

DILEMA-K - Digital life cycle and material development of lead-free piezoelectric and ferritic high-performance ceramics

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DILEMA-K aims to develop a holistic, data-driven digitization strategy covering the entire life cycle of functional ceramic materials, supported by a multi-level ontology, automated text and knowledge processing, ML models, and demonstrator applications – anchored in the MaterialDigital platform and designed for sustainable industrial applications in Germany. This is demonstrated by the examples of textured lead-free piezoceramics and multilayer ferrite components.

Objectives and innovations

Discovery and development of functional ceramics are still characterized by iterative systematic experimental procedures, see Fig. 1. These are all the more efficient and targeted the more empirical knowledge from various sources is incorporated. Traditional material theories and computer-aided numerical simulations provide little practical support. As a result, research into electroceramic materials is slow, costly, overlooks what has already been researched, and is highly dependent on experienced personnel.

We want to make it faster, more efficient and effective, based on all available prior knowledge, and less dependent on individuals, following the suggestions and demands of the 4th paradigm.

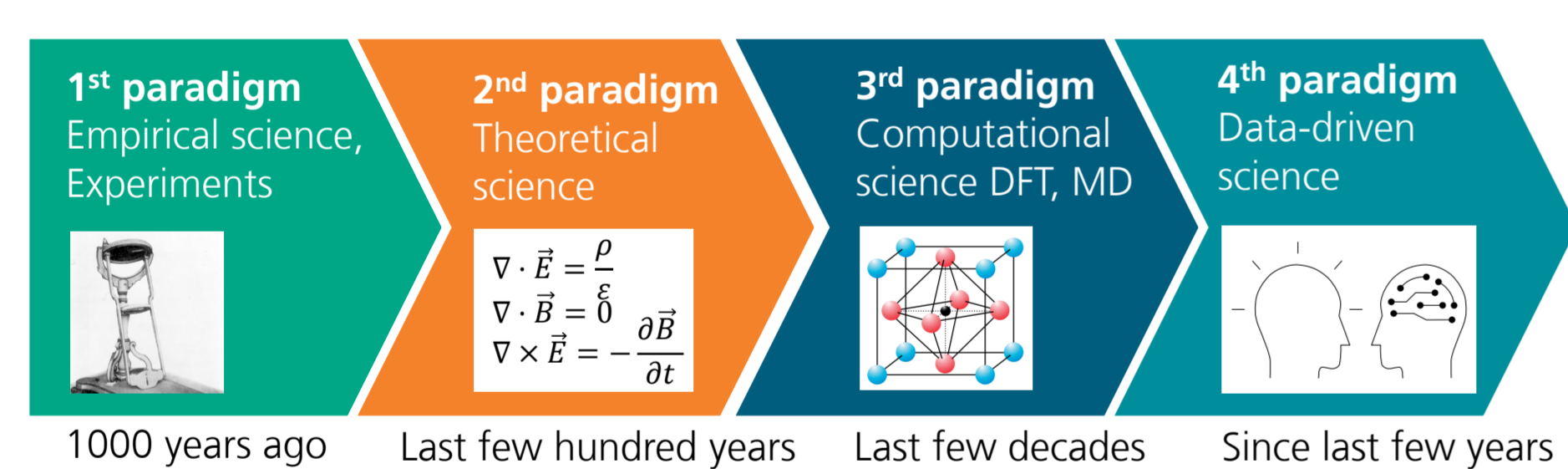


Figure 1. Paradigms in materials science, acc. to: Zhou, T. et al. 2019 Engineering.

Scientific approach

Ontology-based lifecycle-oriented database

- **Middle-Level Ontology** plus **Lower-Level Ontologies** per domain (piezoelectrics, LTCC ferrites)
- Build on PMD core ontology
- Standardized data formats, metadata, and FAIR principles
- **Ontology-based subject-specific database** linked to the PMD for integrating all life cycle-relevant data,
- Implementing the FAIR principles and taking data protection concerns into account

Digital tools to support material research

- Automate **taxonomy generation** and data linking across different sources
- Enable **collaborative ontology development** and semantic inter-operability
- **Automated data extraction** from technical text documents and structured data, mapping, and integration with ML workflows
- Script-based mapping of historical data and newly generated data
- Trained and experimentally validated ML models for piezoceramic and ferrite materials and their technology

Research into new piezoceramics and ferrite ceramics

- **Lead-free high-performance piezoceramics** through texturing and optimized process control
- **Ultrasonic components** made of textured lead-free piezoceramics in industrial use cases
- **Ferrite-based LTCC-integrated multilayer inductors** in a selected electronic application
- Evaluated concepts for **material recycling** of piezoceramic and ferritic materials
- Evidence of a reduction in experimental effort in the development processes

Project structure and partners

Partner	Core role
CeramTec GmbH	Coordinator, textured lead-free piezoceramics; experimental workflows and recycling routes
Aixacct Systems GmbH	Data management for structured measurement data; automated data mapping and ML workflows
Numberland	Ontological data management; extraction of unstructured data; integration of LLMs for question answering
HappyOps GmbH	Ontological data infrastructure and user interfaces; customized tool development
VIA electronic GmbH	LTCC ferrite ontology; technology of multilayer ferrite LTCC inductors
KMS Technology Center GmbH	Data capture in manufacturing of multilayer ceramics
Sonotec GmbH	Demonstrators for ultrasound applications
TRIDELTA Weichferrite GmbH	Ferrite material and technology
TU Berlin	Middle/low-level ontologies; tool integration and collaboration on ontology creation
Fraunhofer IKTS	Textured lead-free piezoceramics, casting of ferrite tapes, recycling concepts; ontology support
Ernst-Abbe-Hochschule Jena	Ferrite material and LTCC components; component design, cofiring guidelines

