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Embracing Multidisciplinarity: Exploring Challenges and Identities of Teachers in the Subject Integrated Sciences

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Abstract

The multidisciplinary subject "integrated sciences" has become a prevalent approach to teaching science in German comprehensive schools as a combination of the traditional science subjects biology, chemistry and physics in the lower secondary level (grades 5-10). However, the existing teacher education system in Germany (during university and preparatory service phase) is structured around two individually chosen subjects. If at least one of their subjects is a science discipline, the teachers in comprehensive schools are expected to teach integrated science courses. As a result, it is common for teachers to find themselves teaching (partly) out-of-field of their expertise.
This study is based on semi-structured interviews involving n=15 teachers. The transcripts of the interviews are analyzed through qualitative content analysis. Using the framework of identity-research [1–4] the question as to whether teachers show a science-teacher identity versus e.g., specialist biology-teacher identity is discussed.

Keywords: *out-of-field-teaching, science teaching, teacher identity*

1. The multidisciplinary subject "integrated natural sciences" in Germany

A broad definition for the integrated teaching approach could be: "A knowledge view and curriculum approach that consciously applies methodology and language from more than one discipline to examine a central theme, issue, problem, topic, or experience" [5]. An example of an integrated approach in natural science teaching could e.g. be the context of bats and wind energy plants leading to the content of biology of bats, physics of their echolocation and finally the conflict of interest between clean energy and conservation of nature [6].
There has been a long and varied history and in Germany about the idea of an integrated natural science subject [7] and the integrated approach to natural sciences in general with multiple arguments for and against [8], however, the debate is not yet sufficiently based on empirical evidence [9].
Reasons for an integrated approach include; integrated instruction in a constructivist sense leads to more meaningful connections of newly accumulated knowledge. It might provide learners with richer opportunities to establish connections between new insights and already existing knowledge. Regarding, for example global challenges it is argued that multidisciplinary approaches are necessary to describe the full scope of problems and to foster problem solving skills. Placing the instruction's topic within a (life-related, ethically challenging) context is believed to improve student interest [10] and studies show that enhanced context strategies yield big effect sizes for learning outcomes [11]. Furthermore, integrated instruction is hoped to foster a broader set of skills useful for the professional world like acquiring a tolerance for ambiguity.
Opponents rightfully reason that these benefits can be equally employed in the traditional approach. Nonetheless an argument can be made that such strategies might come more naturally in the integrated approach [12].
In Germany, science education for the lower secondary level in the traditional school type ("Gymnasium") is mostly separated into the three separated subjects of Biology, Chemistry and Physics and starts at grade 5. This distinction follows an integrated approach to natural and social sciences in one subject in elementary schools. Consequently, not all three disciplines might be taught at the same time and, more importantly, by the same teachers. The early separation of disciplines can lead to separate academic self-concepts [13]. In recent years, some federal states, school forms or even individual schools have chosen to teach science in an integrated manner, often with differing organisational structures [14,15]. The rising comprehensive school form ("Integrierte Gesamtschule"), which also leads to the general higher education entrance qualification, usually organizes science instruction using the integrated approach in one multidisciplinary subject "integrated natural sciences" (German "Naturwissenschaften"). For a detailed description of the German school system see e.g. [16] and for science education in Germany [17].
However, the existing teacher education system in Germany (during university studies and preparatory service phase) is structured around individual subjects, requiring teachers to specialize in

two subjects. With at least one being a science discipline they can become teachers for the integrated natural science subject in schools that offer this subject.

2. Out-of-field-teaching

The phenomenon of out-of-field teaching refers to a misalignment between a teachers' educational and disciplinary background (e.g. disciplines he or she studied in university) and his or hers teaching assignments in school (e.g. which subjects he or she teaches) [18]. The most commonly cited reason for out-of-field-teaching (OoFT) is a shortage of adequately qualified teachers across all or some subset of subjects or depending on the socioeconomic background of the school [19].

Out-of-field-teaching is not uncommon worldwide, however the reporting of such data is not uniformly available. A 2012 survey for Germany suggests that around 30% of teachers in the three science subjects in grade 9 are being classified as (partly) out-of-field [20]. The data also suggest that the likelihood of OoFT seemed to decrease both with higher grades and more rigorous and traditional school types. In the survey no distinction between science as one integrated subject or individual subjects was made. In other subjects such as languages the values were reported as being considerably lower around 15%.

In contrast to e.g. the subjects like mathematics taught by a teacher who did not study mathematics and therefor clearly being out-of-field the consideration is not quite as binary in the case of a multidisciplinary subject like integrated natural science in Germany. Teaching (partly) out-of-field within the sciences might refer to the overwhelming number of teachers who were not not educated for all three subjects of the natural sciences [21].

As a result, it is common for these teachers to find themselves teaching (partly) out-of-field of their expertise because they are not qualified for at least one of the disciplines and usually have no formation or experience in regards to the integrated approach. As a consequence, it can be said that integrated teaching leads to (partly) out-of-field teaching which in turn features multiple challenges for teachers. Challenges can be classified as deficits in the CK, PCK framework (CK; content knowledge, PCK; pedagogical content knowledge) [22] or problems with practical e.g. experimental manners [23] and various „tricks of the trade" [24]. A lack of CK is cited as the primary challenge, yet if they reach a certain level of CK they feel that lacking PCK inhibits them [4].

More broadly, teachers cite higher workloads as a result of more time needed to prepare [18,25]. More specifically, OoFT might hinder teachers' abilities to utilize students' errors to their learning benefit [24]. Mid- and long-term planning of lessons and the development and connection of ideas in the sense of constructivism is hampered, although in contrast and somewhat counterintuitively, some teachers feel that limited CK makes short term planning and teaching easier, perhaps because topics seem less broad, more enclosed and thus easier to grasp an teach when their own perspective differs only slightly from that of their students [24]. Cooperation with others is more important to teachers in OoFT situations [26].

The impact of OoFT on student achievement is certainly among the primary issues to be looked at regarding the phenomena of OoFT. Perhaps surprisingly, the evidence of expected negative impacts of OoFT on student achievement seems not as clear as one might expect [27]. However, this might be partly attributed to methodical differences of studies, different definitions, e.g. the multitude of ways teachers can be classified in or out of field by researches in different administrative educational systems. Overall, there still seems to be a consensus that the OoFT as a single factor negatively impacts students learning outcomes [28] and evidence would support this hypothesis when studies are carried out in a manner that accounts for various other factors such on the teacher, student and school level [27].

Teacher identity can be described as the answer to the question 'who am I as a teacher' and can be seen in light of different theoretical frameworks [2,29,30]. Research has shown that the professionalism of teachers should not be reduced to their knowledge and ability (i.e. focussing on CK and PCK), however, it should include what they think they are as their identity strongly influences how they teach and how they perceive their situation [31]. In the case of OoFT the distinction between seeing oneself as in versus out-of-field is important. Regarding the subject integrated natural sciences being or remaining a one discipline specialist teacher (e.g. a biology teacher) can be contrasted to a science teacher in the sense that he or she embraces the integrated subject even if it poses challenges.

3. Methods: Data collection and analysis

A total of 15 semi-structured, open guided-interviews with teachers in the German state of Lower Saxony were conducted per Video-conference. The duration was roughly half an hour (Mdn: 32:42 min; M: 33:20 min; SD: 8:49 min). Some biographical data concerning teachers' education and

professional experience was also collected via an online survey. Most (12) cases did complete a full teacher education consisting of university studies in education and teacher training. The remaining did for example not study education but rather a single science discipline and joined a preparatory service phase afterwards to become teachers. Surface features like subjects, gender, working experience seem reasonably balanced. Working experience ranges from newly hired teachers to department heads. Roughly half of the teachers taught at at least one other school type in the past before working at a comprehensive school. Natural sciences subjects also seem reasonably balanced with 8, 3, and 7 certified for teaching biology, chemistry and physics respectively. The subject combinations are dominated by mathematics (6) and include various languages (4) and other subjects like history, informatics and physical education. Four (4) teachers combine two natural science subjects.

The interviews were completely voluntary with no direct advantage for interviewee. An Interview-guide was used but the specific wording of questions varied according to the situation as interviewees answered freely. Seven main questions structured the interview as follows:

1 How did you become a teacher for the subject science?
2 Please describe what makes teaching science special for you? What do you spontaneously associate with teaching science?
3 I am particularly interested in your teaching practice in science; please describe how you plan and deliver a sequence on a topic with a content focus in an out-of-field subject?
4 Is there a typical way you approach the planning?
5 You could perhaps be said to be partly out-of-field to the subject of science; please describe if and how this is relevant to you.
6 How would you describe your self-image? Do you see yourself as a “science teacher"?
7 How would you evaluate the subject science overall or in general?

Main questions were accompanied by more detailed follow-up questions that guide the interviewee to specific aspects but giving them the opportunity to raise those certain aspects themselves first or in the order they feel is important.

An automated, local transcription using whisper [32] results in word-by-word transcriptions of the audio recordings followed by some manual cleaning (simplified transcription system based on [33] and anonymization of any revealing proper names. Qualitative content analysis is used to establish an inductive-deductive category system [34].

4. Results: Self-image of teachers

One central way to classify teachers in the integrated natural science subject is the extent to which they embrace the idea of an integrated approach and see themselves as science teachers in the context of that subject. That is not to say that they cannot and should not also embrace their respective specialty subjects when teaching them. Table 1 gives an overview of the distinction and tries to illustrate every case with one concise quote drawn from their interview that best represents their standing toward the integrated subject and its teaching.

Table 1: Concise quote representing teachers’ position towards teaching integrated science

	Concise quote (translated) of case
science teacher	"I'm a science teacher." "But if I go to a school where science is taught, I'm just the science teacher, not the physics teacher, and I would sell it that way accordingly." "If I were to introduce myself for grades 5-10, I would say I'm a science teacher." "At least as far as grade 10 things go, I would say, yeah, I do [see myself as a science teacher]. Seven years ago, eight years ago, I wasn't." "I'm a science teacher in grades five, six, and after that still just a biology teacher." "Science-teacher-in-training, despite having a degree, is how I would describe myself." "So in my role right now, absolutely."
specialist teacher	"I already see myself more as a specialist teacher in any case" "I still think of myself more as a biology teacher." "So I would say right now I would still consider myself a subject teacher for chemistry, but there's definitely an openness there for the transitions." "So I don't sort of identify as a NW teacher." "I'm still a physicist first and foremost." "I think of myself more as a biology teacher." "Actually at the moment I always say I studied computer science and physics but I'm at a integrated school and there's only science there so that's always what I

	have to say at the moment."
generalist	"I see myself as a teacher first."

Many teachers see a well versed multidisciplinary professional for the integrated subject as a development goal for themselves and show a potential to undertake steps to become such a person in the future, i.e. develop their identity in that direction. This is true both for some cases that can be classified in the science teacher category already as well as some that are presently seen as specialist. Some actively acknowledge that they undertook steps to become a science teacher. One case sees more general educational goals as a teacher overshadowing

Another category is whether the being a science teacher versus a specialist is static or situational. Some teachers actively change their own perceived role depending on the situation and the perceived expectations of e.g. students and parents.

In regards to challenges to prepare and perform OoFT with them some cases seem to approve that where CK is missing it is cited as the foremost challenge and once a certain level of CK is attained e.g. via self-study then limitations in PCK become apparent. Some cases also indicate that teachers might feel somewhat closer to their students' needs and understanding during some shorter OoFT situations, however, acknowledge that they struggle to connect ideas and concepts over a longer time frame as opposed to their specialty discipline.

Dealing with these challenges most cases cite schoolbooks and their faculty as go-to mechanism. Cases where the faculty is open to such exchange or actively organizes events for communication e.g. specialist for chemistry showing experiments to non-specialist seem to be most content and confident with their personal situation. Few cases, however, show that they feel themselves to be in a certain dilemma coping with the challenges in their OoFT.

Most cases stress that the structure of the teacher education they received did not adequately prepare them for situation in their classrooms and wish for attention to the integrated science subject during all phases of the teacher education, be it in university studies or as professional development (PD) programs later. This would be necessary to reach the full potential of the integrated approach.

5. Discussion & Outlook

Regardless of whether they are seen more as specialist or science teachers they acknowledge the need to intensify the discussion around OoFT in science. Results concerning challenges and strategies to cope with OoFT seem to align with past research [4,23,24,26].

As a first practical approach the University of Göttingen has established an opt-in additional certificate program of 16 ETCS (11 ETCS in case of 2 natural science disciplines regularly studied) addressing both CK and PCK of the science disciplines not studied regularly as well as a module aiming at the integrated teaching approach to science for its students studying at least one science subject and raising awareness for their potential role in OoFT [35]. Roughly 20% of students enrolled and successfully completed this non-mandatory program which seems like a success in light of the many requirements of studying and the multitude of other additional programs offered.

More broadly, strengthening faculty cooperation in schools and offering teachers PD-opportunities aimed at the specific demand of OoFT seems like useful measures that can be undertaken on the institutional level when changes on the policy level seem more challenging to attain [18].

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