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FALKE: Experiences From Transdisciplinary Educational Research by Fourteen Disciplines

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This article details how the FALKE research project (**F**achspezifische **L**ehrer**k**ompetenzen im **E**rkklären; Engl.: subject-specific teacher competency in explaining) integrates 14 heterogeneous disciplines in order to empirically examine the didactic quality of teacher explanations in eleven school subjects by bringing together trans-, multi-, and interdisciplinary perspectives. In order to illustrate the academic landscape of the FALKE project we briefly outline the nature of the transdisciplinary German “Fachdidaktiken” (Engl.: subject-matter didactics, i.e., special academic disciplines of teaching and learning specific school subjects). The FALKE project required the willingness of all researchers from eleven participating subject-matter didactics to rely on both the concepts and the methods of educational sciences as an overarching research framework (transdisciplinary aspect). All researchers of subject-matter didactics had to develop a shared conceptual, methodological, and administrative framework in order to empirically investigate commonalities in and differences between “good explanations” across the range of school subjects represented (multidisciplinary aspect). The additional perspectives of researchers in speech science and linguistics proved fruitful in recognizing rhetorical and linguistic aspects of teacher explanations (interdisciplinary aspect). Data management and statistical analysis were provided by the discipline methods of educational sciences. Rather than reporting empirical results, we here discuss opportunities and challenges as well as the lessons learned from the FALKE project regarding cognitive-epistemic reasoning, communication, and organization.

Keywords: transdisciplinarity, multidisciplinary, interdisciplinarity, subject-matter didactics, FALKE research project, explaining, teacher competence, pedagogical content knowledge

INTRODUCTION

In matters of learning and education, the question of what makes a good explanation has been pondered for centuries. In his *Didactica magna* (1657), Comenius (1967) was already asking what a good explanation was and how a teacher could explain well. Didactically appropriate explanations are at the heart of high-quality teaching and learning experiences in any subject. According to Gage (1968), explaining is a core aspect of a teacher's professional competence:

Explaining may come close to being the essence of instruction, so that when a teacher is attempting to explain proportionality to his geometry class or irony to his English class, he is behaving more purely as a teacher than when he is attempting, say, to motivate, promote discussion, or maintain discipline (p. 3).

When students are asked about the role of teacher competency in explaining, the empirical evidence is undisputed: based on a survey with more than 1,000 participants, Wragg and Wood (1984) reported that school students clearly considered explanation competency to be the most important skill of a teacher. A more recent study by Kulgemeyer and Peters (2016) demonstrates similar findings with regard to the subject of physics. But even though explaining has been demonstrated to play such a crucial role in teaching and learning in all instructional contexts, there is still a dearth of empirical research on this topic (Odora, 2014; Findeisen, 2017).

The question that really needs to be answered is which scientific discipline can best examine and analyze—theoretically and empirically—what a good explanation or act of explaining actually is, including its ultimate effect on learners. One could argue that educational psychology is the most appropriate research discipline for this task: it has both well-proven methodological tools (i.e., statistics and psychometrics) and a broad foundation of relevant conceptual models and empirical evidence. Ideally, these prerequisites can serve as a productive and reliable basis for general research on explaining. But in meta-studies, the greatest predictors seen thus far on effective teaching can be found in the domain-specific components of teaching (Seidel and Shavelson, 2007), and, in fact, the research community has acknowledged that the subject-related perspective is key to understanding teaching and learning. As early as the 1980s, in a comprehensive theoretical analysis much noticed by the international educational research community, Shulman (1986) had already pointed out the necessity of a stronger relationship between pedagogical processes and the content to be conveyed in research.

In their necessary simplification of the complexities of classroom teaching, investigators ignored one central aspect of classroom life: the subject matter. This omission also characterized most other research paradigms in the study of teaching. Occasionally, subject matter entered into the research as a context

variable—a control characteristic for subdividing data sets by content categories (e.g., “When teaching 5th grade mathematics, the following teacher behaviors were correlated with outcomes. When teaching 5th grade reading. . .”). But no one focused on the subject matter content itself [. . .] Why this sharp distinction between content and pedagogical process? (p. 6).

Over the last two decades, we have seen a substantial number of publications (especially on STEM education) answering Shulman's call for a closer look at subject matter in classroom-based teaching and learning processes. What is still missing, however, is a broader—or even joint—engagement in research on 1) teachers' professional competencies in teaching and 2) students' ensuing learning of subject-matter in all school disciplines. In recent years, even educational psychologists have been critical of the fact that empirical studies in this domain predominantly focus on mathematics and science and then generalize their findings to other school disciplines (Leutner et al., 2017; Praetorius et al., 2018). And one might well doubt whether such generalized statements really could apply to all school subjects. We rather need to ask ourselves—across disciplinary boundaries—which evidence and statements we might be able to generalize from one subject to others. Conversely, we need to consider when we should only look at teaching and learning through the lens of the specific subject, taking into account its highly complex content and domain-specific learning processes.

So, should the competency of explaining well be investigated exclusively within the corresponding subject-matter discipline? The mathematician determines what makes a good mathematical explanation for sine and cosine, the biologist how to explain evolution and the associated genetic changes, and the literary scholar how best to interpret texts or how to elaborate on the nature and function of Francis Underwood's infamous asides in *House of Cards*. Yet, is the academic subject-matter expert automatically an expert on teaching and learning, especially when not the academic but the school-related content of a discipline is considered?

Without a doubt, the only way to make a decision in each of those cases as to what makes a valid explanation of content requires discipline-specific knowledge. Following common sense, a *wrong* explanation (e.g., of why $1 + 1 = 3$) can never be a “good explanation.” However, it is also evident that not every valid explanation is, automatically, a high-quality explanation, for example, in terms of the learning gains of students. Therefore, One idea would be to bring the instructional knowledge of educational science (e.g., psychology, pedagogy, etc.) and expertise of the subject-matter disciplines (e.g., chemistry, English, geography, etc.) together. To this end, Kirschner et al. (2017) proposed an interdisciplinary cooperation between instructional designers and experts from the disciplines:

Assume that I, as a cognitive-psychologically based instructional designer, am designing a new learning environment in a particular subdomain of mathematics. I don't know if I need to have deep

conceptual understanding of the topics to be taught. But of course I will need to have someone working together with me who does have that deep conceptual knowledge. And, of course, I will need some basic knowledge of the (sub)domain in order to make sure that the communication and cooperation with my partner works well. (p. 642).

Kirschner et al. (2017) seem to assume that *interdisciplinarity* (for a distinction between interdisciplinarity, multidisciplinary, and transdisciplinarity, see below) is sufficient for successfully overcoming challenges in domain-specific teaching or explaining. Nevertheless, in our view, this approach to innovation overlooks the fact that the canon content of any school curriculum, and the corresponding understanding of how thoroughly this content should be taught, is subject to continuous change and negotiation (Kansanen, 2002). An academic discipline generates academic knowledge that is intended for the discussion that takes place within that highly specialized discipline. Which of these academic ideas should become part of the school curriculum and how learning from lower to higher levels of abstraction and complexity should take place is a question that scientific communities usually do not engage in (Abraham, 2019).

Educational psychologists possess general knowledge about teaching and learning and the relevant predictors of learning processes on the level of general constructs (such as cognitive activation of learners or classroom management, cf. Kunter et al., 2013). However, these principles have to be transferred to a school curriculum that has a variety of heterogeneous subjects and corresponding contents (Praetorius et al., 2020). Educational psychology tells us, for example, that a *clear structure* in an explanation helps students to gain a better understanding. To map this concept of clarity onto existing structures of teaching and learning specific subject matter, and particularly while keeping in mind real-life learners, is not as easy as it seems at first. Multiple layers of knowledge and expertise are needed to explain well the meaning of a word like “mansplaining” in a multilingual or multicultural class, or the process of creating a convincing argument in a written text, or the orchestration of instruments in a beginning brass band. What is more, which exact competencies should be acquired by school students in different subjects is an open question. Only the core literacies (e.g., reading, mathematics, science, etc.) in large-scale assessments like *Programme for International Student Assessment* (PISA) have been comprehensively defined and empirically validated (e.g., OECD, 2019). The complexity of these demands exceeds the potential of a solely interdisciplinary cooperation between experts in educational sciences and subject-matter research.

The science philosopher Mittelstrass (2011), too, sees interdisciplinary cooperation as not enough of a solution for complex problems (in FALKE: explaining subject-matter content) because in interdisciplinary research, the academic disciplines “contribute what they know, but they do not change themselves in their forms of knowledge or methodology” (p. 336). In order to find out how teachers can provide didactically good explanations, a *transdisciplinary* approach is indispensable. Mittelstrass sees transdisciplinarity

as a form of cooperation that will “lead to an enduring and systematic scientific order that will change the outlook of subject matters and disciplines. Transdisciplinarity is a form of scientific work which arises in cases concerning the solution of non-scientific problems” and “a principle of research and science, one which becomes operative wherever it is impossible to define or attempt to solve problems within the boundaries of subjects or disciplines” (p. 331).

Thus far, truly transdisciplinary research has flourished in areas such as public health science (e.g., Rosenfield, 1992; Turnbull et al., 2019), environmental research (e.g., Hoffmann et al., 2009), sustainability research (e.g., Schneidewind, 2010), nanotechnology or the quantum-mechanic measurement process and the concept of information (e.g., Pohl et al., 2008; Mittelstrass, 2011). Given the importance of school education (e.g., for the prosperity of societies; Woessmann, 2016), it is surprising that we are not yet looking at a similar wealth of transdisciplinary research on educational science and subject-matter didactics.

The characteristics of transdisciplinarity directly apply to the FALKE research program (for details see, e.g., **Figure 1**): finding out what makes up a good explanation in a school context is a non-scientific, real-world problem. Hence, one discipline cannot resolve it on its own. Its untangling is, rather, an endeavor that touches multiple disciplines: First, knowledge of the corresponding (academic) subject-matter discipline is needed to be able to decide on the validity of the explanation. Second, educational psychology provides valuable insights at a general level, for example on learners’ general cognitive development and information processing. Third, applied linguistics offers a sound understanding of the salient linguistic features of explanations (e.g., the recommended number of words per sentence, the limited use of relative clauses, or of the passive voice, etc.), and speech science might supply insights into embodied teacher performance (e.g., voice, body expression, etc.) and its effect on the learner’s perception. In addition, psychometrics can point to how to operationalize the addressed constructs (e.g., by questionnaires or tests), which experimental design has to be implemented, and which statistical analyses have to be conducted for answering specific research questions. What is still missing from this scenario, however, is the expertise and unifying force of subject-matter didactics.

TRANSDISCIPLINARY SUBJECT-MATTER DIDACTICS

Subject-matter didactics were the driving force behind the setting up of the FALKE research program. As subject-matter didactics is not an internationally known academic discipline, we will briefly explain its development and current purpose (also see middle column in **Figure 2**). The disciplines of subject-matter didactics can be found, for example, in many European universities (cf. Kansanen, 2002; Rothgangel and Vollmer, 2020). In Anglo-American countries, the adjective “didactic” has a negative connotation, suggesting oversimplified ideas of teaching and learning or “recipe-book instructions” on teaching methodology

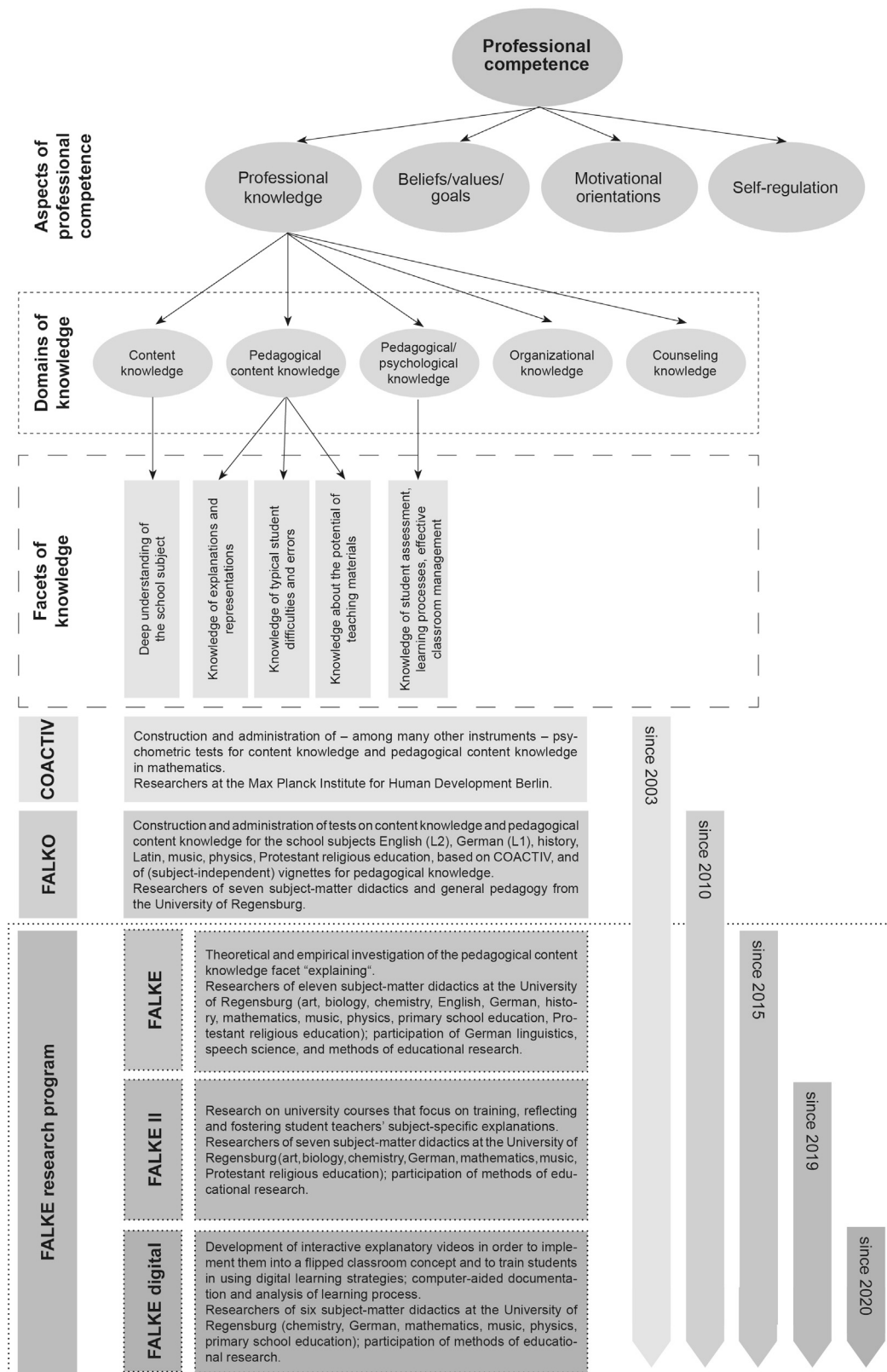
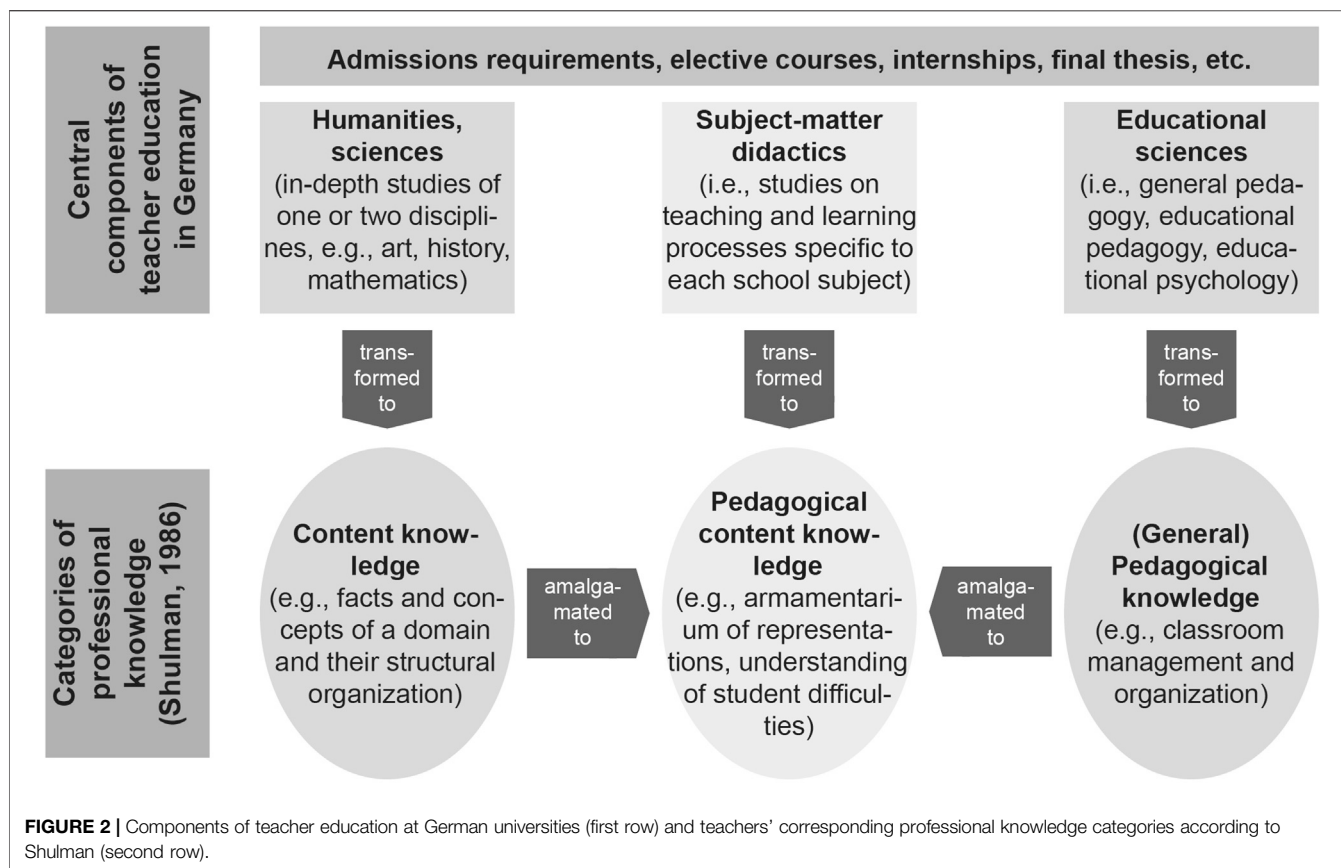


FIGURE 1 | The COACTIV model of teachers' professional competence, the preceding project FALKE (above) and the three projects of the FALKE research program (below) at the University of Regensburg.



(Arnold, 2012), which may carry over to the noun “didactics.” The idea of *didactics* originally stems “from the German tradition of theorizing classroom learning and teaching” (Arnold, 2012; p. 986). *Subject-matter didactics* disciplines (e.g., mathematics didactics, history didactics, music didactics) conceptualize teaching and learning as strongly situated in content.

Traditionally, the subject-matter didactics disciplines were asked to make normative decisions on the canon and to transform (academic) subject-matter content for (school-related) learning purposes. In German-speaking countries, professors of subject-matter didactics are therefore assigned for the most part to the faculties of the corresponding disciplines (e.g., biology didactics in the faculty of biology, etc.). As a result, the subject-matter didactics disciplines tend to connect strongly with the respective subject-matter discourse (left column in **Figure 2**). To a great extent, the logic of the corresponding subject frames the thinking and informs the research interests of the individual researchers in the corresponding subject-matter didactics.

Lately, a growing number of researchers in subject-matter didactics has begun to see their disciplines as an evidence-based science having the following objectives in mind (Leutner et al., 2017): First, seeking to develop theories and models and to formulate (verifiable) hypotheses about subject-specific teaching and learning phenomena and challenges. Second, addressing these subject-specific phenomena and challenges on an empirical level, for

instance by implementing quantitative correlational or experimental designs, or by following qualitative research paradigms such as conducting field-observations or interviews. Third, analyzing the data obtained and integrating the findings into the body of already existing evidence. Note that such attempts are not restricted to students’ subject-specific learning processes but in the same way apply, especially over the last decade, to the subject-specific professional competence of teachers and its development (for a teacher competence model, see **Figure 1**).

This opening toward an evidence-based approach—while simultaneously maintaining the logic and the framework of the corresponding subject-matter discipline—comes with an increased orientation toward and integration of the concepts and methods of educational science (right in **Figure 2**) that provide both an understanding of statistical methods as well as an awareness of general concepts on teaching and learning. In this sense, the field of subject-matter didactics—for those who are open to this path—must address transdisciplinarity on two levels: Beyond becoming more transdisciplinary as academic disciplines themselves, they should—also in line with Mittelstrass (2011), see above—not only reach out toward enduring cooperation with educational scientists but also with educators at schools as well as appropriate governmental officials.

So far, this level of transdisciplinarity (i.e., integration of and cooperation with educational psychology) is not

common practice for most researchers in subject-matter didactics, except perhaps for those working in subject areas that are often tested in large-scale assessments (e.g., PISA). Meanwhile, several researchers in mathematics didactics, science didactics, and the didactics of German language and literature engage on the mentioned levels of transdisciplinarity on a regular basis. In other subject-matter didactics like music, history, or geography, however, currently only a small number of researchers make use of this shifting paradigm. One reason for this discrepancy is that the latter subjects have not been in the focus of national or international large-scale assessments and, therefore, have never experienced the pressure to take on empirical research methods (see below). Furthermore, subject-matter didactics researchers traditionally follow a career path, where they are educated first in the respective subject matter (including its didactics) for being a future teacher but usually receive little training in empirical research methods.

Pedagogical Content Knowledge (PCK) as a Cornerstone in Subject-Matter Didactics

The field of subject-matter didactics increasingly sees teachers' professional competence (e.g., upper part of **Figure 1**) as the central hub for developing and maintaining quality in teaching and learning. Within his prominent taxonomy of teacher knowledge (also see lower part of **Figure 2**), Shulman (1986), in addition to the categories of *content knowledge* (CK) and *pedagogical knowledge* (PK), conceptualizes the concept of *pedagogical content knowledge* (PCK) as one decisive aspect of a teacher's professional knowledge:

Within the category of pedagogical content knowledge I include, for the most regularly taught topics in one's subject area, the most useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations—in a word, the ways of representing and formulating the subject that make it comprehensible to others. Since there are no single most powerful forms of representation, the teacher must have at hand a veritable armamentarium of alternative forms of representation, some of which derive from research whereas others originate in the wisdom of practice. Pedagogical content knowledge also includes an understanding of what makes the learning of specific topics easy or difficult: the conceptions and preconceptions that students of different ages and backgrounds bring with them to the learning of those most frequently taught topics and lessons. If those preconceptions are misconceptions, which they so often are, teachers need knowledge of the strategies most likely to be fruitful in reorganizing the understanding of learners, because those learners are unlikely to appear before them as blank slates. (p. 9–10)

In a theoretical review, Rothgangel and Vollmer (2020) remark that “Lee Shulman’s notion of ‘Pedagogical Content Knowledge’ (PCK) comes closest to the meaning of subject-matter didactics” (p. 129). According to Shulman, PCK can be considered an “amalgam” of CK and PK (Shulman, 1987; p. 8; also see **Figure 2**). Thus, a teacher’s PCK draws on knowledge repositories of subject-matter and pedagogy as well as psychology and transforms them into classroom performance. In German classes, for example, teachers need to combine their knowledge of youth literature and textual genres with insights into the reading process and their own diagnostic knowledge of individual children’s competencies. They should then use this basis to develop an instructional design for the effective teaching of reading, interpreting literary texts, and developing and sustaining reading motivation (Schilcher and Wild, 2018). Of course, by focusing on the concept of PCK, subject-matter didactics does not lose sight of other areas of teachers’ professional competence, like teachers’ beliefs and enthusiasm as well as their continuous professional development in communities of practice.

In the past years, Shulman’s idea of teachers’ PCK has been taken up as a central concept in empirical studies in subject-matter didactics. In the COACTIV study on mathematics teachers’ competencies (**Figure 1**), for instance, PCK tests were constructed including several items on how to explain mathematical content and how to deal with typical student difficulties. These scenarios were implemented in a paper-and-pencil format as well as in a test format based on short video vignettes (Krauss et al., 2020). It could be shown that the PCK of secondary mathematics teachers, especially as measured by the paper-and-pencil instrument, was—among many other modeled teacher competencies—by far the highest predictor for student achievement (Kunter et al., 2013). For an overview on corresponding psychometric knowledge test constructions on PCK in various other subjects than mathematics, for instance, Krauss et al. (2017, 2020) can be consulted. In the following, we focus on some aspects of PCK specific to 1) teacher education and 2) subject-matter didactics research.

PCK in Teacher Education

In 2000, the mediocre PISA results in mathematical literacy, science literacy and reading literacy of German 9th graders (Baumert et al., 2001) were a “shock,” not only for teachers and educational administrators but also for the general German society. Since these results were interpreted as an indication of a potential lack of quality in teacher education in many public and scientific debates, a broad discussion on a reform of teacher education followed—including the role of subject-matter didactics. Later this was fueled by Hattie’s (2009) slogan, “what teachers do matters.” To set compulsory standards, German educational policy makers established new standards of teacher education with an underlying model of teacher competencies (for further development see, e.g., KMK, 2019).

Ideally, teacher education should be regarded as a process of professionalization that integrates knowledge repositories rather than teaching them as isolated content. But the curricular structure of teacher education in various countries shows that CK and PK are most often taught separately even though within the same study program. Following, for instance, Kirschner et al.

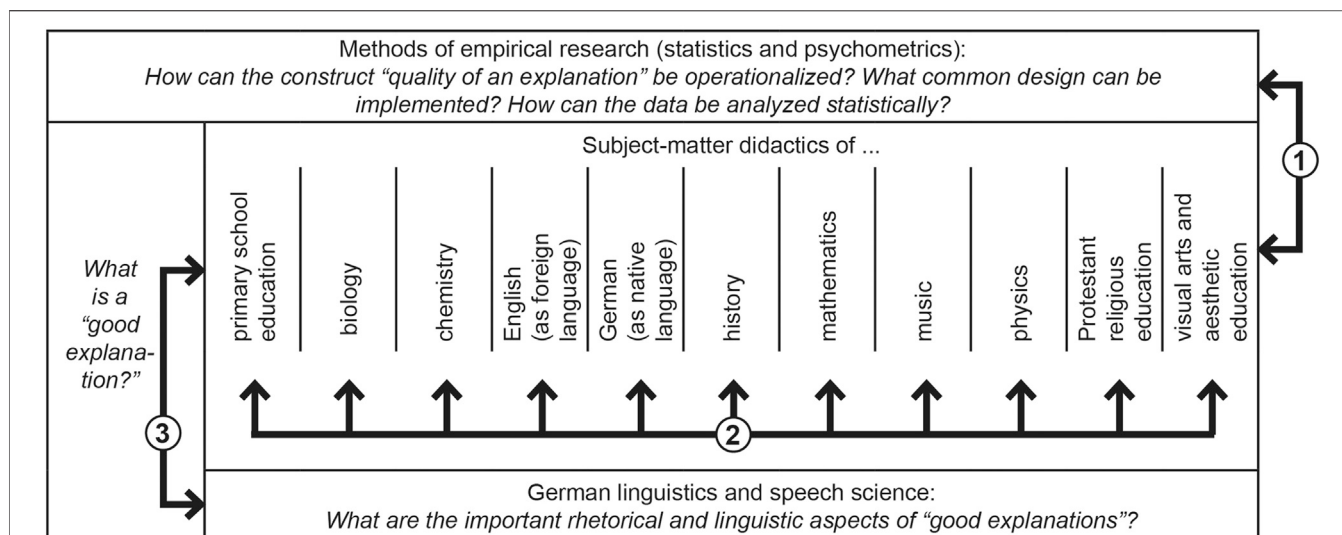


FIGURE 3 | Transdisciplinarity, multidisciplinary, and interdisciplinarity in the FALKE I project.

①: Transdisciplinarity: Experts in empirical research supported construct operationalizations, design development and data analyses (for both shared and subject-specific research questions).

②: Multidisciplinary: The research question (“What determines a ‘good explanation’ in the respective school subject?”) was analyzed domain-specifically (but with a common theoretical, conceptual and administrative framework) in eleven disciplines in parallel.

③: Interdisciplinarity: Both speech science and German linguistics contributed by considering rhetorical and linguistic aspects of explanations in all eleven subjects.

(2017), the underlying idea seems to be that this parallel teaching practice facilitates the implicit development of the “amalgam” of PCK in some miraculous way. Although subject-matter didactics in German teacher education programs includes pedagogy and psychology among its reference sciences—in addition to the respective content-related disciplines—corresponding teaching collaborations remain sparse. Even given the existence of institutionalized subject-matter didactics, the three columns (Figure 2) only rarely communicate with regard to teacher education. Worldwide, the subject-matter didactics disciplines have dedicated themselves to teaching subject-specific PCK in university teacher education (for other areas of subject-matter didactics see, for instance, Rothgangel and Vollmer, 2020).

The German Federal Ministry of Education and Research (Bundesministerium für Bildung und Forschung, 2014) announced in 2014 a program called *Qualitätsoffensive Lehrerbildung* (Engl.: Teacher Education Initiative) in order to promote collaboration in German teacher education among different areas of expertise. From 2015 to 2023, German federal and state governments provide funding for different university-based projects intended to improve the process of teacher education in a sustainable manner along three slightly varying funding lines. A key criterion for the allocation of funding is a better coordination of teacher education specialists across disciplinary boundaries (i.e., the three columns in Figure 2) that is also ideally evidence-based (for research issues, see next section). Each of the three subprojects of the FALKE research program (Figure 1) was funded by one of the three BMBF funding lines (altogether funding for 26 doctoral positions could be acquired across all three FALKE projects). In this





paper we especially discuss experiences in the first subproject of FALKE (Figure 3, Table 1).

Research on PCK

In the history of educational research on subject-matter teaching and learning, two pathways for theoretically and empirically investigating PCK, including its determinants and consequences, have unfolded. On the one pathway, educational psychologists, predominantly in Anglo-American countries, have become experts on subject-specific learning processes. So, for instance, psychologists like Stanovich (1991) and Schiefele et al. (2012) became experts on the development of reading, Graham and Harris (2005) and Hayes and Flower (1980) on the development of writing, and Hill and colleagues on mathematics education (Hill et al., 2005; Hill et al., 2008). As a result, some psychologists have contributed research that specializes particularly in the core literacies mentioned.

Yet, this trend has led to an increasing particularization of subject-matter domains, whereas “the capacity to think in disciplinarity, that is, in larger units of science, (is) decreasing” (Mittelstrass, 2011; p. 33). And while further particularization might work for highly domain-specific research, it may in fact be detrimental in teacher education (see previous section), where a general overview of the subject matter is just as important as in-depth knowledge. What is more, psychologists usually have neither a deep subject-matter knowledge that covers all fields of a certain school discipline (for instance, language teaching with a focus on literary history and youth literature, textual genres, film, media, linguistics, orthography, etc.) nor an understanding of their interdependencies (e.g., for promoting reading literacy).

TABLE 1 | Study design of FALKE.**FALKE I: 11 parallel online questionnaires (evaluation of 6 videos of teacher explanations per subject)**

<i>Evaluation of the same videos</i>	 Six videos at approx. three minutes	 Three selected and shortened video clips at approx. 30 seconds	 Six videos at approx. three minutes
Participants (status groups):	Holistic assessment (school grades from 1 to 6)	Criterion-based assessment (rating scale from 1 to 6)	Criterion-based assessment (rating scale from 1 to 6)
School Students Teacher Students Teachers Subject-matter didactics specialists	 Global judgement on the quality of the explanations shown in the videos	Items on speech and body expression as well as on personality of the explaining teacher	Items on structuredness, addressee orientation, linguistic comprehensibility and subject-specific quality aspects of the explanations

Moreover, the scope of pedagogical and psychological research often does not go beyond what is regarded as a key competency in education, namely reading, writing, mathematics, and foreign-language acquisition (mostly English as a second language) at a basic level. Consequently, classroom-based learning processes in music, art, religious education, and geography, for example, but also in advanced mathematics like integral calculus in the upper grades, have not received an appropriate share of research. In Kansanen's (2002) view, psychological research has not been able to develop the full scope of research on all school subjects and for real-life teaching and learning in all grades (see Kansanen on withdrawal, fractionation, and even irrelevance of research in educational psychology). Most importantly, he also emphasizes that educational psychology has focused on empirically examining learning rather than teaching which may explain the lack of research on teacher's professional competence at this time, especially regarding different school subjects.

In Germany, the "PISA shock" (see above) was a wake-up call for the subject-matter didactics disciplines to reconsider not only the content and quality of teacher education, but also their own research and publication habits. Around the turn of the millennium, there was too little empirically sound knowledge about subject-specific learning and teaching—despite a long-lasting, lively (but mostly only theoretical) discourse on subject-matter didactics. Since then, subject-matter didactics like German (as a first language), mathematics, the first foreign language (English or French), biology, chemistry, and physics that were repeatedly subject to rigorous standardized testing procedures (e.g., in large scale studies such as PISA, TIMSS, DESI, PIRLS, etc.) have managed to use external pressure to shift their research paradigms toward competence- and output-orientation, both based on empirically gathered evidence. In addition, we can observe a sharp increase in publications and international conference contributions at a competitive level, while empirical research in other subject-matter didactics has been much slower to take off (e.g., with regard to researching instructional quality, cf. Praetorius et al., 2018).

Furthermore, the PISA 2000 shock was the driving force behind the modelling of teachers' competencies and the empirical investigation of the impact of specific competence aspects on student learning ('predictive validity'). Thus, the COACTIV study on German mathematics teachers' competencies was undertaken as a satellite study of PISA 2003. One of its main findings that PCK is by far the strongest predictor of students' learning success (e.g., Kunter et al., 2013) was a particularly interesting result for researchers of subject-matter didactics. In the following, in Germany, a second pathway for examining teachers' professional competencies, specifically the concept of PCK, has developed in subject-matter didactics. For this purpose, PCK tests (each of these accompanied by corresponding CK and/or PK tests) were constructed in the following by many other subject-matter didactics (e.g., the German projects FALKE, ProwiN, TEDS or KiL / KeiLa). Comparatively little research has been published in the Anglo-American world on the construction and validation of psychometric tests of teacher knowledge categories such as PCK, CK or PK (cf. Krauss et al., 2020). In the next section we outline the first FALKE-study that focuses on subject-specific explaining, which is—according to Shulman (1986)—a crucial facet of PCK.

THE FALKE STUDY

Development and Outline

The FALKE I research group (Fachspezifische Lehrerkompetenzen im Erklären; English: Subject-specific teacher competency in explaining) is, to our knowledge, the only educational research project that integrates 14 heterogeneous scientific disciplines (Figure 3). In this group, trans-, multi-, and interdisciplinary perspectives are coordinated and orchestrated in order to gain a broad understanding of the act of explaining, its corresponding characteristics, and the effect of (oral) teacher explanations given to school students in the classroom.

The project is positioned in a line of research that started with the German COACTIV study on multiple teacher competencies (**Figure 1** for the history of the FALKE research program). COACTIV was followed by the FALKE project (beginning in 2010), in which six subject-matter didactics disciplines at the University of Regensburg constructed and validated domain-specific knowledge tests on PCK and CK in line with the corresponding tests for mathematics teachers in the COACTIV study. In FALKE the subject-matter didactics of English (as a foreign language), German (as a native language), Latin, physics, Protestant religion, music, and history were involved (Krauss et al., 2017). Finally, the three FALKE projects at the University of Regensburg (FALKE I, FALKE II and FALKE digital, conducted under the three funding lines of the BMBF as mentioned above) followed the overarching concepts of the previously mentioned studies.

In the remainder of the paper, the rationale for, the administration of, and the experiences surrounding the first FALKE project are reported (the authors were researchers under the first funding line, which is why this project is also called “FALKE I”).

The aim of FALKE was to empirically examine the didactic quality of teacher explanations in eleven school subjects in parallel. Among the 14 participating disciplines at the University of Regensburg were 11 subject-matter didactics, namely of biology, chemistry, German as a native language, English as a foreign language (TEFL), Protestant religious education, history, mathematics, physics, primary school education, music education, and visual arts and aesthetic education.

Two other relevant disciplines participated with their expertise, speech science and German linguistics. In addition, specialists on research methodology in educational sciences made a substantial contribution to the project (**Figure 3**). One senior and one junior researcher from each discipline were active members of the group. In all, 13 out of the 14 junior researchers were funded by the BMBF (for details, see above).

At the very start, a common conceptual, methodological, and administrative research framework was developed to create the opportunity to generalize results across the eleven school disciplines (see **Table 1** for the design of FALKE). This design also allowed for identifying commonalities and differences of teacher explanations among the different subjects.

Within this framework, each of the 11 subject-matter didactics produced six video vignettes. Each of those vignettes shows a short, classroom-situated explanation by a teacher to a class that is topically salient for the respective subject. For example, the vignettes for English as a foreign language focused on explicit explanations of vocabulary meaning and morphology. In the music education videos, the teacher concentrated on the use of visual or acoustic forms of representation by explaining elementary issues of music theory.

The video vignettes were embedded in an online questionnaire (resulting in eleven instruments differing with respect to the specific videos) that asked for the perceived structuredness, addressee orientation, linguistic comprehensibility, and speech and body expression in each of the explanations (cf. **Table 1**). These constructs were operationalized—for all participating subjects in parallel—by several closed items each. In addition,

each video was followed by some subject-specific items (which, of course, also differed between subjects).

In the empirical study, participants from four different relevant “status” groups (i.e., students from school, pre-service teachers at university, in-service teachers, and subject-matter didactics researchers) rated the didactical quality in the filmed explanations, holistically first (by giving an overall rating using school grades, i.e., without any suggestions by listed criteria) and then—after seeing the video vignettes again—based on closed items representing the implemented criteria.

The uniform research design (**Table 1**) makes it possible to use classical quantitative analysis methods such as variance analyses or linear regressions to examine group mean differences and relationships between features in each individual subject (e.g., to find out which of the criteria implemented have a particularly strong influence on the perceived overall quality of the explanation; for first results, see Lindl et al., 2019). As this study is based on an extensive overall sample consisting of four subsamples for each school subject (**Table 1**, altogether $N = 3,116$ participants evaluated the videos), it is necessary to consider the individual school subject as a higher level variable in multilevel models and (latent) structural equation models. Only such meta-analytical transdisciplinary approaches allow for the estimation of commonalities and differences between the individual subjects (e.g., via random effects) that can be checked for significance. In a final step, these approaches enable a transdisciplinary generalization of subject-specific findings. Further statistical methods that are especially appropriate for inter- and transdisciplinary educational research (with an exemplary focus on FALKE) are presented and discussed in the same issue of *Frontiers in Education* in Lindl et al. (2020).

Trans-, Multi-, and Interdisciplinary Research in Action

What makes the FALKE project unique is the orchestration of research approaches in trans-, multi-, and interdisciplinary fashion under a common conceptual, methodological, and administrative umbrella that has clearly defined processes, instruments, and procedures of analysis.

The cooperation of the 11 subject-matter didactics with the department of statistics and educational measurement was transdisciplinary in nature (①: first row in **Figure 3**). According to Mittelstrass (2011), this collaboration reorients the participating subject-matter didactics toward an evidence-based positioning that will probably remain in place after FALKE concludes. Underlying this cooperation was the original motivation of addressing a real-world problem: explaining subject-matter.

We call the collaboration of the 11 subject-matter didactics disciplines *multidisciplinary* (②: middle row in **Figure 3**) because all of the subjects implemented the same research paradigm and tried to answer the same questions in parallel. The conceptual framework, study design, and research questions had to be inclusive enough to integrate the characteristics of the individual subject-matter didactics, at least to a certain extent, while at the same time maintaining a minimum level of standardization across subjects in order to arrive at

comparable results. This parallel procedure of 11 disciplines guarantees a higher validity in generalizing the results across a range of school subjects.

The collaboration of the subject-matter didactics disciplines with speech science and German linguistics was interdisciplinary by nature (③: last row in **Figure 3**) because no discipline transformed itself. Just for the FALKE project, the aspects of adequate language, voice, speech, and body expression were added for short-term cooperation.

Lessons Learned: How can more than 20 Scientists Solve a Problem Together?

The final integration of the 11 obtained subject-specific data sets into one comprehensive data set allows for drawing overarching conclusions about which explanations are perceived as good across school subjects and pertinent status groups. In addition to the forthcoming publications of dissertations and journal articles by the junior researchers from each of the subjects involved, the results of the individual subject-matter didactics as well as overall meta-analyses will be summarized in a compendium (Schilcher et al., 2021). Managing researchers in eleven closely collaborating subject-matter didactics disciplines including the fact that all had to gain an understanding of the research traditions, salient questions, and approaches coming from the other research domains was at the same time a challenge and an achievement.

Over the course of the project, each participating discipline had to follow the research plan that had been agreed upon. Sometimes this meant that cherished and certainly valuable subject-dependent presuppositions had to be suspended (or even ultimately questioned) during the study. For example, as far as teaching English as a foreign language is concerned, the strong focus on teacher-centered explanations runs contrary to the central methodological paradigm of communicative language teaching. In other subject-matter didactics, the predominant theoretical paradigm is based on constructivist learning theory, which is itself based on student-centered discovery learning. In practical teaching, however, teacher explanations play a central role (Wragg and Wood, 1984; Scheffel, 2019). Thus, for FALKE, it was first necessary to work out what place teacher explanations on, for example, concepts, experiments or arguments, would find in theories on student-centered instruction.

In such a large project, however, issues other than answering the research questions can arise. Bergmann et al. (2005) define a number of problems that have to be mastered in any transdisciplinary project on three interwoven levels: the organizational level, the cognitive-epistemic level, and the communicative-psychological level. Finally, we will briefly address these issues with respect to the FALKE project.

Issues of Organization

The biggest challenge of large collaborative projects is to establish and maintain a culture of participation within an organizational infrastructure that channels trans-, multi-, and interdisciplinary

development. Such a reliable network of communication should, at the same time, inspire and focus the development of the research project without losing track of the original objectives, as well as the ever-present restraints of time and funding. Naturally, there is a high danger of missing valuable contributions along the way.

A fixed structure for meetings, information exchange, and development of new ideas is a necessary precondition when working in large transdisciplinary groups. The larger the project, the more important a transparent organization of the project processes and agreements is. One of the most difficult tasks in such a project is informing all of the researchers at all times about all processes and involving all of them in the important decision-making processes. Whenever a task is distributed among several people, there is a high risk that information will not necessarily reach all of those involved. In the FALKE project, there was a clear structure of different group meetings: monthly meetings with the entire group and fortnightly meetings between project management and junior researchers.

The objective of the meetings involving the whole group was to set a decisive course, for example with regard to theoretical aspects (e.g., which theories are shared by all 11 subject-matter didactics?), the joint research questions, or the experimental design (①: first row in **Figure 3**). Additional meetings of smaller groups (mainly of subgroups of the doctoral students) were aimed at making progress in terms of content, such as achieving a common understanding of central concepts or discussing the definition and operationalization of the various facets of an explanation following a literature review (e.g., structuredness, addressee orientation, linguistic comprehensibility and subject-specific quality aspects of the explanations, etc.) (②: middle row in **Figure 3**). In addition, a common exchange platform for collecting secondary literature or recording work results or agreements was established. When selecting and constructing the video vignettes, the junior researchers cooperated closely with their respective supervisors (mainly working in pairs), since professional expertise in the subject was of decisive importance here (and thus a fourth kind of cooperation existed within each subject-matter didactics group between the doctoral student and his or her advisor).

On the organizational level, the common analytical framework, identifying relevant predictors (including agreement on their operationalizations at item level), and the (centralized) statistical analyses turned out to be most critical for the progress of the project. With those in place, the methodologists could guarantee the basis for common analyses and interpretation of the data for all disciplines while taking the commonalities and specificities of all of the subjects into account. Simultaneously, the junior researchers engaged in extensive training on empirical research methodology given in centrally organized lectures and workshops. Additionally, the project's experts in research methodology participated in whole-group presentations and discussions during the phase of analyzing the entire data set.

The last phase of the project was dedicated to producing a joint volume of the results to be published in addition to the individual dissertations (Schilcher et al., 2021). In this compendium, the

conceptual framework will be explicated by the project management team in an introductory chapter, and then the individual subject-specific chapters written in cooperation between senior and junior researchers will follow and be uniformly structured in order to allow easy comparisons between subjects. The book will close with a chapter on the overall results (including the meta-analyses) presented by FALKE's experts on statistical analysis.

To sum up, transdisciplinary projects often deal with complex issues where many different levels and problems have to be mastered. The exchange of information between the different working units is a central challenge. Even if minutes and information on results of discussions are provided reliably and on a regular basis, these cannot completely reflect the discussion processes. What is more, working in large groups can be cumbersome at times, and it is an ongoing challenge to keep up the momentum.

Cognitive-Epistemic Issues

On a cognitive-epistemic level, the focus of FALKE was the linking of different types of knowledge and competence repositories, from different disciplines as well as between academic and non-academic stakeholders (Bergmann et al., 2005). In FALKE, research domains that had embraced different epistemic traditions were involved in order to conduct joint research (Figure 3). First, each subject-matter didactics discipline had to clarify its position toward explicit teacher-centered explanations. While some publications and empirical research on explanations had already existed (e.g., in the natural sciences and mathematics), explicit teacher-centered explanations seem to play less of a role in other subject areas, both with respect to research concepts and in daily teaching and learning practices. The apparently universal formula, "Explanation leads to understanding," is only partially true with processes studied in a wider sense, for example in argumentation or regarding aesthetic as well as spiritual concepts and practices (see Baumert et al., 2001, for different modes of encountering the world—in German: "Modi der Weltbegegnung"—that are also differently reflected in the respective school subjects).

In FALKE, knowledge generated by pedagogy and psychology about learning and understanding in general (e.g., "cognitive activation," but also methodological concepts such as "operationalization of constructs" or psychometrical quality criteria) had to be discussed with regard to particular subjects and their respective concepts and had to be transferred to the research traditions of the individual subjects. Speech science presented their findings on the performative side of explanations, which in turn influenced the production of the video vignettes. The same is true regarding German linguistics (e.g., with respect to the length of sentences or the avoidance of complex, non-frequent words, etc.). With regard to research methodology, the measurability and operationalization of all general and subject-specific constructs had to be overseen. The cross-subject discourse, however, revealed an extremely fruitful effect of the project in the sense that subject-matter didactics disciplines with a longer history of empirical research helped

those from fields newer to evidence-based research practices, which in turn stimulated the former with fresh ideas. And teachers participating in pilot studies also functioned as collaborators by assessing the face validity of the selected contents regarding their relevance to daily teaching and learning practices. The same applies to the students from various schools who also commented on the videos during pilot studies of the different subjects.

Obviously, sharing expertise and adapting concepts is fundamental for a trans-, multi-, and interdisciplinary research project like FALKE. It has become impossible for any individual researcher or any academic discipline to apply and combine all of the research perspectives and knowledge repositories of varied subject-matter didactics, subject-matter knowledge, pedagogical and psychological knowledge, and the methodology of empirical educational research, as well as a practical understanding of teaching.

Even though the processes of teaching and learning come together in a complex event, that occurrence has often only been investigated through the lenses of a limited number of academic disciplines. But working teachers have always strived to combine these different repositories of knowledge in their practical work. As can be seen from a single component of the teaching process such as explanation, these individual perspectives of researchers from different disciplines already lead to a condensation of knowledge about teaching processes. Such amalgamated knowledge can be brought into teacher education more easily, a process that is further facilitated when that knowledge is based on empirical evidence accepted by all the participating disciplines.

Communicative-Psychological Issues

It is no surprise that project groups who work on the basis of shared interests and respect, mutual acceptance, openness and transparency, sympathy, commitment, equality, and a willingness to compromise have a good chance for success (Boehm, 2006). Boehm actually concludes that the quality of the personal relationship has a stronger influence on the strength of the group than do the structures or organization in place. She argues that difficulties of cooperation in interdisciplinary projects are therefore more likely to be rooted in problematic emotional relationships than in the differences between the disciplines (Boehm, 2006).

As already mentioned, the FALKE research program developed from the smaller FALKO group (Figure 1), whose members cooperated for many years and could, therefore, look back on a number of joint conference contributions and articles, and on a compendium jointly edited by all participating senior researchers in subject-matter didactics (Krauss et al., 2017). Last but not least, the FALKO group had many meetings both in formal and informal settings. The spirit of this group spread to most of the new members so that cooperation was mostly experienced as an enrichment for both the senior and the junior researchers. It only makes sense to work in a research network if you enjoy attending the meetings and respect the contributions of your colleagues. Overall, trans-, multi-, and interdisciplinary projects require a high degree of personal commitment and mutual tolerance. When individual researchers

who have not previously worked together join forces, those projects can entail risks because there is no relationship in place. Another advantage of FALKE was that the junior researchers were not completing doctorates in the same subject area and thus were not in direct competition with each other. Even though there was occasional friction in FALKE, the group remained stable until the end of the project, and most of its members will continue working together in a spirit of trust in the years to come, as is reflected in the ongoing projects FALKE II and FALKE digital (**Figure 1**, above).

CONCLUSION

A key learning outcome of FALKE I is that trans-, multi-, and interdisciplinary projects, in particular, are largely shaped by the nature of the problem, the scientists and stakeholders involved, and the institutional setting (Thompson Klein, 2008). As discussed, explaining is a complex process. It is also an essential component of a teacher's overall educational expertise (i.e., of his or her PCK). There is still little research being done on explaining, partly because different perspectives have to be considered in order to understand this process.

For FALKE, classroom-based teaching had to be investigated, and stakeholders (e.g., experienced teachers and subject-matter didactics specialists like teacher educators) had to be consulted to include their perspectives in an initial step. In the next step, key aspects of explaining needed to be conceptualized in a way in which both domain-specific and general constructs were addressed as a basis for operationalization (i.e., formulation of items that specify the construct). Then videos had to be produced (six per subject) that could be implemented in a computer-based online questionnaire (with items asking for overall and for criteria-based judgments on the didactical quality of the explanations shown). Next, pertinent populations had to be identified whose respective judgments would be of relevance in this context. Corresponding samples had to be recruited, and the study had to be administered. Finally, the data obtained had to be managed, analyzed, and discussed.

Each step of the research process was dependent on the group having reached the required level of knowledge in each field, but also on the group's mutual respect for each other's perspectives. Therefore, it must be considered that working in a transdisciplinary group puts the junior researchers under considerable pressure. This aspect of the work needs to be permanently on the minds of project leaders and subject-specific senior researchers with responsibility for the well-being of academic novices. Hence, to provide a collegial and non-competitive working atmosphere seems to be an essential criterion for long-term successful cooperation. To achieve this, roles must be clearly assigned and the focus of PhD dissertations should also allow for individual pathways to academic qualification.

On a practical, organizational level, project coordination is indispensable for moderating, bundling, and preparing the various decision-making processes for everyone. However, in FALKE, a flat hierarchy was established; for instance, the junior researchers could decide for themselves on the predictors that they wished to operationalize. An alternative would have been a more hierarchical organization with fixed

functional roles. It might have actually saved time and energy if more functional roles had been specified and the junior researchers had been less intensively involved in the research design process.

While for senior researchers project management is only one of many tasks, a project coordinator should be at least available to the project most of the time. The same applies to statistical analyses: even if a (small) number of researchers on subject-matter didactics worked with empirical methods already beforehand, the actual data management and the analysis of the overall data set is nevertheless a task that should be handled by one person.

Another lesson learned is that previous cooperation among the researchers on smaller projects leads to a basis of trust that minimizes organizational difficulties because direct communication channels and routines (and ideally even friendships) have already been established. In the follow-up projects FALKE II and FALKE digital (**Figure 1**), a number of the group's members opted to continue this type of research approach in related educational contexts.

In Germany, the establishment of university-based subject-matter didactics disciplines was a first important step toward integrating perspectives on classroom-based teaching and learning. Here, researchers have already built a networked repository of knowledge and research practices for providing evidence-based teaching and teacher education. Not least because the sheer number of international publications and novel insights has expanded enormously but also because we have gained a better grasp of the complexity of educational problems, we now need an overarching trans-, multi-, and interdisciplinary approach to researching subject-matter education. In well-established disciplines, transdisciplinary research projects are often common practice. In educational research and, what is more, in subject-matter didactics, we are only now seeing the beginning of this innovative research and novel opportunities to compete for the necessary funding.

The main advantages of this transdisciplinary approach are the development of a common theoretical framework and the extensive comparability of the results from each subject. We are convinced that the FALKE research program can serve as a noteworthy example for promoting this kind of transdisciplinary educational research. We feel that we were able to prove that it is possible for a group of researchers from eleven different subject-matter didactics—with the addition of researchers from German linguistics and speech science on the one hand and educational research methodology on the other—to meet at a common research starting point and thus contribute to our individual disciplines.

Looking at criteria to evaluate multi-, inter-, or transdisciplinary work (e.g., the degree to which new insights relate to prior disciplinary knowledge in the multiple disciplines involved, the sensible balance reached in weaving disciplinary perspectives together, or the effectiveness with which the integration of disciplines advances understanding and inquiry; Boix-Mansilla, 2006), we made substantial progress (Schilcher et al., 2021). Finally, transdisciplinary (educational) projects allow all researchers to experience the search for knowledge as the guiding and connecting principle of universities.

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All authors have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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