on the concepts of the adaptations they made, Type 3 learners showed that the combination of modeling and coding can improve model understanding. Finally, Type 4 learners, who were equipped with conceptual thinking skills before the interviews, were able to develop considerable geographical modeling skills and reached a high level.

In summary, our results reveal four key findings: (1) mere reproduction of learning content is of no value for the development of modeling skills; (2) the ability to access conceptual thinking patterns is crucial; (3) process-level understanding is a fundamental prerequisite for advanced modeling understanding; and (4) poor programming skills hinder but do not prevent at least basic modeling understanding.

4.6.2 Implications for teaching

Unsurprisingly, most students did not know how to program. However, it was surprising that many students did not know what codes were or how programs control computers. This gap in basic technological understanding is probably the reason geography students experience anxiety when confronted with technology (Muller & Kidd, 2014; Rickles & Ellul, 2015). Educators must be wary that many students will try to avoid technological challenges and complex tasks such as modeling (Type 1). In practice, this means that geography students generally perceive model simulations well when the technical overhead is reduced (Pease et al., 2019), but reducing the technical overhead does not do justice to the potential many students possess (Types 2, 3, and 4).

Students need a basic understanding of coding to gain insight into the potentials

and boundaries of computer models; developing a scientific understanding of models is vital to geographic research and teacher education (Bybee, 2014; Justi & Gilbert, 2003; Krell et al., 2019). Understanding and revising a given computer model can help students develop conceptual modeling skills (Type 3). It is sensible to combine the introduction of new technology with a strong conceptional focus to prevent students from focusing exclusively on technology to the detriment of the geographic research component (Type 2).

4.6.3 Fields for future work

Future research in this field is promising. However, if we restrict ourselves to an explicitly practical approach, three areas, in particular, should be explored.

During the 2019/2020 winter semester, reproductive learners did not take advantage of our scaffolding. According to the Program for International Student Assessment (PISA), 80% of German 15-year-old students perform satisfactorily in reproductive science tasks, but only 10% can creatively and autonomously apply their knowledge to diverse settings (Organisation for Economic Co-operation and Development [OECD], 2019). It seems likely that this low percentage is also visible in this study and thus persists throughout students' university careers; it can at least be strongly quantitatively and qualitatively associated with our Type 1 and 2 learners. We find it necessary to conduct further research on low achievers surmounting individual course concepts and competencies to determine if unengaged reproduction is a general study strategy in Germany, as has been discussed for Chinese students (Tian et al., 2020; Zhan & Wan, 2016). If so, the basis of the phenomenon, how it impacts scientific thinking skills, and how it can be effectively addressed are all of interest.

Second, the results show that conceptual understanding of a model is key. This understanding requires (1) geographic thinking skills, specifically the ability to capture spatial structure, function, and process, and (2) a technical understanding of the potential and limits of the tool used. An adjusted course concept focusing on selecting a suitable model for a given target from the NetLogo library and conducting proper research could support the described types of learners. This approach could prevent simple reproduction (Type 1), keep the focus on conceptual learning (Type 2), support amplification of conceptional thinking through external models (Type 3), and enable independent research (Type 4).

Third, we developed a pragmatic approach that can benefit BSc and teacher training programs. Our results encourage contemplation related to both programs. Given that

the final competencies do not reach the level needed, a consecutive module might be beneficial (Walkington et al., 2011). For efficient teaching, we propose specialization, that is, active coding for BSc students and the implementation of modeling in school for prospective teachers.

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Declaration of interest

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Disclosure statement

The authors report there are no competing interests to declare.

Data availability statement

<https://doi.org/10.17192/fdr/63> & <https://github.com/ammrie/ModelingCompetence>

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4.8 Appendices

Appendix 1 Coding matrix after the competence model for geographic modeling (Ammonait et al., 2019)

Dimension	Level	Competence	Coding instruction	Example
Draft	Representative - structure	Define a space as a target and map elements into a spatial model	Clear object of investigation - spatial structure	"The different barriers have various impacts on the path pattern outside of the roads." T6
	Interpretative - function	Map spatial function into the model	Clear object of investigation - functions	"A higher speed (cyclists) leads to an increased formation of paths." T4
	Predictive - process	Map spatial processes and interactions into the model	Clear object of investigation - processes	"Ineffective geometric street networks are being modified into an effective organic paths network." B1
Revise	Representative - structure	Optimize the model by integrating, relocating, eliminating elements	Netlogo model adapted to the research question - world	T2 integrates their research setting into the NetLogo interface and modifies the model slightly.
	Interpretative - function	Optimize function between elements	Netlogo model adapted to the research question - Turtle/functional properties	B6 implements a tool impacting walker behavior.
	Predictive - process	Optimize structure and functions the model is working on	Netlogo model adapted to the research question - World and functional properties integrated	B3 produces the specific setting of movement in a park by elaborately modifying the code.
Apply	Representative - structure	Read patterns from model	The research question is answered by:	T5 uses the outcome picture of one simulation to describe the

			- abstraction of structures	resulting pattern plainly, without explanation.
	Interpretative - function	Explain the interconnection between elements	The research question is answered by: - explanation of a connection	T3 changes the world variables systematically and uses the simulation's outcome to comprehensively describe interconnections between world and walker properties.
	Predictive - process	run a simulation and generate reliable data	The research question is answered by: - systematic derivation of a process	B1 replicates the output, and comprehensively abstracts patterns, explains interconnections, and deducts the formation process.
Evaluate	Representative - structure	verify model by observations and measurements in real space	Discussion of the model output	B6 discusses the technical outcome.
	Interpretative - function	verify interconnection in controlled setting	Successful discussion referring to: - external information	T2 discusses the hypothesis qualitatively.
	Predictive - process	test boundaries of simulation model by variation of settings	Successful discussion referring to: - methodical issues	T1 determines and discusses the threshold of variables for specific path patterns.

Appendix 2 Interview participants

	1. Interview	2. Interview	3. Interview
Pre-service teacher groups ($n = 8$)	T1, T2, T3, T4, T5, T6, T7, T8 ($n = 8$)	T1, T3, T4, T5, T7, T6, T8 ($n = 7$)	T1, T3, T4, T5, T6, T8 ($n = 6$)
BSc groups ($n = 7$)	B1, B2, B3, B5, B6, B8, B9 ($n = 7$)	B1, B3, B5, B6, B8, B9, ($n = 6$)	B1, B2, B3, B6, B9 ($n = 5$)
Total ($n = 15$)	15	13	11

Appendix 3 Extract from coding proceedings

Interview about difficulties	Students' statements without fillers and with highlighted difficulties and key moments	Codes	Categories
Group B8	<p>“To do it in categories, because for me a lot of things were the same. And to classify that in categories was especially difficult. But you didn't think about it beforehand.”</p>	<ul style="list-style-type: none"> • Create categories • Define categories 	Conception
Group B2	<p>"How exactly it should look. The first picture we had wasn't schematic enough. So how exactly this should be schematic, I did find that difficult.”</p>	<ul style="list-style-type: none"> • The task is not sufficiently clear / too much freedom 	Conception
Group T8	<p>“There was an overload with over 50 pictures and then it said: ‘Form categories.’ That was too much freedom. Once you have this structure, it worked. But to bring this structure in at the beginning and get to the point. These technical terms were difficult: system, purpose, and such. Because you had to formulate it and that was kind of weird. You knew what you meant, but you couldn't formulate it scientifically. It was like that, okay we have to do this now, but why?”</p>	<ul style="list-style-type: none"> • Create categories • The task is not sufficiently clear / too much freedom • To formulate • Unclear terminology 	Conception Expression

5 Summary

This work is intended to contribute to the professionalization of prospective geography teachers. It assesses existing deficits and develops how student teachers' ability to reflect on their subject matter can be systematically promoted. For this purpose, a competency model is developed and tested in practical use that explicitly describes the ability to model geographically and thus enables systematic promotion and evaluation of geographic modeling competence. The novelty of this work consists of (1) the systematic and standardized assessment and discussion of pre-service geography teachers' self-assessed ESD competencies, (2) the development of a subject-specific competency model for geographic modeling, and (3) results for the holistic and application-oriented promotion of modeling skills in the context of a course, in which student groups deal with theoretical, practical and technical problems. The methodical research approach required the complex integration of quantitative and qualitative theoretical approaches in a multi-phase mixed methods design. The empirical data collection took place in university geography teaching, the theoretical derivation and embedding on the data basis of national educational goals and the international state of research. This research method made it possible to achieve the methodological and conceptual progress summarized below concerning geographic modeling competence, which is empirically and theoretically justified and has proven itself in practice.

Education for Sustainable Development (ESD) has become an important benchmark in geography lessons and embodies the interdisciplinary geographic approach. The competence self-assessment was comprehensively surveyed among pre-service geography teachers enrolled in Marburg ($n=100$) in the field of ESD and in relation to the training modules in a cross-sectional study to identify whether and, if so, what action is required. The varying correlation of positive competence self-assessments with the various modules shows that active learning settings, such as field and school internships, are perceived as increasing competence. The self-assessed competence increased most in the knowledge dimension over the entire study course. However, personal and social skills in self-assessment do not rise through the study course. Since personal skills are also essential for scientific work and should be encouraged during teacher training, the subsequent studies focused on the action-centered promotion of scientific working methods. The very high assessment of their own level of competence suggests that the students overestimate themselves.

The development of differentiated competency models, which formulate levels within competence dimensions, can enable targeted and reflective support and thus also

help to more realistic self-assessments. Although modeling is mandatory in geography research and also in geography school lessons, for example, for systemic thinking, the analysis of existing concepts revealed a gap. The subsequently developed competence model for geographical modeling systematically integrates the defined geography education goals of the DGfG with the findings of science education research. It hierarchically arranges the complex modeling task in levels along with the system components structure, function, and process. The competence dimensions are defined by the modeling practices design, use, evaluate, and revise. The competency model provides a framework for promoting action competence, which is of paramount importance within education for sustainable development, and at the same time focuses on a central geography-specific practice.

On this conceptual basis, a course for students (bachelor and teaching post) on computer-based geographic modeling with NetLogo was developed in a design-based research approach. The combination of technology and modeling in teaching enables an authentic research-based approach that realistically conveys geographic practices since geographic modeling in science is always computer-based. Interviews with the participating groups accompanied the course ($n=15$), and the final reports and final models were analyzed for their level of competence based on the competence model. The results show heterogeneity in the learning process of the student groups, which can be grouped into four types of learning, regardless of the study program. Almost 50% of students stagnate given technical and conceptual challenges. The other half develop geographic modeling skills to varying degrees. Overall, particularly successful groups already had well-developed skills for conceptual thinking before the course and were able to expand them successfully according to the new requirements. This result emphasizes the importance of continuous competence development throughout the educational path.

5.1 Conclusion

The three studies addressed geography teacher professionalization in higher education by investigating linked but separated phenomena ranging over ESD and modeling competencies. The studies will now be discussed coherently to draw an overall conclusion.

The results of the ESD survey (WP 1) indicate that the tested pre-service geography teachers overestimate their competence level since the extremely high level they assess themselves is unlikely at their given practical experience level. This finding resonates with other international studies in the field (Borg & Edmett, 2019; Podgoršek & Lipovec, 2017). A plausible explanation is that many pre-service teachers have an idealized self-concept; they self-assess high competence towards those traits that seems desirable to them (Rothland, 2018). Due to its extensive scope, the ESD survey did not define the competence for each level but measured the self-assessment on a Likert scale.

In order to promote and assess competence, models with defined levels are needed (Koeppen et al., 2008). Because of its relevance to geography education and ESD, geographic modeling competence was targeted. The developed competence model for geographic modeling was defined to meet standards set for geography school education (DGfG, 2020) but was then used for the conception of a university course. The results show that only a few pre-service teachers and B.Sc. students reach the highest level; many even score outside the model, not reaching the first level. Given the model's reliability, these results should make us reconsider both the quality of the geography teacher education and the standards formulated to be reached in school. Both course development and evaluation give evidence for the competence model's empirical validity and practical applicability. The study results (WP 3) describe four distinct learning types, which is valuable for future course development.

The insufficient competence development of half the participants in the design-based research study (WP 3) and the success of those with conceptional thinking skills stresses the importance of prerequisites. The results from WP 3 document that many pre-service teachers avoid challenges and rely on reproduction instead. Motivational and cognitive dispositions can be causes for deficits in competence development (Watson et al., 2020) and impact both the cross-sectional results (WP 1) as well as those within the specific course (WP 3). They might also explain the avoidance reported on (WP 3).

Concludingly, a bias in self-assessment could be identified, as pre-service geography teachers are highly confident in their competencies but perform weakly within a

defined frame of geographic competencies. Including a competence-oriented approach to developing geography teacher education is successful because it enables efficient assessment of pre-service teachers' self-concept and specific performance. It also supports directed course development that emphasizes challenging engagement with disciplinary practices. Furthermore, competence frameworks allow to explain the scope of a class and give appropriate feedback (WP 3), which is essential in supporting students to develop a realistic self-concept (Rothland 2018). Finally, introducing competence models to assessment allows analyzing the overall course performance for patterns. This analysis can help to develop teaching based on empirical evidence.

5.2 Outlook

Discussing the results towards the aim of reflected disciplinary professionalism leads to the question of whether the propagated crisis concept is thoughtfully applied and implemented in education practice. The self-assessed high competence level and a routine avoidance of challenge suggest the answer has to be no. If pre-service teachers are to become reflected disciplinary professionals who confront students with and guide them through crises of understanding (Meister & Hericks, 2021), there is a need to develop study programs that provide reasonable and defined disciplinary challenges which go hand in hand with appropriate competence levels and dimensions. The dissertation proved that a competence-oriented approach helps directing challenges to geographical knowledge and providing appropriate feedback structures. The approach thus offers a way to improve geography teacher education that is also following the aim of ProPraxis.

However, there are at least two major system-related obstacles to implementing study programs that embrace crises and demand confronting them with the consequence that avoiding crises (Kosinár, 2014) results in insufficient academic achievement. The first one is located on the level of the individual instructor, who is confronted with aggression when giving negative feedback and low grades to students (Barry et al., 2006; Vaillancourt, 2013). The second one can be identified at the level of the department as insufficient academic achievements is the main reason for students dropping out (Neugebauer et al., 2019). Despite this limitation, the dissertation presented here showed that a framework based on specific competence requirements, in which accompanied crises are managed, represents a suitable means of professionalization and the basis for the differentiated development of such learning environments. This approach will support the many pre-service teachers who confront challenges in their personal and professional development. Consequently, it has

the potential to educate professional teachers, who will enrich their students' thinking and acting with a strong geographic perspective on the world, a crucial perspective in times of global crises.

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6 Zusammenfassung

Diese Arbeit soll einen Beitrag zur Professionalisierung von angehenden Geographielehrkräften leisten. Es wird erhoben, welche Defizite vorhanden sind und wie sich die Fähigkeit der Lehramtsstudierenden zur reflektierten Fachlichkeit konkret und systematisch fördern lässt. Dazu wird ein Kompetenzmodell entwickelt und im praktischen Einsatz erprobt, dass die Fähigkeit geographisch zu modellieren explizit beschreibt und damit die systematische Förderung und Evaluation ermöglicht. Der Neuheitswert dieser Arbeit besteht aus (1) der systematischen und standardisierten Erfassung und Einordnung der Selbst einschätzung von BNE-Kompetenzen unter Erdkundelehramtsstudierenden, (2) in der Entwicklung eines fachspezifischen Kompetenzmodell für die geographische Modellierung, sowie (3) Ergebnissen zur ganzheitlichen und anwendungsorientierten Förderung von Modellierkompetenz im Kurskontext, indem sowohl theoretische, praktische als auch technische Probleme zusammenhängend von Studierendengruppen bearbeitet werden. Der methodische Forschungszugang erforderte komplexe Integration sowohl quantitativer als auch qualitativer Theorie-Ansätze in einem Multi-Phasen-Mixed-Methods-Design. Die empirische Datenerhebung erfolgte in der universitären geographischen Lehre, die theoretische Herleitung und Einbettung auf der Datengrundlage von nationalen Bildungszielen und dem internationalen Forschungsstand. Diese Arbeitsweise ermöglichte es den nachfolgend zusammengefassten methodischen und konzeptionellen Fortschritt bezüglich geographischer Modellierkompetenz zu erzielen, der empirisch und theoretisch begründet ist und sich in der Praxis bewähren konnte.

Die Bildung für Nachhaltige Entwicklung (BNE) ist zu einer wichtigen Benchmark im Erdkundeunterricht avanciert und verkörpert mit ihrem interdisziplinären Ansatz das geographische Selbstverständnis. Die Kompetenzeinschätzung der Lehramtsstudierenden mit dem Fach Erdkunde wurde in Marburg ($n=100$) im Bereich der Bildung zur Nachhaltige Entwicklung und in Bezug auf die Ausbildungsmodule in einer Querschnittsstudie umfassend erhoben, um zu identifizieren ob und falls ja, welcher Handlungsbedarf besteht. Die unterschiedliche hohe Korrelation positiver Kompetenzeinschätzung mit den verschiedenen Modulen zeigt, dass vor allem aktive Lernsettings, wie das Gelände- und Schulpraktikum als Kompetenz steigernd empfunden werden. Der Kompetenzzuwachs über das gesamte Studium erscheint den Studierenden in der Wissensdimension am höchsten. Hingegen erfahren personale und soziale Kompetenzen in der Selbsteinschätzung durch das Studium keinen Zuwachs. Da personale Kompetenzen insbesondere auch für das

wissenschaftliche Arbeiten unerlässlich und während des Lehramtsstudiums gefördert werden sollten, wurde in den folgenden Studien die handlungszentrierte Förderung der wissenschaftlichen Arbeitsweise fokussiert. Es ist evident, dass die sehr hohe Bewertung des eigenen Kompetenzniveaus eine ausgeprägte Selbstüberschätzung der Studierenden nahelegt.

Die Ausarbeitung differenzierter Kompetenzmodelle, die Stufen innerhalb von Kompetenzdimensionen ausformulieren, kann eine gezielte und reflektierbare Förderung ermöglichen und so auch zu realistischeren Selbsteinschätzungen verhelfen. Obwohl das Modellieren in der Geographieforschung und auch im erdkundlichen Schulunterricht, beispielsweise für das systemische Denken, zwingend erforderlich ist, ergab die Analyse bestehender Konzepte eine Lücke. Das daraufhin entwickelte Kompetenzmodell für geographisches Modellieren integriert systematisch die definierten geographischen Bildungsziele der DGfG mit den Erkenntnissen der naturwissenschaftsdidaktischen Forschung. Es ordnet die komplexe Aufgabe des Modellierens in Stufen entlang der Systemkomponenten Struktur, Funktion und Prozess hierarchisch an und definiert die Dimensionen entwerfen, anwenden, evaluieren, revidieren. Das Kompetenzmodell bietet einen Rahmen, um Handlungskompetenz zu fördern, der innerhalb der Bildung für nachhaltige Entwicklung eine herausragende Bedeutung zukommt, und zugleich eine zentrale geographiespezifische Praktik fokussiert.

Auf dieser konzeptionellen Basis wurde ein Kurs für Studierende (Bachelor und Lehramt) zur computerbasierten geographischen Modellierung mit NetLogo in einem Design-Based-Research Ansatz entwickelt. Die Verbindung von Technologie und Modellieren in der Lehre ermöglicht einen authentischen forschungsbasierten Ansatz, der geographische Praktiken realistisch vermittelt, da geographisches Modellieren in der Wissenschaft faktisch immer computergestützt ist. Der Kurs wurde durch Interviews mit den teilnehmenden Gruppen ($n=15$) begleitet und die Abschlussberichte und finalen Modelle wurde auf der Grundlage des Kompetenzmodells auf ihr Kompetenzniveau hin analysiert. Die Ergebnisse bilden eine Heterogenität im Lernprozess der Studierendengruppen ab, die sich unabhängig vom Studienprogramm zu vier Lerntypen zusammenfassen ließen. Knapp 50 % der Studierenden stagnieren angesichts technischer und konzeptioneller Herausforderungen. Die andere Hälfte entwickelt geographische Modellierkompetenz in unterschiedlichem Maße. Insgesamt zeigt sich, dass besonders erfolgreiche Gruppen bereits vor dem Kurs gut entwickelte Fähigkeiten zu konzeptionellem Denken hatten und diese

entsprechend der neuen Anforderungen erfolgreich erweitern konnte. Dieses Ergebnis betont die Bedeutung stetiger Kompetenzentwicklung über den gesamten Bildungsweg.