

Article

Facilitating Preservice Biology Teacher Development through Material-Based Lesson Planning

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Abstract: Lesson planning is a core task for preservice teachers and simultaneously a major challenge due to the complexity of the planning process. This complexity can be reduced by using pre-selected teaching materials (material-based planning). To explore its potential, think-aloud protocols of material-based planning on the topics of photosynthesis and digestion by 13 preservice biology teachers at a German university serve as the main data source. The data were coded using qualitative content analysis, whereby a superordinate distinction was made between core and secondary dimensions of lesson planning. The results reveal a focus on core dimensions such as instructional strategies (visible structures) and student understanding (deep structures), while secondary dimensions like reflecting task authenticity are comparatively rare. This shows the potential of material-based planning, which enables preservice teachers to concentrate on central planning dimensions due to a reduced workload. Further analysis of the code frequencies shows an imbalance between visible and deep structures, which is more commonly observed in the planning of photosynthesis and is interpreted as an indicator of students' overload due to the complexity of the topic. Successful planning by preservice teachers is therefore dependent on both planning task and topic selection. Corresponding implications for teacher education are discussed.

Keywords: material-based lesson planning; teacher education; topic specific; preservice teachers

Citation: Koberstein-Schwarz, M.; Meisert, A. Facilitating Preservice Biology Teacher Development through Material-Based Lesson Planning. *Educ. Sci.* **2024**, *14*, 42. <https://doi.org/10.3390/educsci14010042>

Academic Editors: Martin Rusek and Xinqiao Liu

Received: 5 October 2023

Revised: 19 December 2023

Accepted: 27 December 2023

Published: 29 December 2023



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1. Introduction

Lesson planning is a core task of professional teachers [1,2] and has been an essential component of teacher education worldwide for decades [3–6]. In particular, it offers an important and typically first opportunity for theory and practice to become meaningfully intertwined in teacher education [7]. Since lesson planning cannot be learned intuitively or solely through classroom experience [3,8–10], diverse attempts have been made to create planning tasks that are fictitious but as authentic as possible as a means of facilitating lesson planning in university courses (e.g., adaptation of curriculum materials [8]; planning with generic planning models [9]). A promising approach is to plan based on topic-specific, preselected instructional materials (material-based planning (MBP) [10]), as the selection of material is a fundamental and demanding step in real planning processes [11]. The restriction to preselected instructional material promises to reduce the complexity of the planning process, since the selection from an overabundance of materials, e.g., from the internet, is experienced as overwhelming by preservice teachers [11,12]. However, there is little evidence on how the topic and the instructional material influence the planning process.

Beyond the specificity of the topic, there are other challenges for preservice and in-service teachers associated with inquiry-based learning [13]. However, there have been few studies concerning whether and how these problems are already present in lesson planning [14]. Against this backdrop, this study aims to investigate the suitability of topics for inquiry-based learning to facilitate preservice biology teachers' development through

material-based lesson planning. To this end, the topics of photosynthesis and digestion were selected as exemplary for planning inquiry-based learning with divergent planning challenges, comparable complexity and frequent implementation in schools. Thus, this study aims to illuminate the usefulness of material-based planning as a planning setting for teacher education with particular attention to the importance of the topic in facilitating preservice teachers' lesson planning. The presented results of the material-based planning processes are interpreted against the background of previous findings.

1.1. Teachers' Lesson Planning Process

The aim of lesson planning is to “design a coherent sequence of lesson steps” [15] (p. 280) and “[...] every activity in a lesson sequence [...] function in a specific manner in order to move students towards achieving a specified learning goal” [16] (p. 83). Accordingly, in lesson planning, professional knowledge (both conceptual and procedural) must be applied in a complex, integrative process to make both generic and subject- or possibly even topic-specific decisions regarding content, goals, activities, methods, materials, etc. [17–20]. In the literature, the quality of the planning process has been examined through expert-novice comparisons under the assumption that experts exhibit a high degree of quality in the planning process [21–24]. Despite the basic problem of defining experts in the teaching profession [25,26], this research has shown that a main characteristic of expert planning is the use of cognitive analysis in the planning process. Westerman [24] (p. 292) concretely noted that “[...] expert teachers thought about learning from perspective of the student and performed a cognitive analysis of each learning task during planning”. In so doing, experts have verified the fit between learning tasks and students' learning dispositions while referring, albeit implicitly, to defined learning goals [27]. Accordingly, Blömeke et al. [28] (p. 758) argued that “it seems as if thinking about goals of teaching is the strongest indicator of professionalism”. Thus, expert planning is an integrative alignment of processes that are visible in the classroom with both cognitive and affective preconditions, processes and goals [29]. While experts succeed in designing a sequence of lesson steps according to a learning path to facilitate learning progression, novices have difficulties in doing so [24,30]. They focus primarily on visible structures, such as students' activities, classroom management or methods and media, while neglecting deep structures, such as prior content knowledge and students' understanding or goals [15,24,31,32]. Thus, PSTs have difficulty selecting learning activities that fit with appropriate learning goals and analysing those activities cognitively to anticipate potential difficulties or interactions with prior knowledge [24,33]. Drawing from this theoretical background, there are two core planning dimensions (visible and deep structures), and an imbalance between these dimensions indicates problems in planning [29] (see Figure 1).

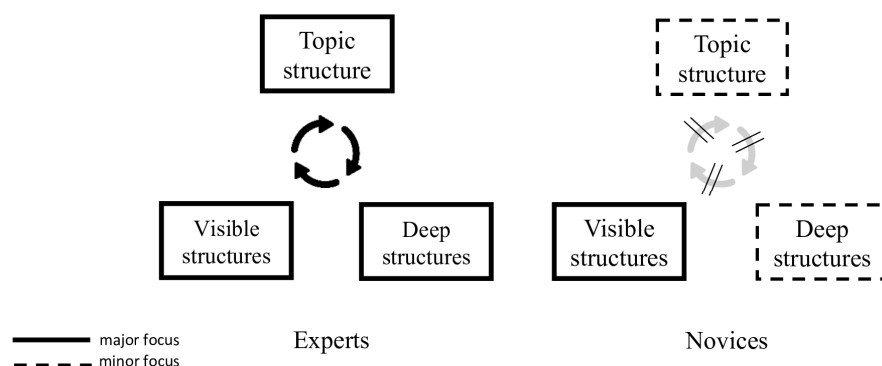


Figure 1. Representation of experts' and novices' use of core planning dimensions according to Oser and Baeriswyl [29]; Westerman [24].

Besides the core planning dimensions of visible and deep structures, teachers must understand both the central ideas of the lesson topic to be taught and the structure of the topic. This topic understanding is a basic requirement of both subject- and topic-specific analyses of representation or learning tasks [1,27]. The corresponding process of analysing representation or learning tasks from a content-oriented perspective has been described by Authors (2022) [10] and referred to as the topic structure. The topic structure is a third core planning dimension and must be integrated if expert planning is to be achieved (see Figure 1). As novices usually have less content knowledge and thus struggle to integrate this knowledge in planning [32,34], this dimension of the topic structure is particularly relevant to modelling lesson planning, both in analysing the planning activities of PSTs and as a means of overcoming the limitations of generic planning models.

1.2. Lesson Planning in Teacher Education

Despite the consensus that lesson planning has been central for professionalisation in teacher education and corresponding research since the 1970s (e.g., [35–37] and remains ongoing (e.g., [17,22,38,39]), there is almost no evidence (1) regarding the relationship between planning quality and teaching quality, (2) concerning the influence of professional knowledge on planning or (3) pertaining to the progression of planning skills in teacher education [23]. Because there is little agreement on how to promote lesson planning in university courses, different planning settings are found in the literature that differ in contextualisation, material base and supporting models (e.g., [9,10,32,40]). Therefore, these three factors should be taken into account when selecting a suitable setting to promote lesson planning and will be discussed and consequently justified as secondary planning dimensions in the following.

1.2.1. Contextualisation (Authenticity)

Approaches to fostering planning skills vary in terms of how they are contextualised, namely, whether planning is targeted to real learning groups (e.g., [22]), fictional learning groups (e.g., [10,40]) or fellow students (e.g., [9,41]). The context of planning settings is very important since “knowledge of students [...] has a great influence on a teacher’s pedagogical reasoning and their cycle of planning, teaching, and reflecting” [42] (p. 88). Therefore, the goal of teacher education should be to generate an authentic context as a “necessary condition for a quality in teacher education program” [43] (p. 291). Since such an authentic learning context is available only in planning for real learning groups during an internship [43], one alternative that can provide a context for planning in university courses is the task of planning microteaching sequences for fellow students. Nevertheless, inauthenticity might be a problem in planning for microteaching because PSTs are uncertain regarding the preconditions and level of prior knowledge that they should assume when planning for peers [9]. Therefore, important in-depth analysis of the core planning dimension, such as thinking about learners’ preconditions, is impossible or very limited [9,44]. Thus, case scenarios, in which fictional classroom settings are established as a framework for planning university courses, offer a promising alternative for PSTs’ planning [45]. From accompanying information about the learning group, such as students’ prior knowledge, PSTs might become more certain about relevant preconditions, and the planning process might be experienced in as authentic a manner as possible. With accompanying information about the learning group (e.g., about students’ prior knowledge), PSTs could experience the planning process contextualised in this way as more reliably assessable in terms of relevant prerequisites, thus making the planning process feel as authentic as possible.

Therefore, determinants of whether contextualisation is appropriate in a planning setting include, first, certainty regarding, e.g., the preconditions that are met with respect to the core planning dimensions and, second, the act of considering the authenticity of the setting as a secondary planning dimension (see Figure 2).

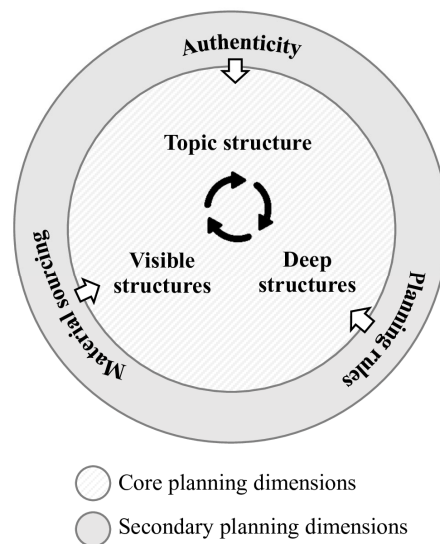


Figure 2. Representation of Core and Secondary Planning Dimensions in Teacher Planning According to Karlström and Hamza [9], Oser and Baeriswyl [29] and Westerman [24].

1.2.2. Material Base (Material Sourcing)

There are differences in the material base available for planning. In certain planning settings, no material base is provided (e.g., [32]), while in others, PSTs can use preselected material for planning (e.g., [10]), and in still others, complete lesson plans can be adapted during planning (e.g., [8,45]). Comparing these different material bases, one overwhelming cause of problems with planning in teacher education might be the difficulty of selecting appropriate source material [9]. PSTs have only a small repertoire of familiar materials to use in planning and are less experienced at selecting and adapting materials, e.g., from the internet [12]. Therefore, the use of source material should be made easier in the context of planning for academic courses [10]. This goal can be achieved through, e.g., adapting curriculum material, including all important materials (curriculum planning; see [46]). Adapting such planning usually leads to qualitatively better results (e.g., better implementation of inquiry-based learning) than would be produced by leaving plans to be designed by PSTs themselves [47]. However, this type of planning as an adaptation of curriculum materials is disadvantageous since it is primarily the teacher's own planning decisions that produce in-depth analysis [40]. A compromise is material-based planning [10], in which preselected, fragmentary materials are provided as a basis for planning, but lesson plans must be designed based on this material by the teachers themselves. The preselection of the material base is crucial and is carried out according to certain criteria [10]. First, the material base must be suitable for inquiry-based learning because inquiry science instructions have a positive impact on students' learning [48]. There must be material for all phases of the inquiry cycle (e.g., phenomena in a video = questioning, planning an experiment = exploration, etc. [49]). Second, the material base must contain different forms of representation (e.g., diagrams, texts, photos, etc.) because different representations go hand in hand with alternative conceptions or students' understanding. Third, there must be a variety of direct and indirect instructions (e.g., guided inquiry vs. open inquiry; [13]) because the degree of instruction has an influence on students' understanding [50]. An overabundance of material and required selection from this material for concrete lesson planning enable both in-depth analysis of the material and the integrated planning of visible structures [10]. Therefore, we consider material sourcing as a secondary planning dimension that determines whether the material base is appropriate (see Figure 2). This includes both the search or demand for materials beyond the material base or dissatisfaction with the given material base.

1.2.3. Supporting Models (Planning Rules)

Third, there are differences with respect to the guidance of the planning process. In some settings, participants are instructed to use generic planning models (e.g., [9]) or subject-specific planning guides (e.g., [15]). In other settings, no guidance is provided (e.g., [40,51]). The literature shows that in-service teachers do not plan with generic planning models [52]. In addition to their lack of references to the subject or topic specificity of planning, generic planning models do not resemble the real planning process due to their linearity [18]. On the other hand, some authors see great potential in the use of generic planning models, as they might allow for more targeted planning tailored to the learning group [53]. Therefore, the usefulness of these generic models in teacher education is controversial. Alternatively, planning can be guided by subject-specific questionnaires [15,54], thus facilitating the activation of professional knowledge. On the one hand, these guides help structure the planning process; on the other hand, they constrain it through narrowly predefined planning rules. However, the closest analogue to real planning situations encountered by teachers is the act of planning without a given model or guide to structure the planning task, although familiar models or guides can still be consulted during the planning process. The extent to which students structure their planning process through generic planning models or guides can be seen in, e.g., their explicit mentions of planning rules [9]. This consideration of planning rules derived from generic planning models or subject-specific planning guides can be defined as another secondary planning dimension.

In summary, lesson planning conducted in universities has specific characteristics and challenges that might become apparent during the planning process (e.g., authenticity, material sourcing or planning rules) [9]. Therefore, in addition to the core planning dimensions (visible structures, deep structures and the topic structure), there are also secondary dimensions, such as authenticity, material sourcing or planning rules, that are considered during the planning process (see Figure 2). Thus, the use of core planning dimensions, specifically the ratio of visible to deep structures, and the additional use of secondary planning dimensions provide a great deal of relevant information both regarding PSTs' planning skills and pertaining to the suitability of planning settings for teacher education.

1.3. Topic-Specific Lesson Planning

A consensus has emerged in the literature that pedagogical content knowledge is topic-specific [55–58]. For example, topic-specific knowledge regarding strategies for teaching, representations or activities is important [58,59]. Park and Chen [58] demonstrated the importance of this topic specificity for photosynthesis and heredity. Furthermore, since topic-specific pedagogical content knowledge is fundamentally integrated into pedagogical reasoning, planning skills themselves might be topic specific as well. Nevertheless, no recent studies have compared PSTs' planning skills on different topics. Thus, the extent to which difficulties in PSTs' planning processes are topic-specific remains unknown, and accordingly, the question of which topics are best suited for facilitating planning in teacher education remains unanswered.

However, a particular potential for planning and teaching in science teacher education has been noted with respect to inquiry-based topics [14,46,60]. First, inquiry-based learning has been envisioned as a central element in science education [13,48]. It has been described as the best science teaching environment to activate learning, especially in terms of understanding the nature of science. Accordingly, inquiry-based learning has been incorporated into both national and international standards [61,62]. Second, various studies have shown that inquiry-based teaching is a challenge for both preservice and in-service teachers; PSTs have difficulty guiding students through inquiry-based lessons that require an understanding of the nature of science [46,56,60]. Moreover, PSTs themselves often lack an understanding of inquiry-based learning or the nature of science [34]. Consequently,

inquiry-based learning is often equated with hands-on activities [45,46,63,64]. In line with this view, PSTs often choose tasks that are fun to perform [30,46] or “science activities that work” [65,66], neglecting the cognitive activation of students [30,67] or the goal of producing empirical evidence. In the literature, challenges for teachers have more generally been noted in the context of inquiry-based teaching (e.g., [67]) rather than with respect to specific topics, although each topic entails specific challenges. Two common topics involving different challenges for teaching and learning are photosynthesis and digestion. These and other topics differ in their relevance to the scientific principles of biology, students, complexity or possible practical demonstration (see Table 1). However, no research has been conducted on how different inquiry-based topics such as photosynthesis and digestion are suited to the design of planning settings in teacher education.

Based on these considerations, this study designs a contextualised planning setting for PSTs to facilitate the integration of the core dimensions (visible structures, deep structures and topic structures) and to minimise distractions from the secondary dimensions (authenticity, material sourcing and planning rules). In this setting, PSTs’ planning is examined with respect to two different inquiry-based topics (photosynthesis and digestion) to derive conclusions regarding (1) the potential of material-based planning and (2) the potential of the topics of photosynthesis and digestion to facilitate planning in teacher education. The study is guided by the following research questions:

1. (RQ1) (a) Which planning dimensions do PSTs use in material-based lesson planning, and (b) are there differences between the topics of digestion and photosynthesis in this context?
2. (RQ2) (a) What ratio of visible to deep structures is used by PSTs in their planning, and (b) are there differences between the topics of digestion and photosynthesis in this context?
3. (RQ3) (a) What difficulties occur during planning due to imbalanced or balanced use of visible and deep structures, and (b) are there differences between the topics of digestion and photosynthesis in this context?

Table 1. Characteristics of the topics of starch digestion and the light dependency of photosynthesis.

Characteristics/Challenges	Starch Digestion	Light Dependency in Photosynthesis
Relevance to students	Concerns one’s own body, thus inspiring interest ‘Finding out how our bodies work’ [68]	Studying plants inspires less interest [69]
Complexity	Misconceptions concerning the interaction between structure and function ‘Breaking foods down’ vs. ‘melting foods’ [70]	Experimental strategy as a challenge with respect to an inquiry-based learning path [71]
Principles of biology	Molecular interactions such as enzyme-substrate-complex, key-lock principle	The concept of energy [72]
Practical demonstration	Diverse options for qualitative experimental access (e.g., sugar proof after chewing or comparing the influence of saliva or simulated mechanical crushing)	Diverse options for qualitative or quantitative experimental access (e.g., the classic Elodea experiment [73], starch detection in exposed and unexposed leaves) Limitations of practical demonstrations due to unreliable results and expensive equipment [71]
Phenomena for exploration	One most significant phenomenon (bread becomes sweet if you chew on it for a long time)	Several phenomena (e.g., phototropism or vegetation in caves)

2. Materials and Methods

2.1. Participants

As the study uses new methods (think-aloud protocols of planning processes) and explores a new lesson planning setting (material-based planning), it is highly exploratory in nature. Accordingly, as recommended by Patton [74]), a small sample (N = 13 PSTs; seven female, six male; ages ranging from 24 to 37 years, M = 26.7) was used to conduct

in-depth analyses and to explore the suitability of the new research method and the innovative lesson planning setting. This study was conducted in the context of an academic course for secondary preservice biology teachers at a German university. All of the participants had completed their bachelor's degrees and were about to start studying for their master's degrees in secondary education. In bachelor's degree programs in Germany, two subjects and the associated educational science as well as general educational science are studied [75]. Therefore, PSTs participating in this study were assumed to have basic content knowledge in biology due to required university courses in human biology, cytology, zoology and botany, as well as in biology education, including, e.g., the concept of inquiry-based learning or student preconceptions. In addition, the participants were familiar with generic models for general lesson planning (e.g., [76]) and completed a four-week internship at a secondary school, planning and conducting at least one lesson using these generic models. Only one participant had planned a lesson that was thematically similar to that used in this survey as part of an internship. The participants were randomly assigned to two different topic groups (photosynthesis: $n = 6$; digestion: $n = 7$, see Table 2).

Table 2. Overview of the participants.

Participant	Age	Sex	Experience in Planning the Topic		Duration of Lesson Planning
			In Internship	At University	
Topic group D: Unit: Digestion; Lesson topic: Degradation of starch to sugar by amylase; 7 th –8 th grade					
D1	27	Male	No	No	39 min
D2	25	Female	No	No	37 min
D3	27	Female	No	No	35 min
D4	26	Male	No	No	50 min
D5	24	Male	No	No	29 min
D6	25	Female	No	No	25 min
D7	23	Female	No	No	28 min
Topic group P: Unit: Photosynthesis; Lesson topic: Light dependency in photosynthesis; 7 th –8 th grad					
P1	29	Male	No	No	23 min
P2	30	Male	Yes	No	55 min
P3	28	Female	No	No	26 min
P4	24	Male	No	No	35 min
P5	25	Female	No	No	41 min
P6	37	Female	No	No	41 min

2.2. Intervention

Based on the theoretical background, individual material-based planning without a predetermined use of planning models or guides was chosen as the planning setting to ensure authenticity and efficient material sourcing and to enable the integration of visible and deep structures instead of planning rules. In this setting, the PSTs created plans for two different topics: (topic group D) digestion, the degradation of starch to sugar by amylase, and (topic group P) photosynthesis, light dependency in photosynthesis. Both topics are included in the German science curriculum [64] and are suitable for inquiry-based teaching, but each topic has different characteristics (see Table 1).

The intervention was divided into a preliminary phase and two intervention phases to structure the planning task (see Figure 3).

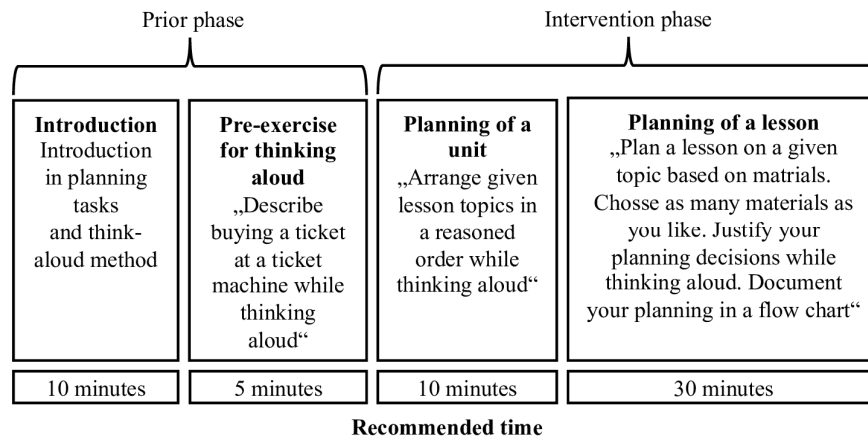


Figure 3. Intervention structure and planning tasks in material-based planning.

In the first part of the introduction phase (Introduction, see Figure 3), the first author introduced the PSTs to the think-aloud method and the planning tasks. The PSTs received information regarding the lesson topic as well as information pertaining to the grade level (7th–8th) and school type (secondary) for which they were required to plan. During subsequent phases, the PSTs were separated into rooms to work on the planning tasks individually. The time spent during these phases was not restricted, but time frames were recommended (see Figure 3). First, the PSTs practiced the think-aloud method in accordance with Sandmann [77]. After the intervention phase, the PSTs located the lesson to be planned as part of a teaching unit (D: Digestion, P: Photosynthesis). For this purpose, the PSTs were provided with a list of possible content (e.g., for the topic of digestion, the function of enzymes and the structure and function of the stomach). The PSTs chose which content to teach before and after the lesson to be planned. Therefore, the PSTs received information regarding students' prior content knowledge related to digestion or photosynthesis. On this basis, the PSTs planned a lesson to address the topic in question (D: The degradation of starch to sugar by amylase; P: Light dependency in photosynthesis). Lesson planning tasks were based on fixed, preselected sets including eleven to twelve materials each. The sets of materials were topic specific and included photos, text, diagrams, models and experiments taken from textbooks or the internet (for example, see Figure 4).

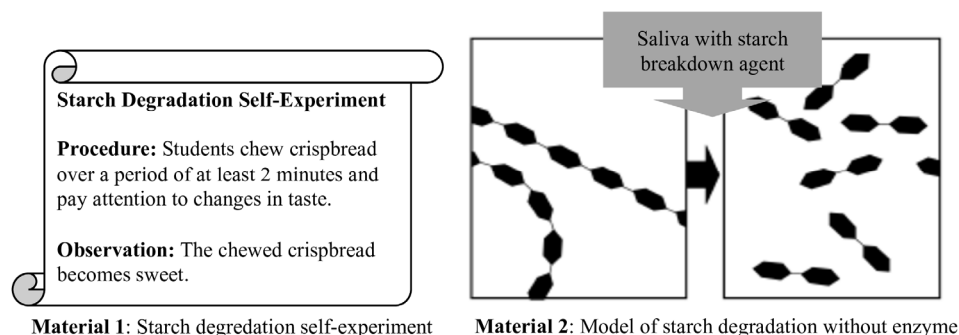


Figure 4. Examples from the material set for lesson planning on the topic of the degradation of starch to sugar via amylase (translated from German).

The materials should cover a wide range of possible instructional strategies and representations for inquiry-based learning (according to Magnusson et al., [59]), as knowledge of instructional strategies and representations is crucial for planning [59,78]. For this reason, instructional strategies and representations were varied in the materials.

Accordingly, the following criteria were used to select the materials (see [10]): (a) suitability for inquiry-based instruction (e.g., phenomena, experiments, data tables), (b) varying degrees of abstraction in the representations (e.g., texts vs. photos) and (c) varying types of instructional strategies (e.g., guided inquiry vs. open inquiry [13]). The material base was selected by the first author and discussed with three scientists and two teachers regarding the fulfilment of the criteria. Subsequently, the material was supplemented and discussed again. In a pilot study with three master's students, it was checked whether the students found the material suitable for planning the given topic or whether material was missing. Requested material was added. The new material was discussed again with three scientists.

The PSTs were able to choose as many materials as they wanted for their planning and were supposed to document the lesson in a flow chart (describing learning steps and including their chosen material). To ensure comparability within a topic group, PSTs in the same topic group received identical material sets. No additional material taken from the internet or textbooks was allowed.

2.3. Data Sources

The PSTs performed the planning task using the think-aloud method. Therefore, the data source for this study was a set of nine audio-recorded think-aloud protocols documenting the PSTs' lesson planning processes (see Figure 3, Intervention phase: Planning of a lesson). The average length of lesson planning during the 3rd phase was close to the recommended 30 min ($M = 35.7$ min; see Table 2). Another data source was the flow charts for the lesson plans. The flowcharts were not analysed separately, but were used when materials were not clearly named in the think-aloud protocols.

2.4. Data Analysis

A mixed-methods approach was used to explore the PSTs' (topic-specific) planning activities in the context of material-based planning. Their planning activities were analysed via qualitative content analysis in accordance with Kuckartz [79]. Kuckartz describes the creation and use of deductive-inductive code systems. The steps recommended by Kuckartz have been followed and are explained below. First, a deductive-inductive code system for planning dimensions (see Table 3) and the core dimensions of visible and deep structures (see Table A1) was designed in an iterative process by the first author. The subcodes for the core dimensions were identified inductively in the think-aloud protocols and assigned to the visible and deep structures according to Kleickmann et al. [80]. Kleickmann et al. identified cognitive support, cognitive activation and motivational support, among others, as deep structures. Codes were defined in a coding manual [according to 84]. The coding manual was discussed and optimised by the working group several times throughout its application. All of the data were coded completely by the first author and partially (10%) by a second coder using MAXQDA™ 2022 analysis software (VERBI Software, 2019). Disagreements were discussed. The percentage of coded planning dimensions was compared. The average agreement was 79%.

To answer the three research questions, different qualitative and quantitative analysis strategies were combined. Codes for planning dimensions and subcodes for the core dimensions of visible and deep structures were quantified according to Kuckartz [79] using MAXQDA™, and the topics of digestion and photosynthesis were compared (RQ1). The ratios of visible to deep structures were determined for each PST (RQ2). Based on these ratios, different cases were selected for the qualitative analysis of their planning processes to identify both idiosyncratic and topic-specific planning difficulties (RQ3). The selection of relevant cases was based on the comparison-focused sampling method developed by Patton [74].

Table 3. Core and secondary planning dimensions in the planning process of PSTs in the context of material-based planning.

	Dimension	Description	Example
Core planning dimensions	Visible structures	Thinking about concrete activities, tasks, media, etc.	“First, students do a self-experiment”.
	Deep structures	Thinking about the cognitions of students/the potential of the material to activate cognition	“[...] because it enables students to understand that saliva contains certain enzymes”.
	Topic structure	Thinking about the material or content from a topic perspective	“A crispbread is pounded in a mortar and water is added [...] another sample is soaked in saliva. Both samples are checked for sugar content with Fehling’s reagent”.
	Material sourcing	Thinking about the acquisition of material	“[...] if you are looking for other materials, that might be good, too”
Secondary planning dimensions	Authenticity	Thinking about the authenticity of the task	[no coding found]
	Planning tasks	Thinking about performing the task	“What was the task? [...] Well, present the lesson steps [...]”.
	Planning rules	Thinking about the organization/structure of the planning process	“I’m just thinking about what I’m going to use as a starter”
	Overload	Thinking about one’s ability to accomplish the task	“Okay, I have a bit of a mess in my head. I’m kind of blocked right now”

2.4.1. The Analysis of the Planning Dimensions (RQ1)

First, the think-aloud protocols for lesson planning processes were transcribed. Dialects, repeated words and filler sounds were corrected. In these protocols, sections that could be assigned to the planning dimensions found in the literature were identified; visible structures, deep structures [29] and the topic structure [10] were identified as deep structures; and planning rules, material sourcing and authenticity were identified as secondary dimensions [9]. The category planning rules was inductively subdivided into planning tasks and planning rules (see Table 3). The category cognitive overload was added inductively.

To analyse the use of visible and deep structures, all of the sections assigned to one dimension were summarised and examined to produce further categories, resulting in six categories for visible structures and five categories for deep structures (see Appendix A Table A1). To examine the specific characteristics of topics referring to inquiry-based learning categories, both student activities and cognitive learning goals were divided into the subcategories of inquiry-based aspects and non-inquiry-based aspects. In addition, the categories pertaining to students’ prior knowledge were divided into the subcategories of certain use and uncertain use since engaging with students’ prior knowledge permits additional evaluation of the suitability of the planning setting.

All of the collected sections of a dimension were coded accordingly and subsequently quantified. Categories that occurred rarely (<10% of the total codes for one dimension) were subsumed into the categories of other visible structures or other deep structures. The frequencies of dimension use for topic groups D and P were compared.

2.4.2. The Analysis of the Ratio of Visible to Deep Structures (RQ2)

To identify additional topic-specific differences in the use of planning dimensions, the ratio of visible to deep structures with respect to the total number of planning dimensions addressed (not including secondary dimensions) was determined for each PST separately. The question of whether students within a topic group employed a similar ratio of visible to deep structures or whether the ratios were idiosyncratic was investigated. Based on the data, different ratios of visible to deep structures were distinguished. Cases with a ratio of visible to deep structures that was greater than 2:1 were identified as the

visible dominant group, while cases with a ratio that was lower than 1:2 were categorised as the deep dominant group, and those with a ratio between 2:1 and 1:2 were recorded as the balanced group.

2.4.3. The Analysis of Difficulties in Planning (RQ3)

Based on these quantitative results, cases with different ratios of visible to deep structures were identified. Two extreme cases (“outlier sampling”; see [74] (p. 405): visible dominant or deep dominant) and two balanced cases in different topic groups (“homogenous sampling”; see [74] (p. 406) a balanced ratio of visible to deep structures) were chosen for the qualitative case study. First, selection was made following the outlier sampling in accordance with Patton [80] because “cases on the tails of a distribution [...] can reveal a great deal about intense manifestation of the phenomenon of interest” [74] (p. 405). Second, in the homogeneous sampling, cases were selected “that [we]re very similar to study the characteristics they ha[d] in common” [74] (p. 406).

Difficulties in planning were analysed qualitatively. Therefore, which characteristics the PSTs demonstrated in matching visible and deep structures and designing a sequence of lesson steps to facilitate learning progression was investigated. These characteristics are highlighted with example quotations.

3. Findings

3.1. The Use of Planning Dimensions (RQ1)

A total of 1407 sections were coded: 83% of these codes were employed for core dimensions, and 17% were used for secondary dimensions. There were 790 codes for topic group D (82.5% core dimensions, 17.5% secondary dimensions) and 617 for topic group P (82.7% core dimensions, 17.3% secondary dimensions). Detailed analysis of the planning dimensions showed that visible structures were used most frequently for both topics (D = 37.5%, P = 36.8%), followed by deep structures (D = 30.1%, P = 27.7%) and the topic structure (D = 14.9%, P = 18.1%). The distribution of codes across the three core dimensions was similar for both topics. For the secondary dimensions, planning rules were used most frequently (D = 9%, P = 8%), while authenticity and material sourcing were almost non-existent (Figure 5).

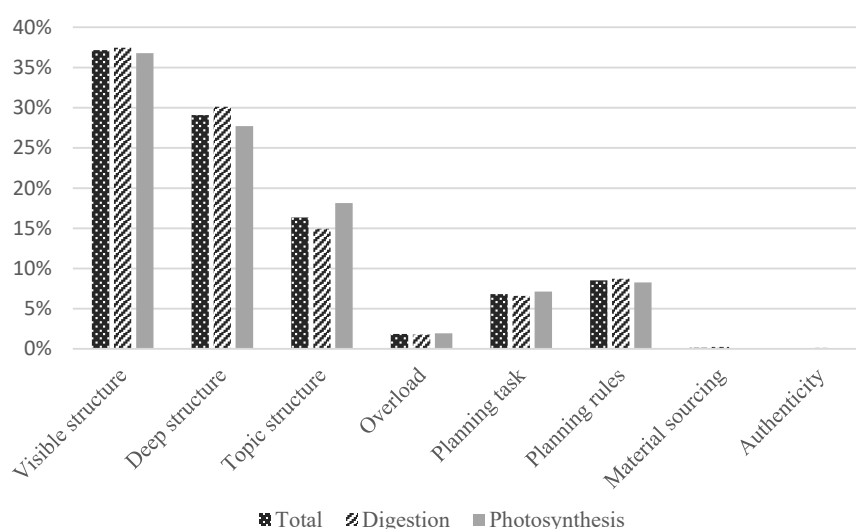


Figure 5. Relative frequency of codes for the core dimensions and the secondary dimensions.

Analysis of the visible and deep structures showed that student actions (39% of visible structures) and cognitive learning goals (40% of deep structures) were the dominant aspects that the PSTs considered with respect to these core dimensions. Other subcategories were addressed between 10% and 20% each (see Figure 6).

Comparing topic groups revealed that student actions were dominant in both topic groups, but the proportion of student actions among all of the visible structure codes in the topic group was larger for topic group D ($D = 46\%$, $P = 28\%$). The categories of method and media and time management had a larger proportion in topic group P (each subcategory accounted for more than 20% of the total) than in topic group D (each subcategory accounted for less than 20% of the total).

With respect to deep structures, cognitive learning goals occurred most frequently ($D = 47\%$, $P = 29\%$), with a larger proportion for topic group D. In contrast, the proportion of the categories of potential for interpretation ($P = 12\%$, $D = 5\%$), student preconditions ($P = 9\%$, $D = 5\%$) and student prior content knowledge was the same for both topic groups ($D = 21\%$, $P = 20\%$) (see Figure 6).

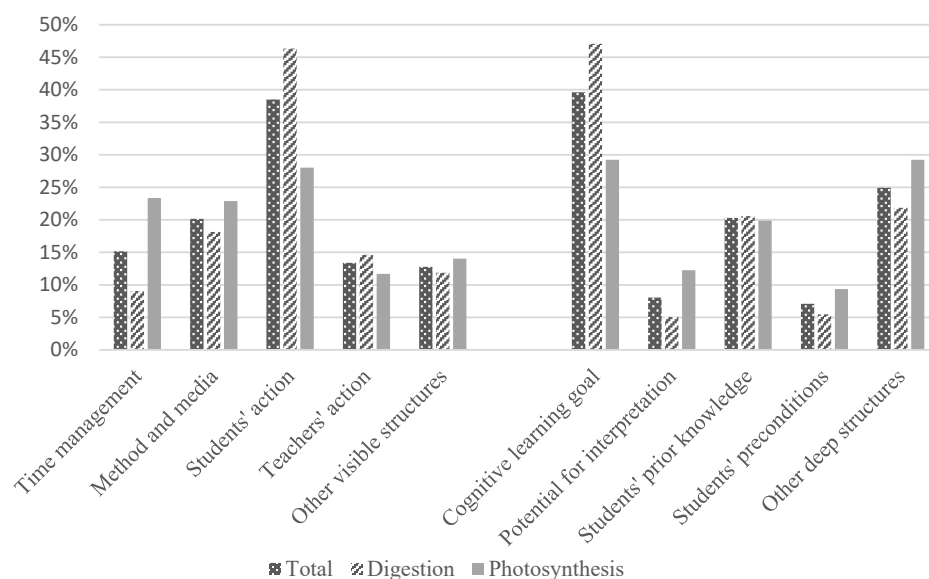


Figure 6. Use of visible and deep structure aspects in lesson planning according to topic group.

3.1.1.1. Student Actions and Cognitive Learning Goals

Both the subcategories of cognitive learning goals (a deep structure) and student actions (a visible structure) could be divided into inquiry-based and non-inquiry-based groups (see Table A1). For both subcategories, in total, more than half of the mentions were inquiry based (see Figure 7). The analysis of all the cognitive learning goals and student actions within a topic group showed that a much larger proportion of inquiry-based actions and learning goals was shown by topic group D (see Figure 7).

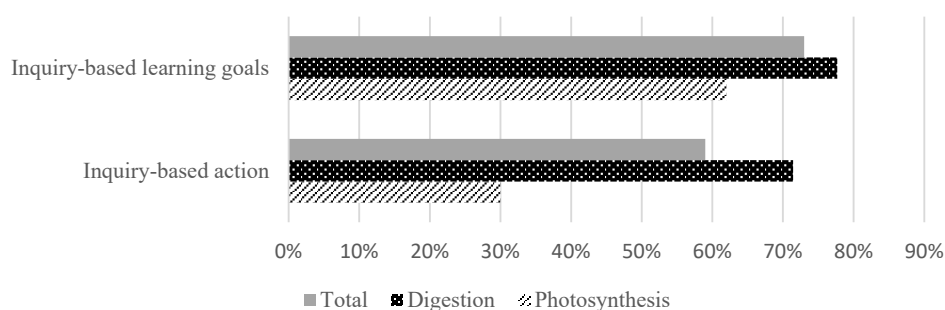


Figure 7. Proportions of the subcategories Student Actions and Cognitive Learning Goals that were inquiry-based.

3.1.2 Student Preconditions and Prior Content Knowledge

The deep structure subcategories of student prior knowledge and student subject knowledge could be divided into groups with uncertain vs. certain use (see Table A1). Both subcategories were dominated by the certain use group; only 23% of students' prior content knowledge and 29% of preconditions would not certainly be used (see Figure 8). For both student prior content knowledge and students' preconditions marginal differences between the topic groups were detected.

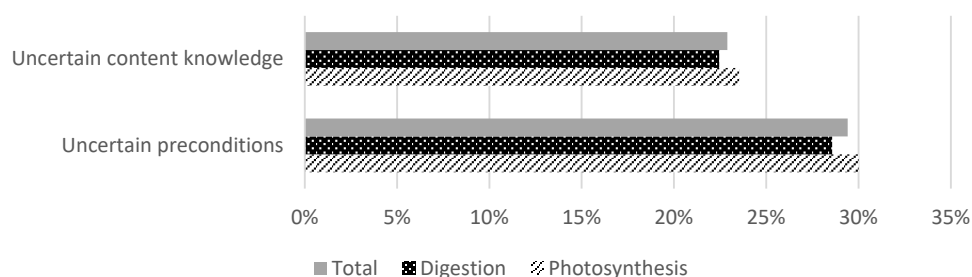


Figure 8. Proportions of the subcategories of Preconditions and Content Knowledge that were uncertain.

3.2. The Ratio of Visible to Deep Structures (RQ2)

To analyse topic-specific characteristics in the use of planning dimensions, the percentages of visible and deep structures were determined for each PST. Figure 9 illustrates the use of planning dimensions for each PST, comparing topic groups P (squares) and D (triangles). Cases from topic group P exhibit great diversity, ranging from a high ratio (P1) to a low ratio (P2 and P3) of visible structures, while all the other cases in topic group D and those from group P demonstrate a more balanced ratio of visible to deep structures.

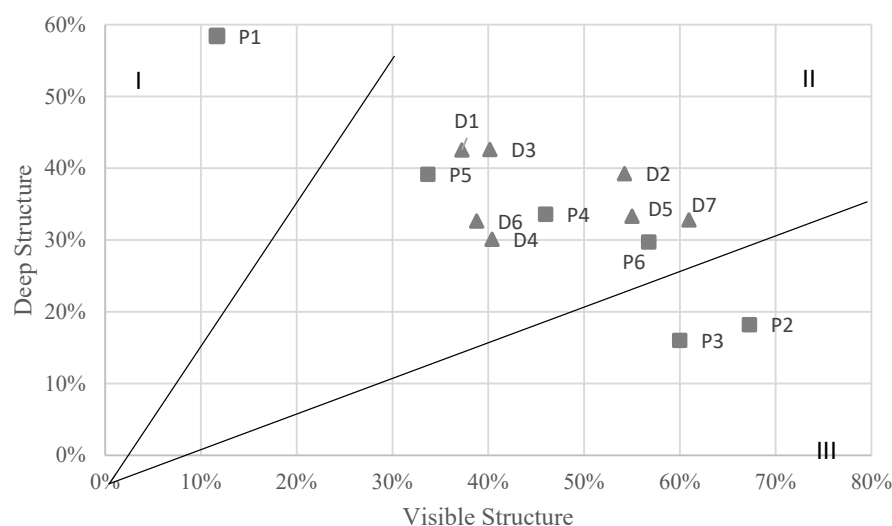


Figure 9. Idiosyncratic use of deep and visible structures. Note: The horizontal axis shows the percentage of visible structures in relation to the total number of codes. The vertical axis shows the percentage of deep structures in relation to the total number of codes (planning subject: D = digestion; P = photosynthesis). I cases above the straight line (2:1) = imbalanced, deep dominant; II cases between the straight lines (2:1) and (1:2) = balanced; III cases below the straight line (1:2) = imbalanced, visible dominant.

3.3. Difficulties in Planning (RQ3)

To analyse difficulties, contrasting cases were selected based on differences in code frequency (see Figure 9). Extreme cases were found in topic group P, while balanced cases existed in both topic groups. Therefore, two extreme cases from topic group P and two balanced cases, one from each topic group, were chosen:

- (1) A high proportion of visible structures in relation to deep structures (P2 as a representative case)
- (2) A low proportion of visible structures in relation to deep structures (P1 as a representative case)
- (3) A balanced ratio of visible structures to deep structures (P4 and D4 as representative cases with similar mean visible-deep balances but different topics)

3.3.1. The High Proportion of Visible Structures in Relation to Deep Structures—P2

After reviewing the material, P2 focused on a cognitive goal: “The students recognise that photosynthesis varies depending on the amount of light. A lot of light equals a lot of photosynthesis” [deep structure—cognitive learning goal]. However, the subsequent visible structures used during the planning activities were not related to this goal but focused on the selection of a method in the form of requiring students to work at stations. This step was followed by the selection of materials for student activities at these stations. Criteria for the selection of materials refer to the dimension of visible structures, such as in the following examples: “If I have four groups, then a film could actually be quite good” [visible structure—method and media], “I won’t use this, although it would be nice for 90 minutes” [visible structures—time] and “Maybe I’ll do this experiment. The only question is whether it will work” [visible structure—other visible structure/practicability]. A more detailed analysis of the cognitive learning goals to be achieved at the stations or even the learning path to be completed was not conducted.

3.3.2. The Low Proportion of Visible Structures in Relation to Deep Structures—P1

P1 analysed the material repetitively according to deep structure criteria: *“I don’t think the experiment is suitable for an introduction because you have to know how fire works”* [deep structure—students’ prior content knowledge], *“I would not give a complicated introduction”* [deep structure—other deep structure/complexity] and *“In this picture, students can see directly that light is important. Plants grow in front of the cave—not in the cave”* [deep structure—potential of material for interpretation]. Furthermore, P1 planned lesson steps with respect to the dimension of deep structures. He planned a learning path that related cognitive learning goals to each other. Then, he looked for suitable materials that the students could use to follow these steps: *“Now, the next step would be to find out why the plants need light. Therefore, I have to look at the materials again”* [deep structure—cognitive learning goal]. However, P1 had difficulty specifying the selection and implementation of materials. As he noted, *“To be honest, I’m a bit unsure and unfortunately not well versed enough in the subject to be able to argue well concerning how to fill the main part of the lesson. But I’ll just leave it out because many materials can be used here”* [overload].

3.3.3. The Balanced Ratio of Visible Structures to Deep Structures (D4, P4)

After a short material review, P4 selected materials according to both visible and deep structure criteria: *“I’d like to start with something nice and fun”* [deep structure—other deep structures/motivation], *“I wouldn’t like to show a film; I’d rather have the students do something themselves”* [visible structure—other visible structure/involvement] and *“The experiment could probably be done, but I don’t know if the concentration would be high enough”* [visible structure—other visible structure/practicability]. In contrast, at the beginning, D4 mainly used deep structure criteria for material selection: *“Of course, you could show the diagram at the beginning of the lesson, but this is too complicated for the eighth graders”* [deep structure—other deep structure/complexity], *“I’m wondering if the material is useful for this purpose because it’s very detailed and that only confuses the kids”* [deep structure—other deep structure/transparency], and *“Probably they haven’t heard of enzymes, so I would just go ahead with an experiment”* [deep structure—students’ prior content knowledge].

When both P4 and D4 planned how to implement the material, they reviewed what students might learn during this step. P4: *“Then they conduct the experiment and see that something is produced. So, students understand that it has something to do with light”* [deep structure—cognitive learning goal]. D4: *“So, I’m sure I’ll start with the self-experiment, [...] then we have the phenomenon and the students realise that we are eating something and it becomes sweet”* [deep structure—cognitive learning goal].

However, both P4 and D4 failed to sequence visible structures to achieve a purposeful deep structure (i.e., learning progression). Instead, visible structures were arranged additively, and the corresponding deep structures were derived.

In addition to these planning problems, in both cases, successful phases featured the participants sequencing cognitive learning goals first and thinking about a non-inquiry-based visible structure that could be used to achieve those goals afterwards: P4: *“After students see that there are more bubbles in light, students should understand that light is important for plants [...] [deep structure—cognitive learning goal]. Maybe students can watch a movie [visible structure—students’ actions/noninquiry-based]; then they will understand that light is vital for plants and that nothing works without light”* [deep structure—cognitive learning goal].

D4: *“The logical question is, then, what is in the saliva that breaks it down? You should lead the children to answer that question [deep structure—cognitive learning goal] [...] I would actually say to the children: ‘so, it’s not the mineral salts’”* [visible structure—teachers’ actions/non-inquiry-based].

P4 and D4 planned visible structures and analysed related deep structures, but each had difficulty linking activities to establish a learning path. On the other hand, when P4 and D4 identified a goal as part of a learning path, they failed to create student-activating,

inquiry-based visible structures. D4 confirmed the second problem via a reflexive statement: “[...] I can’t think of anything great concerning how the students can examine the question themselves. I’m sure there’s a better way” [overload].

4. Discussion

The paper reports on PSTs’ use of both core and secondary planning dimensions in topic-specific material-based planning. The findings confirm the potential of material-based planning to activate thinking in core planning dimensions and provide initial insights into the differences in the suitability of the topics of photosynthesis and digestion for promoting planning skills in teacher education. First, PSTs’ use of core and secondary planning dimensions in material-based planning are discussed; second, PSTs’ topic-non-specific difficulties with using core dimensions (e.g., in designing the sequence of lesson steps) are highlighted; and third, topic-specific differences are emphasised.

Comparisons of material-based planning with other planning settings based on results from other studies (e.g., curriculum planning, refs [8,45,46] or open planning settings without materials [32]) are limited as the research designs differ. Nevertheless, the exploratory approach may be helpful in identifying initial trends in the use of planning dimensions in material-based planning that may point the way for future research.

4.1. The Use of Planning Dimensions in Material-Based Planning

The findings show that material-based planning as a planning setting encourages teachers to plan with substantial reference to the core dimensions of visible structures, deep structures and the topic structure and not to limit themselves to just one dimension (e.g., visible structures) (see Figure 5). Little use was made of the secondary dimensions, confirming the suitability of this planning arrangement for PSTs. On average, both visible and deep structures were considered in similar proportions, albeit with a slight preponderance of visible structures (see Figure 5). On the one hand, this result tends to confirm the claims in the literature that PSTs tend to plan with respect to visible structures, especially student activities [15,24,31], but on the other hand, it also shows the potential of material-based planning to activate thinking regarding deep structures, especially cognitive learning goals. The need to choose between different materials seems to stimulate in-depth analysis or consideration of the possible cognitive goals to be achieved with the materials (see Figure 6) [10]. This can be interpreted as a potential advantage of material-based planning over curriculum planning e.g., [8,45,46]. Curriculum planning does not require the comparison of materials or instructional representations, but adaptation of an existing plan. Davis [46] reports that PSTs hardly think about instructional representations when adapting curriculum material and neglect deep structures. Our results show that material-based planning activates this thinking about instructional representations in the core dimension of deep structure. This advantage should be verified in future research by comparing the planning settings in an experimental design.

Furthermore, the extensive use of the topic structure dimension (see Figure 5) can also be interpreted as an influencing factor that initiates or enables planning consideration related to deep structures, as content knowledge, and particularly a deeper understanding thereof, is an essential prerequisite for planning [27,32,42,57]. The literature shows that PSTs often lack content knowledge [67,81]. Especially in an open setting of lesson planning without books or other materials (lesson preparation method) Käpylä et al. [32] describe that a lack of content knowledge is a problem in lesson planning for PSTs. Therefore, one possible interpretation of the frequent use of topic structure is that by analysing materials that vary in their level of abstraction and instructional degree (e.g., diagrams and texts), PSTs might deepen their own content knowledge during planning [10] in order to cope with the perceived lack of content knowledge. However, it is also possible that the PSTs have sufficient content knowledge and internalise the content in the dimension of topic structure. Thus, the selected material supports the claim that “novices [...] first in-

ternalised the content or learned the material and prioritised important information themselves” [52] (p. 63). This potential of MBP to create a basis of content knowledge has to be discussed critically with regard to the phase of teacher professionalization. While preservice teachers may profit from this because of their lack of knowledge with regard to school topics, this potential may disappear in later phases of teacher education.

Regarding secondary dimensions in particular, authenticity and, of course, material sourcing were rarely mentioned by the PSTs (see Figure 5), although these factors are often described as challenges or limitations in teacher education [9]. Therefore, material planning is a promising approach that both activates relevant planning dimensions and avoids central difficulties that are common in PSTs’ planning processes. The lack of pre-selected materials often leads to unproductive material sourcing due to a lack of criteria to analyse the available sources [12]. Sawyer and Myers [12] show that in an open planning setting that includes searching for materials on the internet, materials are selected according to the popularity of the website. Similarly, Ulusoy and Incikabi [82] show that mathematics PSTs prefer ready-to-use materials from the internet or textbooks and make hardly any adaptations to these materials. In contrast, preselected materials might offer a fruitful basis for planning by preventing disorientation and loss of motivation due to unlimited options for material sourcing, which can be unproductive and unsettling. Nevertheless, as above this potential must be differentiated with regard to the phase of teacher professionalization, as the relief of the material search is not sufficient, for example, for the first steps in lesson planning. In connection with the above-mentioned limitations, a middle phase of professionalization seems to be particularly suitable for this approach.

Regarding the secondary dimension of authenticity, its complete absence in the data confirms the assumption that planning for hypothetical students seems more authentic than planning for one’s fellow students. In contrast, when planning for one’s fellow students in the context of microteaching, authenticity is present [9].

Another aspect that can evoke inauthenticity is a lack of information regarding student preconditions [42]. Although no further information concerning the students was given in this study, only a small number of planning aspects or codes, such as prior content knowledge and student preconditions, were described by the PSTs as uncertain (see Figure 8). This low occurrence of uncertainty might be due to the previous planning for the unit from which the students’ prior content could be drawn [9], while information pertaining to student preconditions might have originated from the PSTs’ general knowledge regarding students in a given grade. The remaining uncertainty might have resulted from a lack of experience [83] or a lack of contextualisation, i.e., information concerning the learning group. The PSTs in this study planned “for teaching a particular topic in a particular way for a particular purpose [...] for enhanced student outcomes” [57] (p. 36), but they did not plan for “particular students” as an authentic planning situation would require. Since PSTs’ lack of experience is an immutable condition [83], there might be demand for broader contextualisation. However, broader contextualisation might lead to cognitive overload, as such extensive information requires additional linkages with respect to planning decisions. The more information that needs to be processed during planning, the greater the risk that teachers will be overwhelmed [38]. Therefore, one interpretation might be that material-based planning in university courses, not despite a lack of contextualisation but because of a minimisation of contextualisation in combination with appropriate materials, offers a promising opportunity to stimulate and examine PSTs’ planning skills in sequencing and integrating visible and deep learning structures.

4.2. PSTs’ Difficulties with Using Visible and Deep Structures

Despite the potential of material-based planning to stimulate thinking with respect to the core dimensions, difficulties in planning have been confirmed and broadly addressed in the literature [7,15,22,24,30–32,40]. Nevertheless, individual analysis of the use of visible and deep structures shows that there are more balanced than imbalanced cases (11:3, see Figure 9). Particularly grave problems can be seen in the imbalanced cases, e.g.,

the exclusive planning of visible structures that have no connection to the learning goals of the lesson (P2) or the exclusive consideration of deep structures without the development of a lesson plan (P1). However, even in balanced cases, difficulties could be identified. Consequently, the balanced use of deep and visible structures can be used as a rough analysis criterion but requires more in-depth analyses to enable reliable quality statements. Thus, all PSTs had difficulty sequencing visible structures purposefully to achieve learning progression (e.g., [30]) and creating student-activating, inquiry-based visible structures in relation to deep structures [64,67]. These difficulties first became apparent in the lack of any integration of core dimensions, and they remained noticeable in situations featuring the secondary dimension of “overload”. One reason for these difficulties might be a lack of content knowledge [32]. In line with that possibility, P1 noted that he did not know the topic of photosynthesis well enough to be able to select material. The “problem of insufficient CK” was also reported in a study on the influence of content knowledge on pedagogical content knowledge in the context of teaching photosynthesis conducted by Käpylä et al. [32] (p. 1406). Another reason for these difficulties might be PSTs’ lack of experience processing relevant information for lesson planning [83]. These difficulties due to a lack of knowledge and strategies might lead to a focus on simpler, more generic decisions and an avoidance of complex, in-depth analysis for making subject-specific decisions [1]. Such a focus on generic decisions, in turn, might lead to difficulties in sequencing learning steps to achieve learning progression, as in-depth analysis of subject-specific decisions is a prerequisite for such a task.

Other authors attribute the failure to plan challenging cognitive inquiry-based activities to a lack of knowledge regarding inquiry-based teaching or the nature of science [60]. Likewise, PSTs’ orientations and beliefs with respect to the nature of science or student learning (e.g., transmissive orientations or conflation of hands-on activities and inquiry-based learning) could lead to less student-activating lesson plans [56,84]. Both could also be possible reasons for the failure to include cognitively activating inquiry-based activities in lesson planning in this study.

In summary, material-based planning activates thinking with respect to core planning dimensions, but even with the balanced use of visible and deep structures, longstanding difficulties persist for PSTs. This suggests that the planning of inquiry-based learning needs to be supported by specific planning strategies in addition to appropriate learning materials.

4.3. Topic-Specific Characteristics in Material-Based Planning

Overall, the proportions of both visible and deep structures and that of the topic structure were similar for the digestion and photosynthesis groups (see Figure 5). However, taking this proportion into account for each PST, differences in the range of ratios found between the topic groups begin to emerge. For topic group D, the ratio of visible to deep structures was rather balanced for all of the participants. In topic group P, this ratio was balanced only for one PST (see Figure 9). Other participants in topic group P showed imbalanced use of visible and deep structures, which indicates that they experienced difficulties in planning for the topic of photosynthesis. Additionally, the analysis of certain aspects of visible structures shows that considering methods and media as well as time management accounts for a larger proportion of planning for photosynthesis than planning for the topic of digestion (see Figure 6). This also indicates the higher complexity of the topic of photosynthesis, as favouring generic planning decisions could be a strategy to avoid complex, topic-specific decisions [1]. This possibility is confirmed by the findings that less subject-specific, inquiry-based actions/goals were planned for photosynthesis than for digestion and that less certain preconditions were coded for topic group P than for topic group D (see Figure 8). Focusing on the uncertainty of knowledge might also be a strategy to avoid complex planning decisions. The excuse that could be used is as follows: *If I don’t know students’ specific preconditions, I cannot plan*. Thus, some of the problems described could also result from difficulties inherent in the topic of photosynthesis, which

are thus independent of PSTs' prior states. Similarly, Forbes and Davis [85] and Forbes [84] demonstrated that there are "curriculum-dependent and curriculum-independent factors" that influence PSTs' planning of inquiry-based lessons.

One topic-dependent difference might be that designing inquiry-based phases for the topic of the light dependency of photosynthesis is more complex than designing inquiry-based phases for the topic of the degradation of starch to sugar by amylase. In preparing for each phase, complex scientific decisions must be made [49]. For the first lesson phase, a phenomenon must be selected [49]. While there are several phenomena that are relevant to the light dependency of photosynthesis (e.g., phototropism or vegetation in caves, see Table 1), there is obviously one most significant phenomenon in the degradation of starch to sugar by amylase (bread becomes sweet if you chew on it for a long time, see Table 1). Additionally, several elementary decisions must be made to choose experiments (see Table 1), including the following examples: Should photosynthesis-activity be measured by oxygen production or by starch production? Should photosynthesis be measured quantitatively or qualitatively? [71]. Therefore, the topic of photosynthesis seems to be more demanding, while in the case of planning for the topic of the degradation of starch to sugar by amylase, the decisions that must be made are less complex.

Another topic-dependent difference is that the topic of digestion is closer to students' lives [68,69]; see Table 1), thereby facilitating the planning of a learning path accessible to learners. Furthermore, the main concept of an interaction between structure and function (digestion) might be easier to grasp than the concept of energy (photosynthesis) [72]. Therefore, it is possible that PSTs were overwhelmed in planning for the topic of photosynthesis and therefore less confident, which might result in a focus on visible structures, difficulty with considering deep structures or a focus on less student-activating, non-inquiry-based actions [30,64].

Thus, it can be assumed that, in addition to idiosyncratic prerequisites [85,86] and the suitability of material [84], the choice of lesson topic has consequences for the potential of developing tasks when planning inquiry-based science lessons and is therefore a key area in the ability to optimise planning tasks.

4.4. *The Limitations of the Study*

The present study is an explorative study testing a rarely used but often requested method (think-aloud protocols for capturing planning processes) and a newly developed planning setting (material-based planning). The explorative nature of the study led to the decision to take a small sample of $n = 13$ PSTs and analyse the data in depth using a complex coding procedure and additional case analyses. In this way, detailed insights can be gained into the suitability of the method for capturing planning processes and the suitability of the planning setting for activating PSTs' thinking in core planning dimensions. The following limitations, therefore, are primarily suggestions for future research designs that can build on the findings of this study.

First, there were limitations that resulted from the intervention design. Each PST planned only one lesson on only one topic, so it cannot be conclusively proven whether differences in the use of planning dimensions are idiosyncratic or topic specific. To investigate this question, each PST would have to plan both topics to compare individual planning skills on different topics. This exercise was not carried out in this study because planning is a complex and strenuous process, especially for inexperienced teachers. Therefore, planning two topics in rapid succession might be overwhelming, and planning the second topic at a later time could include effects from the master's seminar in which the planning task was integrated. Second, this study compared only two topics and included a small number of participants ($N=13$) due to the explorative character. A greater number of participants and comparison with other topics would be desirable for future research. Third, there is no comparison between material-based planning and planning without materials. An experimental design could clarify whether the potential is inherent to the topics of

photosynthesis and digestion or related to the material base. This is a promising approach for future research to support the findings presented in this study.

Nevertheless, the careful selection of the inquiry-based topics of digestion and photosynthesis and the combination of quantitative and qualitative case analysis offer insight into PSTs' topic-specific planning skills. As such, conclusions can be drawn regarding the potential of both material-based planning and different topics for promoting planning skills in teacher education.

5. Conclusions and Implications for Teacher Education

Material-based planning is promising for PSTs, with the potential to initiate processes that substantially focus on core planning dimensions (the integration of both visible and deep structures and the topic structure). Thus, it can be assumed that material-based planning has an advantage over more open planning settings or the adaptation of curriculum material, in which students often focus on visual structures and neglect the analysis of instructional representations at the level of deep structures. These advantages must be tested in future experimental designs and analysed with regard to different phases of teacher education. In addition, the results of the study confirm students' difficulties in creating cognitively activating lesson plans by linking visible and deep structures. Given the lack of integrated deep structures and visible structures a further recommendation is to foster planning strategies such as integrating visible and deep structures more intensively in teacher education in terms of procedural knowledge about planning, as these central planning strategies cannot simply be developed through observation in internships. Therefore, strategies that are realised by experts need to be made explicit for PSTs, i.e., through cognitive modelling [87].

Further potential can be seen in the contextualisation of lesson planning. Although this study lacks contextualisation in a particular school or particular class with particular students, the setting approximates an exemplary planning situation for teachers and can be employed independent of hands-on training in theoretical academic courses. The lack of contextualisation might even be beneficial for this process. Therefore, one recommendation in university teacher training is to plan for learning groups without precise information about individual students in order to reduce complexity. However, this advantage should be tested in an experimental design in future research.

Furthermore, in this study the frequent use of the topic structure dimension highlights the need for students to deepen their understanding of the topic, confirming the common experience that planning processes in teacher education often fail due to a lack of CK [32,67]. Regardless of the planning setting, it could be recommended for teacher education that CK is deepened as part of the planning task. Janssen et al. [88], who develop topic-specific scaffolds for deepening CK in lesson planning, also recommend this.

Finally, this study suggests that the choice of topic is important for promoting planning skills. Not only are personal content knowledge and topic-specific pedagogical content knowledge critical, but so is the complexity of the topic. In this study, it is shown that PSTs have fewer difficulties with planning for the topic of starch degradation by amylase than with planning for the topic of light dependency in photosynthesis. This selection of suitable topics for planning tasks in teacher education is obviously important in general, but it is particularly relevant to the goal of supporting the planning of inquiry-based lessons. However, these insights into the topic-specificity of lesson planning gained in this exploratory study should be investigated in more detail in future research.

Author Contributions: Conceptualization, M.K.-S., and A.M.; methodology, M.K.-S., and A.M.; software, M.K.-S.; validation, M.K.-S. and A.M.; formal analysis, M.K.-S.; investigation, M.K.-S.; data curation, M.K.-S.; writing—original draft preparation, M.K.-S.; writing—review and editing, A.M.; visualization, M.K.-S.; supervision, M.K.-S. and A.M.; project administration, M.K.-S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Ethics Committee of the University of Hildesheim.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Data is unavailable due to privacy.

Acknowledgments: The authors thank the working group Biology Didactics of the University of Hildesheim for numerous discussions and suggestions.

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

Appendix A

Table A1. Categories of the core dimensions of visible and deep structures in the planning processes of PSTs in the context of material-based planning.

	Categories	Description	Example
Visible structure aspects	Time management	Thinking about time management, e.g., how long it takes students to read a text	"Then, spend 5 min writing down the mnemonic".
	Method and media	Thinking about methods and media, e.g., whether students should work alone or in groups	"First, they do an experiment with partner work".
	Students' actions		
	Inquiry-based	Actions in an inquiry-based learning setting such as developing a hypothesis or conducting and evaluating experiments	"Students mention hypotheses concerning why chewed crispbread becomes sweet". "Then, students conduct an experiment [...]"
	Non-inquiry-based	Actions in a non-inquiry-based learning setting such as writing down sentences to be memorised, reading texts, or watching films	"After that, the students read the text" "At the end, I would have the students fill in a cloze exercise".
	Teachers' actions	Thinking about what the teacher should do in class	"Then, I explain the model to the students"
	Other visible structures	Thinking about other visible structures, e.g., practicability, involvement, or teacher-student interaction	"And that is somehow set up next door in an extra room".
Deep structure aspects	Cognitive learning goal		
	Inquiry-based	Cognitive learning goals that are derived from an inquiry-based learning setting/inquiry-based action.	"If you do this experiment, students can find out that [the change in taste of the chewed crispbread] must be due to saliva, [...]"
	Non-inquiry-based	Cognitive learning goals that are derived from a non-inquiry-based learning setting/non-inquiry-based student actions or from undefined student actions.	This text is about specificity. And what we're aiming at when we're dealing with starch degradation is that we need a specific enzyme, amylase. Students read this text to find out about amylase".
	Potential of material for interpretation	Thinking about the potential of material for interpretation without planning implementation in class	"This material is good because it can be used to show that saliva contains certain enzymes".
	Students' prior content knowledge		
	Certain use	Certain use of knowledge regarding students' prior content knowledge pertaining to the topics of digestion or photosynthesis	[...] the lock-and-key principle, they have learned that before. It is a prerequisite; they have learned that before in the unit I planned.

Uncertain use	Uncertain use of knowledge regarding students' prior content knowledge pertaining to the topics of digestion or photosynthesis	Unfortunately, I don't know when nutrition will be taught and in what detail. And whether this [knowledge] is still present in the students.
Students' preconditions		
Certain use	Certain use of knowledge concerning general preconditions of students aside from content knowledge (e.g., reading ability, interest, or everyday knowledge)	Cutting with scissors is always nice too. Because it exercises motor skills a bit. Because I've already seen at school that there are children who can't even cut with scissors.
Uncertain use	Uncertain use of knowledge concerning general preconditions of students aside from content knowledge (e.g., reading ability, interest, or everyday knowledge)	Depending on how good the class is, you can watch the film twice or have the students write it down from memory. [I can't decide that without knowing the class]
Other deep structures	Thinking about other deep structures (e.g., motivation, complexity, or transparency)	"Then, the children have fun with it"

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