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Technical experiments in TVET: A comparative study with South African and German lecturers

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ABSTRACT

Experiments in scientific and engineering education promote understanding of theory, enable discovery-based learning and focus on the central ways of thinking and working of those disciplines. While there are expansive national and international findings on scientific experiments and their scholarly implementation, the barely differentiated knowledge regarding technical experiments remains limited. A research gap can also be observed in the scholarly implementation of technical experiments in technical and vocational education and training (TVET). This article addresses this gap within the context of educational cooperation between South Africa (ZA) and Germany (DE). It reports on an explorative comparative study, from an international perspective of educational research, with German and South African TVET lecturers (N = 20). The results present current challenges and potentials, provide insight into country-specific differences and similarities and exhibit a research need within technology education.

Keywords: Technical experiment, learning objectives, international cooperation in technical and vocational education and training (TVET), Germany, South Africa

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Introduction

Scientific and technical experiments in class can illustrate central ways of thinking and working in these disciplines (e.g. for science: Kircher et al., 2020; for engineering: Zinn, 2018). Across countries, experiments are employed as an educational method for obtaining knowledge (KMK, 2005; South African Curriculum and Assessment Policy Statements (CAPS)). In this way, experiments provide action-oriented learning opportunities that promote motivational and cognitive learning outcomes (Reiss et al., 2016; Schwippert et al., 2020) while enhancing retention performance and learning motivation (Füller, 1992; Killermann, 1996).

Although field-specific didactics distinguish between scientific and technical experiments (e.g. Zinn, 2026), this distinction has received little attention in vocational education practice (Rauner, 2024). The state of research confirms this: while there are numerous national and international studies on scientific experiments (for overviews, see: Arndt, 2016; Meier & Mayer, 2012; Murer, 2023), research on technical experiments remains limited. This gap exists even though experimentation is considered a characteristic method employed in technology education (Zinn, 2026) and can foster technological and engineering literacy (Brändle et al., 2024). Research gaps concerning technical experimentation encompass, among other aspects, the actual use of technical experiments in vocational education and the experimental competencies of teachers and students. Within the context of international cooperation, there is also interest in country-specific particularities regarding the implementation of experiments in classes at technical and vocational education and training (TVET) colleges.

This article addresses these research gaps through an explorative comparative study conducted with South African and German TVET lecturers (N = 20). The focus lies on generating systematically collected insights about lecturers' familiarity with technical experiments, their use in class and the associated learning objectives. In this research, the results of the study are assumed to:

- Generate a first impression of this largely unexplored topic;
- Yield insights that connect to existing national research gaps;
- Contribute to technology education research within the context of international vocational education and training (VET) cooperation;
- Identify new research desiderata for international teacher education research; and
- Offer points of reference for bilateral research and development projects of South Africa and Germany.

Following this introduction, the article outlines the theoretical background on international cooperation in vocational education and discusses the role of experiments in class. It then examines the current research status in the corresponding research field. Building on this foundation, the text describes the methodological approach of the empirical study, which is followed by the presentation of the study's results. The article closes with a summary of the central findings, a reflection on the limitations and a discussion of the results.

Theoretical background

International cooperation in vocational education and training

This study is situated within the context of international VET cooperation between Germany and South Africa, which is based on the German Federal Government's 2013 strategy for coordinated international VET cooperation (Deutscher Bundestag, 2013). Within this framework, international VET research has increased in importance, including the German–South African partnership because of, among others, its designation as a central action field in the German government's Africa Strategy, which anchors the systematic promotion of VET and VET research (BMBF, 2018). Despite initial research dating back to the 1990s (Stockmann, 1992), international VET research has long gone unnoticed (Gessler et al., 2021). Its renewed prominence since the 2010s is attributed to increased political attention and expanded research funding, although a substantial need for comparative and critically reflective international and intercultural VET research remains (Gessler et al., 2021). Such research should emphasise reciprocal learning and exchange along dimensions of similarity and difference in order both to foster cross-national understanding and support targeted development goals (Evans, 2020).

The selection of participating countries is grounded in substantive and research policy considerations. Germany's dual system is widely regarded as an international reference model for practice-oriented VET (Euler, 2013). South Africa, on the other hand, plays a key role in international VET cooperation owing to its extensive partnerships (BMBF, 2018). Both countries are linked through long-standing bilateral agreements concluded in 1996 (BMBF, 2023), with the current focus being on the professionalisation of South African TVET lecturers (GOVET, 2025). Comparing countries' observations reveals structural and substantive differences in teacher qualifications. Germany follows a structured three-phase model comprising universities, preparatory service and vocational schools (Tramm, 2003). After completing a five-year master's degree at university, candidates undergo a one-and-a-half-year traineeship. This traineeship involves collaboration with the State Institute for Teacher Education and Training and a designated TVET college. Candidates alternate between these two learning environments, gaining practical teaching experience at the TVET college and knowledge about teaching methods and subject-specific pedagogy at the state institute (BSPO, 2023/10. October 2023). However, South Africa has a more heterogeneous landscape (e.g. Zinn et al., 2019), where TVET lecturers often only hold academic or occupational qualifications, with pedagogical and didactic training frequently lacking (DHET, 2017).

In light of these differing professionalisation frameworks, the question arises whether distinct views on technical experiments in teaching are evident and how a bilateral German–South African comparison can generate impulses for research and practice in international VET cooperation. The study aims to identify similarities and differences without normative judgement, thereby deepening understanding of the conditions and potentials of teacher

education systems in an international perspective. Such insights emerge only through cross-national comparison and bilateral collaboration (Lauth et al., 2015).

Experiments in class

Experiments are a versatile teaching method that can motivate students, support discussion and learning, or serve as part of technical design and optimisation tasks (Zinn, 2018). Classroom experiments address cognitive, affective and psychomotor learning domains equally and contribute substantially to their attainment (Bruchmüller & Haug, 2001). In this way, a distinction is made between scientific and technical experiments. Technical experiments examine means–end relations to identify applicable solutions or dimensions (Zinn, 2018): for instance, the insulation-material experiment in the field of civil engineering from the AdUmint project focuses on finding the optimal insulation material for the roof of a residential building (Nell et al., 2023). Heating a small-scale wooden house creates a controlled testing environment. The independent variable consists of the different types of insulation materials applied to the roof, while temperature measurements are used to quantify the dependent variable, namely the heat loss through the rooftop. Scientific experiments, by contrast, aim to explain correlations and confirm laws of nature by proving a hypothesis through cause–effect relations (Rauner, 2024). In the context of the above example, a scientific experiment would focus on the specific thermal resistivity of the materials to identify a universal relationship between their chemical composition and their insulating properties. Consequently, the objectives of scientific and technical experiments diverge. Zinn (2018) identifies seven learning objectives linked to technical experimentation, including fostering *interest* in Science, Technology, Engineering and Mathematics (STEM), acquiring *subject knowledge* and *engineering-related ways of thinking and working*, improving *problem-solving*, reducing *misconceptions*, deepening understanding of the *nature of science and nature of technology*, and strengthening *academic language*.

The process of technical experimentation has been systematised repeatedly in subject-didactic literature (for overview, see: Walker, 2013, p. 31). A foundational model by Schmayl (1982) distinguishes three phases: *preparation*, *execution* and *evaluation*. This tripartite structure remains established but is viewed as a basic framework requiring further differentiation to capture the complexity of technical experimentation. Building on this, Pahl (2013) proposes a more detailed, six-phase model for technical experiments comprising *problem identification*, *clarification and formulation of hypothesis*, *planning*, *execution*, *evaluation* and, finally, *summary,* including transfer. Walker (2013) develops a similar six-phase model which differs mainly as regards the terminology employed. Zinn (2026) likewise outlines a process model for technical experiments comprising *preparation*, *planning*, *execution*, *evaluation* and *testing*.

Scholarly practice differentiates various forms of experimentation, each offering specific methodological possibilities and requirements (Girwidz, 2020). To systematise these forms, Girwidz (2020) classifies the scientific experiment along five aspects: *data collection*,

organisational structure, *teaching phase*, *use of equipment* and *mode of execution*. In relation to these findings from science education, Pahl (2013) adopts two of these dimensions and further specifies them for technical experiments. Therefore, the *use of equipment* is categorised according to the degree of representation, ranging from real-world and model-based to thought experiments. The *organisational structure* is classified by student involvement, spanning teacher demonstrations, partially participatory experiments and fully independent student experiments (Pahl, 2013, pp. 192–193). The remaining three dimensions have not yet been further specified for technical experiments. Pahl's expanded perspective reveals that, although scientific classifications are useful, they require adaptation to meet the specific demands of technical experimentation.

State of research

The empirical research on teaching and learning with engineering-related experiments in general education, especially in vocational technical education, is, based on the available data, limited. As outlined below, a few empirical studies exist that systematically examine the design, use and effects of technical experiments.

The survey by Pätzold et al. (2003) of predominant teaching methods in technical and vocational education showed that around 40% of the 170 participating lecturers at TVET colleges, covering commercial and technical disciplines in Germany, made use of experiments at least once a week. However, the study did not distinguish between scientific and technical experiments. Bleher's (2008) survey, with 211 teachers from secondary schools in south-west Germany, came to similar conclusions. The results showed that technical experiments tended to be used 'occasionally' to 'rarely', placing them at the lower end of the list of teaching methods employed (Bleher, 2008). The document analysis by Schray and Geißel (2016) likewise showed that technical experiments played a subordinate role regarding the methodical implementation of electrotechnical content in technology classes of lower secondary education.

Regarding the effectiveness of technical experiments, several studies show consistent results as outlined below. Bünning (2010) showed that instruction-based teaching in basic building and woodwork training led to no superior effects on the development of declarative knowledge, whereas lessons based on experiments led to significant gains in procedural knowledge. What is remarkable is how weak students were not disadvantaged but specifically supported in their competence development (Bünning, 2010). These findings are supported by Bünning and Jenewein (2008). Two sub-studies from construction engineering prove that action-oriented classes incorporating experiments are not only equal to directive forms of teaching regarding declarative knowledge but even exhibit positive tendencies. Moreover, experimentation sustainably promotes the acquisition of procedural knowledge, enabling independent reproduction, analysis and modification in technical processes. Results regarding the acquisition of problem-solving skills through technical experiments are not yet clear (Bünning & Jenewein, 2008). Walker (2013) likewise

confirms the importance of technical experiments for knowledge development. In a study with 358 students using a control-group design, he found significant learning gains using technical experiments in both declarative and procedural knowledge. Remarkably, this effect occurred regardless of the type of experiment, whether student-led, demonstrative or paper-based. The large effect sizes highlight the potential of engineering-related experiments for developing technical competence (Walker, 2013).

Regarding the phases of experimentation, Bruchmüller and Haug (2001) note that lecturers often prepare, or even predetermine, the initial phases, such as problem identification, formulation of hypothesis and experimental design. Consequently, students are primarily responsible for executing the experiment and integrating the findings into their existing knowledge (Bruchmüller & Haug, 2001). This approach reduces opportunities for independent planning and exploring, potentially limiting the development of deeper problem-solving and planning strategies. As far as design and implementation are concerned, findings by Bodemer et al. (2005) show that targeted instructional support during experimentation can improve learning success. This indicates that a balance between student autonomy and targeted instruction is didactically beneficial for complex technical experiments.

Based on the available data, the state of research regarding the use of experiments in class seems even more limited in southern Africa than it is in Europe. It remains unclear whether this is due to a lack of research focus, to deviating terminology like case studies, assignments, projects, portfolios, demonstrations and group work (Hassan & Wai, 2019) or to hands-on practical activities (Maeko & Makgato, 2014). However, these teaching methods are clearly distinguishable from technical experiments. In his interview-based study (N = 12) with South African physical science teachers, principals and curriculum advisors on key teaching methods in secondary physics education, Zenda (2017) shows that experiments are considered important, yet their implementation fails due to insufficient facilities and limited resources. Magadza and Mampane (2025) conducted a study on teaching methods used in engineering courses at TVET colleges in the province of Mpumalanga. In their study, experiments are neither mentioned in the theoretical examination of possible methods, nor in the empirical findings (Magadza & Mampane, 2025).

As '[t]echnology is interwoven with humans, from the birth of civilization' (Hallström, 2023, p. 348), so is technology education (Mason et al., 2025). The Standards for Technological and Engineering Literacy (STEL) define technology education as equipping students to understand the impact of technology on the environment, society and their personal lives. Additionally, they provide knowledge of technical products, systems and processes (ITEEA, 2020). Experiments are one way of learning about these concepts, as well as how these technologies are used and how they can enhance human capabilities (ITEEA, 2020). At an international level, empirical studies list a country's competitiveness, cybersecurity, business ease, political stability and level of economic development (e.g. developed, emerging or developing nations) as factors that can influence individual technical

experience and the acceptance and adoption of new technologies (El-Masri & Tarhini, 2017; Hooks et al., 2022; Im et al., 2011). These differences are often examined using models such as the Technology Acceptance Model (TAM) by Davis (1989) or the Unified Theory of Acceptance and Use of Technology (UTAUT) by Venkatesh et al. (2003), as do Martens et al. (2017) who evaluated the acceptance of mobile payments across Germany and South Africa. Their findings show no correlation between the intention to use new technology and the nationality of the German and South African participants; instead, it is mainly predicted by the perceived usefulness (Martens et al., 2017).

In summary, the literature shows that technical experiments in education play a relevant, though not dominant, role. The empirical findings as presented highlight their potential to support students gain insight and knowledge. It remains unclear which methodological competencies teachers possess and which objectives they associate with using technical experiments. Given the limited data on implementation conditions in TVET concerning the technical experiment, there is a need for systematic, descriptive and explanatory research from the lecturers' perspective. This study addresses this gap by conducting an exploratory comparative study, systematically presented in the following section.

Empirical investigation

Research objective and questions

The study's objective is to generate descriptive and explanatory knowledge regarding the current use of technical experiments in TVET colleges. The study itself focuses on TVET lecturers in Germany and South Africa and their perspective on incorporating technical experiments in class. The study also addresses the following research questions (RQ):

- (RQ1) What **knowledge** do South African and German TVET lecturers possess regarding technical experiments and their use in class?
- (RQ2) How do South African and German TVET lecturers **integrate** technical experiments into their class?
- (RQ3) What **objectives** do South African and German TVET lecturers pursue by using technical experiments in class?

Research design

Considering the current state of research and the lack of empirical evidence, the study adopts an exploratory design. Semi-structured individual interviews are employed, providing room for the participants' personal depictions and reflections while ensuring systematic data collection and comparability (Mayer, 2013). The interview guide is developed based on the theory presented and state of research, alongside RQ 1–3 (see Table 1). The guide enables analysis and comparison of individual interviews by providing a canonised framework, while simultaneously remaining open for detailed follow-up questions according to the

course of the conversation (Bortz & Döring, 2006). The interview guide is structured into four sections: (1) Use of experiments in class; (2) Knowledge of using experiments; (3) Technical experiments in contrast to scientific experiments; and (4) Acquisition of experimental competences.

- The first section, Use of experiments in class, explores how experiments are employed in educational settings. The interview questions address the frequency and purpose of using experiments, their didactic integration, underlying motivations, instructional contexts and intended learning objectives, alongside perceived benefits and challenges.
- The second section, Knowledge of using experiments, focuses on recording participants' theoretical knowledge. Questions cover definitions, structures, phases, and types of experiments and their differentiation.
- The third section examines distinctions between technical and scientific experiments. The aim is to understand whether, and how, lecturers differentiate these forms and where they see potential for incorporating technical experiments.
- The fourth section investigates which substantial, didactic and practical competences lecturers consider necessary for implementing technical experiments, and how, and where, they acquired these competences.

Table 1 presents a sample of guiding questions, including their allocation to the research questions (RQ1 – RQ3) and corresponding intentions.

Table 1
Research and guiding questions

Research question	Guiding question	Comment
RQ1: Knowledge of using experiments	*Please define the experiment (in general).*	The lecturers are asked to provide a known definition of the experiment or to provide their own definition.
RQ2: Class integration	*In what context do you use experiments in class?*	The lecturers are asked to name examples of experiments that they use and to describe the integration of these experiments into classroom teaching.
RQ3: Learning objectives	*Which objectives do/ could you pursue using experiments?*	The lecturers are asked to explain which learning objectives they pursue through the implementation of experiments or, if they do not use experiments, which learning objectives they consider pursuable.

Sample and implementation of the qualitative study

The method of theoretical case selection (Glaser & Strauss, 1999) is employed to obtain a random sample. Participants were selected according to the following criteria: (1) active service at a TVET college; (2) broad variation in teaching experience; (3) teaching in at least one of the four occupational fields of electrical engineering (EE), mechanical engineering (ME), construction engineering (CE) or computer science (CS); (4) participation of lecturers from Germany and South Africa. Following a qualitative logic, additional cases were included until the interviews no longer provided new insights and theoretical saturation was reached.

A total of N = 20 lecturers (m = 17; f = 3) were interviewed. The first data collection took place in South Africa between September and October 2024. N = 10 lecturers (m = 8; f = 2) from five South African provinces (Northern Cape = 3, Eastern Cape = 1, KwaZulu-Natal = 2, North West = 2, Limpopo = 2) participated. The participants' mean age was 35.9 years (SD = 3.21; MIN = 30; MAX = 41), with an average of 9.9 years (SD = 4.18; MIN = 3; MAX = 17) of teaching experience and 3.3 years (SD = 2.05; MIN = 0; MAX = 8) of industry experience. The second data collection took place in Germany from December 2024 to January 2025. Again, a total of N = 10 lecturers (m = 9; f = 1) from the federal state of Baden-Württemberg participated. Here, the mean age of the participants was 46.8 years (SD = 13.07; MIN = 27; MAX = 66), with an average of 14.5 years (SD = 11.17; MIN = 2; MAX = 32) of teaching experience and 5.15 years (SD = 5.48; MIN = 0; MAX = 19) of industry experience. Participation was voluntary and all personal data have been anonymised. Table 2 presents the random sample's statistical data, comparing both countries.

Table 2
Description of the sample

	Age in years			Years of teaching experience			Years of industry experience		
	Total	**ZA**	**DE**	**Total**	**ZA**	**DE**	**Total**	**ZA**	**DE**
$\bar{x}$	41.35	35.90	46.80	12.20	9.90	14.50	4.23	3.30	5.15
SD	10.96	3.21	13.07	8.74	4.18	11.17	4.24	2.05	5.48
MIN	27	30	27	2	3	2	0	0	0
MAX	66	41	66	32	17	32	19	8	19

Table 3 is an overview of the anonymised, occupation-specific characteristics of the participants, including years of teaching experience, highest educational qualification, teaching subjects and whether a vocational qualification had been completed.

Table 3
Profile of participating lecturers

No.	Country	Gender	Years of teaching	Highest qualification	Teaching subjects[1]	Vocational training
L01	ZA	m	11	National diploma	EE	Yes
L02	ZA	f	12	National diploma	EE, P	Yes
L03	ZA	m	8	National diploma	ME, P, M	Yes
L04	ZA	m	11	National diploma	EE	Yes
L05	ZA	f	17	National diploma	ME, M	Yes
L06	ZA	m	14	Bachelor's degree	ME, EE	Yes
L07	ZA	m	3	National diploma	EE, M	Yes
L08	ZA	m	11	National diploma	EE, P	Yes
L09	ZA	m	9	Bachelor's degree	EE, P, M	Yes
L10	ZA	m	3	Bachelor's degree	ME, EE, P, M	Yes
L11	DE	m	32	Master's degree	EE, CS	No
L12	DE	m	27	National diploma	EE	Yes
L13	DE	f	8	Bachelor's degree	EE, P, M	Yes
L14	DE	m	31	Master's degree	EE, CS	No
L15	DE	m	14	PhD	ME, EE	Yes
L16	DE	m	2	Master's degree	EE, D	No
L17	DE	m	13	Master's degree	CE, EBA	Yes
L18	DE	m	2	Master's degree	ME, P	No
L19	DE	m	14	Master's degree	EE	Yes
L20	DE	m	2	Master's degree	ME, P	No

All interviews were conducted by the authors during one-to-one sessions, with an average duration of M = 33:48 minutes (*SD* = 10:52; MIN = 16:45; MAX = 54:14). Each interview consisted of three steps: (1) signing the consent form; (2) completing the paper-based demographic questionnaire (based on TALIS) (Organisation for Economic Cooperation and Development (OECD), 2018); (3) conducting the oral interview. Since the study aims to capture participants' current knowledge (RQ1), no preparatory material is provided. The interviews in South Africa were conducted in English, while those in Germany were

1 *EE* Electrical Engineering, *ME* Mechanical Engineering, *CE* Civil Engineering, *CS* Computer Science, *P* Physics, *M* Mathematics, *D* German, *EBA* Economics and Business Administration.

undertaken in German. The conversation follows the interview guide; all documents (consent declaration, questionnaire, interview guide) are identical in English and German. The interviews were recorded using a voice recorder and transcribed later using f4 software (Version 7.0.6).

Data evaluation

The transcribed data were systematically evaluated according to the qualitative content analysis procedure outlined by Mayring (2022), using the MAXQDA software (version 18.2.4). The coding system encompasses deductive and inductive categories. While deductive categories enable structured, theory-guided analysis but limit openness, inductive categories counter this and increase sensitivity to the data (Bortz & Döring, 2006). After two researchers independently coded three transcripts, results were compared and discussed and the coding system was refined, especially regarding category boundaries. Following Berger (2015, p. 177), a final coding manual was developed, containing three categories with 17 subcategories (deductive: 5, inductive: 12) and their characteristics, definitions and anchor examples (see Table 4). Coding rules specified that no passages may be double-coded and that code overlaps are not permitted.

The category, *Knowledge* (addressing RQ1), was developed deductively and inductively and encompasses eight subcategories. The first subcategory, *Definition of the experiment*, is derived inductively and captures individual understandings of the term. *Phases of experimentation* is deductively derived from established models by Schmayl (1982) and Pahl (2013). Given the limited state of research in engineering education, *Classification of experiments* is adopted from science according to Girwidz (2020). This remains necessary until existing research gaps in technical experiments are closed. The participants' attempts to *differentiate between technical and scientific experiments* are inductively clustered. The subcategory, *Difference known*, consists of the dichotomous variables *yes* and *no*. *Competence acquisition* is again dichotomous, with the variables being *formal* and *informal*. *Experiments in own education* is developed deductively along relevant vocational fields (*EE*, *ME*, *CE*, *CS*), extended by the variables *other* and *none*. Finally, *Competencies of experimentation in teacher training* is coded inductively.

The category, *Integration* (addressing RQ2), is developed primarily inductively and includes eight subcategories concerning the embedding of experiments in educational contexts. *Use in class* is derived inductively and captures scenarios in which respondents employed experiments. *Examples* of experiments used in class is deduced along the vocational fields (*EE*, *ME*, *CE*, *CS*), plus *other*. The subcategory, *Implementation*, is inductively developed and includes differentiated statements on how experiments were carried out (e.g. duration, group size, materials, lecturers' role). When applicable, reasons for *No use* are coded inductively with the dichotomous variables *lack of time* and *other*. Inductively coded, *Advantages* and *Disadvantages* of experiments are based on the participants' subjective assessments, *Method selection* captures statements on how lecturers justify choosing a suitable experiment and

Curriculum integration documents lecturers' assessments of where the curriculum permits the use of technical experiments.

The category, *Learning objectives* (addressing RQ3), is developed deductively based on Zinn's (2018) categorisation, expanded by the category, *Other*. Table 4 presents an exemplary extract of the coding manual.

Table 4
Extract from the coding manual

Category	Subcategory	Characteristic	Definition	Anchoring example
Integration	Integration curriculum	Everywhere	Various possibilities to integrate technical experiments into the curriculum are mentioned.	'Basically, in all subject areas, in some more, in some less. … so one could do experiments everywhere.' (L19 par.: 36, translated)
		Partly	Some ways to integrate technical experiments into the curriculum are mentioned.	'… I'm teaching level 2 and 3. I think it will be only level 4.' (L05 par.: 58)
		Nowhere	No possibilities to integrate technical experiments into the curriculum are perceived.	'For the level that I'm currently teaching, unfortunately, there's none on their syllabus.' (L05 par.: 56)
		Subject-specific	Specific subjects, where technical experiments can be integrated, are named.	'Yes, in the area of strength of materials; I see that.' (L18 par.: 40, translated)
		School type	A school type, where technical experiments can be integrated, is named (e.g. NCV or NATED for South Africa or TG or AVdual for Germany).	'Where one could of course do something would be in the TG [technical secondary school] curriculum…' (L20 par.: 70, translated)

In total, 519 codes were assigned to the three categories and 17 subcategories. The intercoder reliability was computed in MAXQDA using Brennan and Prediger's (1981) kappa, yielding a value of 0.73, which indicates good agreement according to common interpretation guidelines (Rädiker & Kuckartz, 2019, p. 303).

Results

This section presents the results of the empirical study. To ensure a coherent progression from research objectives to findings and discussion, the structure follows RQ1 to RQ3. In each research question, results are systematically compared between South Africa and Germany. Selected quotes are presented with reference to the interviewee. The German quotes were translated as accurately as possible, in accordance with the statement, rather than being translated word for word.

Results of the category, Knowledge/RQ1 (256 codes)

A total of 60% (n = 6) of the surveyed South African lecturers and 30% (n = 3) of the German lecturers defined the experiment as a mere practical verification or implementation of previously learnt theory. Among individual South African participants (n = 4), four other definitions of the experiment are found: collection of information, problem-solving through trial and error, obtaining new knowledge and execution of psychomotor activities. The remaining seven German lecturers described experiments as measuring and comparing, visualising phenomenon using measuring instruments, observing initial and final states of a reaction, testing a hypothesis, live visualisation of physical and technological principles, proving a hypothesis by using components or transferring reality into the laboratory.

> To me an experiment, I would say, is … proving what you've learnt in class. (L06)

When asked about the *Phases of experimentation*, 11 lecturers (55%; ZA = 4; DE = 7) named the trilogy of *Preparation*, *Execution* and *Evaluation*, based on Schmayl (1982). Six lecturers (30%; ZA = 5; DE = 1) mentioned only one or two of these phases. The remaining three lecturers (15%; ZA = 2; DE = 1) failed to mention any phase or saw no need for such segmentation, as the following quote illustrates.

> Phases of experimentation … don't, I think, apply to me. I go into my little room, get what I need and present it. (L11, translated)

The frequencies shown in Table 5 are obtained if the statements are coded according to Pahl's (2013) six-phase model.

Table 5
Frequency of naming the phases of experimentation, with coding based on Pahl (2013)

Phases of experimentation	Named by ZA lecturer	Named by DE lecturer	Total named
Problem identification	3	3	6
Clarification and formulation of hypothesis	1	2	3
Planning the technical experiment	8	5	13
Executing the technical experiment	5	8	13
Evaluation of the experiment	1	4	5
Summary, including transfer and outlook	3	4	7

Nine lecturers (45%; ZA = 4; DE = 2) could name different classifications of experiments according to Girwidz (2020). Eight participants (40%; ZA = 5; DE = 3) did not know of the classifications, while three (15%; ZA = 1; DE = 2) classified experiments by topic and subject area or by the level of instructional guidance (open as opposed to structured). Almost half of all respondents (40% (8); ZA = 20% (2); DE = 60% (6)) indicated that they could not differentiate between scientific and technical experiments and had never heard of this distinction before.

> I can't say I know different types …, I just know an experiment. (L05)

> Well, I couldn't name the difference [between scientific and technical experiments] right now, what the differences are. (L15, translated)

The participants gained their experimental competencies at various stages of their professional careers. Only three German lecturers named university-based teacher education as a formal learning space. In contrast, formal training and continuing education for teachers were mentioned exclusively by four South African respondents. Vocational training (e.g. diesel mechanic) and academic studies (e.g. engineering) not related to teacher training programmes were mentioned eight times (ZA = 3; DE = 5). As informal learning spaces for developing skills to execute experiments with students, extracurricular work experience was mentioned seven times (ZA = 2; DE = 5) and everyday school practice six times (ZA = 1; DE = 5). Four participants (ZA = 2; DE = 2) never conducted experiments during their own post-school education. Regarding teacher training, 45% (9; ZA = 5; DE = 4) indicated not having been trained to conduct experiments with students, while 45% (9; ZA = 4; DE = 5) had been partly trained. Two lectures (10%; ZA = 1; DE = 1) indicated not having received any teacher training at all.

> Well, life experience, because I always try to carry out experiments that are as close to real life as possible. And the proper electrical engineering experiments I conduct, that's simply professional experience as an electrician or whatever. (L13, translated)

> No, I haven't been taught yet. What I did is I used my own knowledge [of] what I've learnt over the years and tried to … take some of the stuff that's in the book, for instance, and make an experiment out of that …. (L04)

Results of the category, Integration/RQ2 (223 codes)

To address the second research question, participants were asked about their use of technical experiments in school. Eight lecturers (40%; ZA = 5; DE = 3) reported using experiments in selected subjects (e.g. physics, metal technology and electronical engineering). Half (45%; 9; ZA = 3; DE = 6) of the lecturers used experiments to achieve specific objectives, such as introducing a problem or topic, illustrating basic principles or theory, or consolidating learning outcomes. Every sixth (15%; 3; ZA = 2; DE = 1) lecturer did not use experiments in class for three main reasons: because the syllabus did not include experiments, because there were no suitable technical experiments related to the teaching content and because there was no time. When asked where technical experiments could be integrated into the curriculum, five respondents (20%; ZA = 2; DE = 3) said they could be integrated *everywhere*, three (12%; ZA = 2; DE = 1) said they could be *partly* integrated, and one (4%; ZA = 1; DE = 0) said that they could be integrated *nowhere*. Eleven participants (44%; ZA = 5; DE = 6) referred to specific subjects (e.g. robotics, electronics, electrotechnology, electric machines, mechatronics, energy technology, strength of materials, control systems), while six (20%; ZA = 1; DE = 5) mentioned particular school types, for example three-year vocational college (*dreijähriges Berufskolleg*), technical college (*Fachschule für Technik*), technical secondary school (*Technisches Gymnasium*) and occupational programmes.

> In connection with the illustration of basic principles of technical system operations in class, experiments are used. (L17, translated)

> Basically, in all thematic areas – in some more, in some less. Here at the school, we place … great importance on the fundamentals, which is why more is done in that area, but, for example, one could also do experiments in other areas, that is, one could conduct experiments everywhere. (L19, translated)

According to the lecturers, experiments in vocational-technical education are conducted in classrooms, laboratories or workshops and are used in all three lesson stages. Regarding organisational structure, both student-centred and demonstration experiments are employed, with demonstrations being carried out either by the lecturer or with student participation. Student-led experiments are typically conducted in pairs or small groups. Ultimately, available time and materials largely determine the choice of organisational structure. While demonstration experiments are considered less time-consuming, student-led experiments are sometimes not feasible due to limited equipment. Consequently, opinions about the suitability of organisational structures vary considerably, as illustrated by the following quotes:

> They do it themselves. I actually do very little because … I can't really remember being in any way interested whenever someone was doing something up front. (L13, translated)

> I … rarely [include] student involvement because I've realised that it brings little benefit, since they also have additional lessons in the workshop … [where] they practise … separately. That's why I usually conduct the experiments myself. [This also avoids] any issues regarding safety concerns…. (L14, translated)

The selection of experiments was primarily guided by the current lesson topic and the defined learning objectives. Additional influencing factors included available resources, time constraints, group size and personal experience. Of the examples mentioned, 23 (66%) experiments can be assigned to the field of electrical engineering and three (8%) to mechanical engineering. Other experiments (9; 26%) originated from areas such as optics, thermodynamics, kinematics, first aid and firefighting. No examples were named related to the subject areas of construction engineering and computer science. The use of equipment ranged from self-made set-ups and everyday objects to videos, simulations, modular experiment kits, complete integrated systems, oscilloscopes connected to projectors and document cameras for visualising small experimental set-ups.

> …the decision is actually made mainly based on them [but] also based on the availability of the experiments. So, which ones, which resources are available to me? (L14, translated)

> Well, … I would bring a cup of coffee and milk and then the temperature would change because I have a thermometer in my glass. So, I would use that to show … [the students] that the temperature changes from that cold milk into the hot coffee and then it's equivalent at the end of the time. (L02)

Regarding the advantages of experiments, the learning effectiveness is emphasised 17 times (50%; ZA = 9; DE = 8) and the promotion of motivation and interest 12 times (35%; ZA = 1; DE = 4). Other advantages (15%; ZA = 1; DE = 4) are: linking theory and practice, understanding functionality, increasing clarity and 'just doing it, just trying things out and perhaps developing an appetite for the topic' (L19, translated). Reported disadvantages included the time required (41%; ZA = 4; DE = 9) and materials required (22%; ZA = 3; DE = 4). Additional challenges (25%; ZA = 3; DE = 5) included potential safety risks, technical problems and insufficient learning outcomes or limited suitability for different students' proficiency levels. Four participants (12%; ZA = 2; DE = 2) indicated that there were no disadvantages to using class experiments.

> Can there be a disadvantage? … I don't think there is a disadvantage [to] doing experiments or any practical [related to] a trade or [something similar]. … I only see [a] positive. (L04)

Results of the category: Learning objectives/RQ3 (40 codes)

To address the third research question, lecturers were asked about learning objectives associated with using experiments in class. The most frequently mentioned learning goal was the acquisition of *subject-specific knowledge* (33%; ZA = 5; DE = 8), followed by the development of *engineering-related ways of thinking and working* (30%; 12; ZA = 4; DE = 8). Other learning objectives, such as fostering *interest*, improving *problem-solving*, reducing *misconceptions* and strengthening *academic language* are named once or twice. Instead of linking learning objectives to the use of experiments, two lecturers considered them a 'means to an end' (L15, translated). No answer could be assigned to the category, *Nature of science and nature of technology*.

> [T]he experiments are … not directly linked to learning objectives but are rather like a … step in between to increase understanding and … to create an example situation, so that I can practically design an exercise which relates to the experiment. (L14, translated)

Summary, limitations and discussion

The study results are summarised below. In addition, its limitations are addressed and the entire work is discussed. In this way, similarities and differences relating to both countries are highlighted and implications for practice and research are outlined to reveal existing gaps in the professionalisation of TVET lecturers.

Summary

The central aim of this study was to generate exploratory and descriptive insights into the actual use of engineering-related experiments in vocational and technical education. Based on the individual findings, the three research questions can be briefly answered as follows:

- RQ1: The majority of South African and German TVET lecturers possess substantial knowledge regarding technical experiments, but this has been obtained mainly outside formal teacher training.
- RQ2: South African and German TVET lecturers primarily integrate experiments as a means to support learning and to foster motivation and interest. Although implementation is diverse, it depends largely on available resources (e.g. materials, personal experience) and institutional conditions (e.g. group size, time frame).
- RQ3: The learning objectives pursued by South African and German TVET lecturers through the use of technical experiments predominantly address *Subject-specific knowledge* and *Engineering-related ways of thinking and working*.

The cross-national comparison between the demographic data of the two participating countries reveals significant differences in the participants' professional profile (see Table 3). For instance, 70% of the South African participants do not have a university degree,

although all have completed formal vocational training. In contrast, 90% of the German participants hold a university degree, while only 50% have completed vocational training. This discrepancy is also reflected in the acquisition of experimental competences. Only three German lecturers mentioned university education and four South African lecturers formal in-service training as relevant learning contexts.

The cross-national comparison analysing the interview data reveals no significant differences between the two countries regarding knowledge, classroom implementation or contextual conditions. One possible explanation for this is that, despite their higher academic qualifications, German lecturers did not acquire specific competences for conducting technical experiments during their teacher training programmes. Consequently, the investigated categories can be considered as independent of systemic factors, thus enabling a combined analysis of the entire sample.

Future research could include a curriculum analysis to systematically identify the extent to which content related to technical experimentation is embedded in vocational teacher education. Another research consideration emerging from this exploratory comparison concerns the empirical validation of existing process and competence models for conducting technical experiments (for an overview, see the subsection, *Experiments in class*). The interview data indicate that the model proposed by Pahl (2013) is only partially reflected in the lecturers' statements.

Limitations

This exploratory comparative study has some limitations that must be considered when interpreting the results. In view of the small sample size, the transferability of the results to the entire teaching staff at TVETs is limited. Furthermore, the sample represents a positive selection, as only lecturers who volunteered to participate were included. This could mean that more committed lecturers, who are highly interested in learning methods concerning experiments, are represented, while sceptical or less-experienced lecturers remain under-represented. Additionally, the four subject areas, EE, ME, CE and CS, are not equally represented. A gender bias can also be observed. While 20% of the South African sample is female, this figure drops to 10% for the German sample. This unequal distribution does not reflect the actual ratio (Statistisches Bundesamt; DHET, 2017), which further limits the representativeness of the study's findings.

Discussion

The results regarding lecturers' knowledge (RQ1) show heterogeneous definitions of experiments, potentially owing to inconsistent definitions in literature and different subject-specific understandings (Philipp, 2013, pp. 16–18). The designation of the phases of experimentation aligned only partly with theoretical models by Schmayl (1982) and Pahl (2013), leaving it unclear whether discrepancies stem from limited knowledge or

divergent school practice. In total, 40% (8; ZA = 2; DE = 6) of participants could neither classify experiments nor distinguish between technical and scientific ones, while others failed to justify their responses with factual knowledge. The poor quality of explanations among those claiming to know the distinction further weakens cross-national differences. Not even half of the lecturers (35%; 7; ZA = 4; DE = 3) acquired knowledge of experiments through formal teacher training. The majority transferred their knowledge from other areas, such as their own vocational training. This indicates that systematic engagement with experiments is rarely incorporated into formal teacher training, resulting in inconsistent understandings of its definition, structure and pedagogical use. Zenda (2017) concludes in his South African study that further professional development is urgently required to strengthen lecturers' didactic and methodological competences, particularly regarding the effective implementation of teaching methods such as experimentation. Besides the named cross-national differences concerning the distinction between scientific and technical experiments, response patterns were largely comparable across both countries, thereby precluding country-specific conclusions.

Despite challenges such as lack of time, most lecturers (85%; 17) reported using experiments in class (RQ2). Besides lesson topics and intended learning objectives, external factors strongly influenced method selection, aligning with findings by Magadza and Mampane (2025). Consequently, the variations in implementation reflect the full range of approaches outlined by Girwidz (2020) and Pahl (2013), with additional perceived opportunities to integrate technical experiments throughout the curriculum. Differences arise in the rationale for organisational structure, where personal factors such as experience and convenience often outweigh pedagogical or didactic considerations. Regarding the frequency of naming exemplary experiments, it is noticeable that mainly electrical experiments are mentioned. Possible causes could be the subjects taught by the sample or the suitability of the subject for experimentation. The reported advantages of experiments closely mirror the four positive effects identified by Hartinger (2003), which are enhancement of understanding through visualisation, increasing motivation, fostering (scientific) reasoning and linking students' experiences to disciplinary methods. Cross-country comparison in the results of the second research question show that all German participants used experiments in class, whereas only 70% of South African lecturers did. The data provide no explanation for this disparity. The most frequent learning objectives associated with technical experiments (RQ3) are the acquisition of subject-specific knowledge (33%) and the development of engineering-related ways of thinking and working (28%), which aligns with previous studies (e.g. Karaböcek & Erb, 2014; Welzel et al., 1998). Rauner's (1975) observation that experiments are primarily used as instructional tools rather than to achieve learning outcomes is also reflected in participants' statements. The objective of fostering key competences through experiments (Bruchmüller & Haug, 2001) was not evident in this study's results.

In summary, the exploratory findings suggest that, while technical experiments are regarded as important by TVET lecturers, both structural (e.g. availability of material)

and individual barriers (e.g. insufficient professional training) limit their systematic use in vocational education. The results highlight the need to place greater emphasis on technical experimentation in teacher education. Expanding professional-development opportunities (e.g. see Van der Bijl & Taylor, 2018) and embedding experimentation more firmly in curricula could promote its sustainable integration into teaching and finally foster students' competence in conducting experiments.

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