Natural Sciences and Advanced Technology Education | Volume 34 Number 4, 2025 | Обучение по природни науки и върхови технологии

https://doi.org/10.53656/nat2025-4.01

Education: Theory and Practice
Образование: Теория и практика

QUALITATIVE EDUCATIONAL PERSPECTIVES ON THE DIVERGENCE AND CONVERGENCE OF SCIENTIFIC THEORY AND PRACTICE

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Abstract. Qualitative perspectives on the convergence and divergence of scientific theory and practice emphasize the shaping of scientific knowledge towards shared understanding. Sometimes these can move in different directions, creating divergence when theoretical models don't accurately represent real-world scientific observations or when practical applications reveal limitations in current theories. Effective educational practice involving experimentation and theory can refine understanding, creating a dynamic interplay between the two.

Keywords: Qualitative perspectives; Theory and Practice; Convergence and Divergence; Learning improvement

Introductory Perspectives

The scientific method is a systematic approach to advance knowledge involving observations, hypothesis formation, data collection, hypothesis testing, and the development of theories and further refinement of ideas (Suppes, 2014; Dąbrowski, 2001; Colley, 2003; Mohan & Slater, 2005; Homer, 1996). Initial observation of a phenomenon or pattern prompts a question to understand it better, leading to a hypothesis, a testable explanation/prediction. Further studies or experiments are designed and conducted to collect relevant qualitative/quantitative/mixed data, depending on the nature of the research, regarding the hypothesis. The data is analysed, and the results are interpreted to support or refute the hypothesis. If the evidence from multiple experiments supports the hypothesis, it can evolve into a theory to explain some aspect of the natural world.

Convergence can occur when theoretical and practical results support and reinforce each other (Hendricks, 2001; Bainbridge & Roco, 2016; Parkes et al., 2003; Kihlstrom, 2013). For example, theories can be developed based on practical observations, or practical applications can be improved based on new theoretical insights. Knowledge is created and disseminated in different ways across different cultures, settings, and social contexts. Scientific theories are often tested and refined through practical applications, and practical results can lead to new theoretical insights. Scientific knowledge also depends on interpretations of data, shaped by researchers' perspectives and their constructed narratives. A theoretical prediction of climate change may predict a certain warming rate, but glacial ice melting and sea level rise may show a faster rate of change (divergence) (Langford et al., 2015; Schwartz, 2017; Gabalda et al., 2010; Van de Ven & Johnson, 2006: Koivu & Hinze, 2017). Observations of materials' properties in specific conditions may lead to the development of new theories to explain the observed phenomena. These theories can then be used to develop more efficient and advanced materials. Critical analysis of the interplay between theory and practice through a qualitative lens can provide insight into the complex and dynamic nature of knowledge and its relationship to the world.

The paper offers a comprehensive overview of educational perspectives on the convergence and divergence of scientific theory and practice. Its coverage of topics such as the significance of theories and experiments, theory vs practical higher education, a modern approach to higher science education, sustainable science benefits, and bridging the gap between theory and practice is extensive. The narrative weaves general education aspects such as blended instructional approaches, sustainable living, and bridging educational gaps into practical world contexts. The author presents common examples that are understandable for a broad readership. Integration of convergence and divergence of theory and practice provides a holistic view of why subject understanding matters beyond classrooms. A small section on minimizing divergence to improve accuracy in the end analyzes the convergence and divergence aspects of true value and measured values in scientific experiments.

The importance of connecting theory and practice in education is widely recognized, and the educational context and the specific innovative approach being offered include emphasis on reflective practice and mentorship in teacher training, connecting i) academic knowledge with professional practice, ii) theoretical concepts with hands-on design and problem-solving in a laboratory setting in the higher education system, and iii) theoretical knowledge with practical skills for specific professions, that bridges the gap between theoretical knowledge and real-world classroom experiences. It is essential to encourage student teachers to critically analyze their own teaching experiences and how they align with blending theoretical frameworks with practical practices. Experienced educators can provide guidance and support in applying theory to practice in mentorship programs. Utilizing virtual reality or simulated classrooms allows faculty to practice their skills in a safe and controlled setting. Pairing faculty with problem-based learning that involves real-world problems requires them to apply theoretical knowledge to find effective solutions.

Significance of Scientific Theories and Experiments

Scientific theories describe cohesive explanations for a large set of observations and are extensively tested hypotheses evaluated by the scientific community (Lakatos, 1974; Winther, 2015; Hodson, 1988; Harré, 2002; Agazzi, 1988). These theories provide a framework for understanding natural phenomena, and experimentation/observations allow for testing and refining those theories. Both are crucial components of the scientific method, complementing each other to advance scientific knowledge. Theories provide a structured way to interpret observations and experimental results to understand and explain natural phenomena that help us make sense of the world around us. Well-established theories have predictive ability for future events or outcomes. They can suggest the direction of research in specific areas and hypotheses to test. Discoveries are made by challenging and refining existing theories, contributing to the constantly evolving understanding of the world. Practicals provide a method to test the validity of scientific theories by comparing theoretical predictions with practical results. They help learners to think critically, collect and analyse data, and draw conclusions based on evidence. Different practical approaches can spark creativity and lead to innovative ideas. Extensive experimentation in certain areas of science can lead to novel theories or modifications of existing ones. Practical work helps develop essential skills for scientific inquiry, like observation, data collection, analysis, interpretation, and conclusions. Thus, the scientific theories provide the intellectual framework while practicals provide evidence to test, validate, and refine our understanding of the natural world.

Theory vs Practical Higher Education

Theoretical knowledge, practical experience, and bridging theory and practice help in continuous learning and holistic experience in real-world settings (Elliott, 2012; Ferreira & Morais, 2020; Treagust & Duit, 2008; Kirschner & Huisman, 1998; Gott & Duggan, 1996). Theoretical knowledge is based on abstract concepts, principles, and ideas, while practical knowledge is based on real-world experience and application. The former focuses on understanding concepts and principles through reading/studying and academic research, while the latter focuses on implementing those concepts and principles through hands-on experience and experimentation. Theoretical knowledge is often used to develop new theories or advance existing ones, while practical knowledge is used to solve real-world problems and generate practical solutions. Theoretical knowledge can be developed and discussed over an extended period, while practical knowledge requires immediate application to solve present problems. Both are essential for progress and innovation in science, engineering, and technology. They are intertwined and mutually dependent to provide foundational understanding/frameworks and allow for the application/testing/improvement.

Theoretical knowledge helps us understand why things work the way they do, and it is developed to explain phenomena, predict outcomes, and guide problem-solving. It helps in the design of experiments, the interpretation of results, and understanding the real-world scenarios (abstract and idealized). Practical applications allow us to test/validate theoretical concepts to reflect real-world complexities, often indicating further refinement in theoretical frameworks. Practical challenges often lead to discoveries, innovations, and advancements. The process of learning and development (L & D) involves a cycle of theoretical exploration, practical application, and further refinement. A deep understanding of both theory and practice is critical for success in many scientific/engineering fields. For example, engineers use theoretical principles of physics/mechanics to design structures and rely on practical experience/testing to ensure safe and reliable structures. Similarly, data scientists use statistical theory to construct predictive models and rely on data cleaning, model evaluation, and proper deployment. Theoretical knowledge foundation and practical experience are essential for applying that knowledge, adapting to real-world situations, and driving innovation in science, engineering, and technology (SET).

Science practical experimentation is crucial for effective learning and understanding in science to develop a keen sense of observation, critical thinking skills, strengthen theoretical knowledge, and a sophisticated approach to problem-solving. Further, a practical work involving sophisticated instruments fosters a deeper understanding of scientific concepts and makes learning engaging/memorable. Practical work enables learners to see scientific theories and concepts in action, making the subject easier to understand. By manipulating variables and careful observations, we can verify theories, reinforce theoretical knowledge, design experiments, collect data, analyse results, draw conclusions, and identify error sources. Hands-on experience with scientific equipment and procedures is essential for developing laboratory/practical skills. Some unprecedented experimental results can lead to new questions and further investigations. Learners are more likely to develop a genuine interest in modern science and a positive attitude towards the subject. Laboratory sessions provide opportunities for higher education students to develop solutions through experimentation and are a fundamental component of science higher education, promoting a lifelong love for science.

A Modern Approach for Higher Education

A blended instructional approach involving both theory and practice on the same topic develops learners' analytical, creative, and practical intelligence (Fie Tsoi, 2009; Bidarra & Rusman, 2017; Erdosne Toth, et al., 2009; Wörner et al., 2022; Antonio, 2022). For example, while teaching optical activity in theory class, it is better to blend a practical polarimetry experiment in the laboratory into the curriculum design. Optical activity is the ability of chiral molecules to rotate the plane of plane-polarized light (PPL). If a compound rotates the plane of polarization clockwise, it is known as dextrorotatory, or counterclockwise as levorotatory. This rotation is quantified by a rotation that is characteristic of each chiral compound under specific conditions of temperature, wavelength, path length, and concentration. Polarimetry is the technique used to measure this rotation using a polarimeter instrument to analyze the behavior of polarized light passing through such a sample. It has a light source (sodium vapor lamp), a polarizer to produce PPL, a sample tube to hold the chiral solution, and an analyzer. The analyzer is rotated until the light intensity is minimized, and the angle of rotation is measured. Polarimetry can be used to probe the molecular structure and purity of chiral molecules by analysing how they interact with PPL.

Blended learning in SET combines traditional face-to-face instruction with online learning activities/laboratory sessions to enhance theoretical understanding and practical skills. This approach leverages the strengths of both approaches, offering flexibility, personalized learning experiences, and access to diverse resources/hands-on training while fostering critical thinking, problem-solving, and teamwork. The integration of theory and practice in blended learning modalities facilitates the use of theoretical knowledge through hands-on projects/experiments, computer simulations, and real-world case studies. It allows learners flexibility and accessibility at their convenience while also engaging in face-to-face interactions and demonstrations with instructors. The combination of interactive lectures, virtual labs, physical lab sessions, online quizzes, and collaborative/internship projects can boost motivation and engagement in SET subjects. It promotes the development of 21st-century skills such as communication, critical thinking, digital literacy, and problem-solving skills, which are crucial in science, technology, engineering, and mathematics (STEM) fields. Examples of blended learning activities include flipped classroom sessions, project-based learning, virtual labs and simulations, physical laboratory experiments, and online collaboration and communication. This blended approach requires the application of theoretical knowledge and practical skills. Several studies suggest that blended learning can lead to improved learning outcomes and a deeper understanding of concepts (Francis & Shannon, 2013; Badrus & Arifin, 2021; Sahni, 2019). Increased student motivation and engagement, development of essential skills, enhanced flexibility and accessibility, and preparation for future careers are other benefits of blended learning. Challenges of blended learning include technological barriers like reliable internet access, adequate technical support, teacher training and support, equitable access to technology, and the need for student self-regulation.

Sustainable Science Benefits

Sustainable Science focuses on the dynamic relationship between human activities and the natural ecosystem, including environmental protection, biodiversity conservation, human health improvement, economic growth, and social well-being (Baulcombe et al., 2009; Ekins & Zenghelis, 2021; Spangenberg, 2011; Keller & Limaye, 2020). It promotes sustainable practices and enhances the quality of life for present and future generations. Efficient resource management reduces the strain on natural resources like energy, minerals, and water. Implementing sustainable technologies helps reduce air, water, and soil pollution. The long-term ecosystem health can be maintained by sustainable practices like biodiversity conservation and natural habitat preservation. Promoting renewable energy resources and reducing greenhouse gas emissions play a crucial role in reducing climate change. Encouraging healthy food systems and reducing atmospheric pollution can lead to better public health outcomes. Enhanced quality of life is possible through sustainable living conditions, access to green spaces, and a stronger sense of community. Sustainable science can promote social equity by addressing poverty, inequality, and access to resources. It can promote education and awareness of environmental issues and empower individuals to make informed decisions. Economic benefits from job creation in various sectors like renewable energy, sustainable agriculture, and green technology. Long-term cost savings via reduced energy consumption, sustainable waste management, and proper resource use occur. Innovation, attracting investments, and creating new markets for sustainable products/services enhance competitiveness in businesses. Other benefits include breakthrough innovations and technological advancements that address various societal challenges, preparing communities better equipped to adapt to changing conditions, and ensuring that future generations inherit a healthy planet with enough natural resources (intergenerational equity). Comprehensive reforms in global education and research institutions with a visible, real impact are essential. Credibility and effectiveness of scientific endeavours, sustainable development, and technology access must make constructive contributions to all subjects and work in the interest of humanity.

Bridging the Gap between Theory and Practice

There is a disconnect between the knowledge and skills learned in academic settings and the demands of real-world applications. This learning gap can manifest as a lack of practical application skills to tackle complex challenges, difficulty in translating theoretical concepts into practical solutions, and limited understanding of real-world constraints. Bridging this gap is essential to enhancing professional competency and fostering innovation. According to conventional curricula, the emphasis is on theoretical knowledge rather than practical skills, leaving learners with limited exposure to hands-on experience. Limited interaction between the institute and industry hinders the development of practical skills. Rapid technological advancements require continuous learning and adaptation. There is a gap between the topics taught in universities and the technical requirements in the workplace. The real-world constraints, such as resources, budget, time, and regulations, need to be considered while implementing a project, and these aspects are generally not a part of the curriculum.

Bridging these gaps includes project-based learning (PBL) that can provide hands-on learning, teamwork opportunities, and the chance to apply theoretical concepts to solving real-world problems (Allsopp et al., 2006; McIntyre, 2005; Shephard & Carr, 2005). Active collaboration between the institute and industry can facilitate industrial visits, internships, and joint research projects, exposing learners to industry practices. Incorporating laboratory sessions, workshops, and simulations into the curriculum helps students develop practical skills. Further interactive experiences using virtual labs and augmented reality to mimic actual environments will enhance engagement and understanding. Mentorship programs involving industry professionals can provide valuable guidance and insights into the practical application of theoretical knowledge. Encouraging students to think critically and solve problems creatively can help them adapt to the technological landscape change.

The future of higher science education depends on the commitment to transitioning from rote-to-relevance learning, incorporating micro-learning modules and mini lectures, to thrive in today's dynamic and challenging environments. Rapid technological advancement, sophisticated instrumentation, digital transformation, and automation have put us to the challenge of building professionals of tomorrow with the required knowledge and skills. It is now essential to develop a deep understanding, critical thinking, creative problem solving, and the ability to innovate to be competitive in the global career market. The modern curriculum must provide learners with an opportunity to explore, question, discover, and innovate to face the challenges of the modern science landscape. Today's industries, academic institutes, and research laboratories require specialists who can work across disciplines, integrate new technologies, ability to collaborate, learn continuously, and adapt to rapid transformations. Always, scientific solutions are increasingly interconnected and multidisciplinary, and in nature, every scientific discipline exists together to display phenomena, exhibit certain properties, or applications. Higher education institutes/universities must prioritize experiential learning, incorporating internships, hands-on projects, case studies, collaborative exercises, and practical problem-solving sessions to develop a deeper understanding of how scientific concepts apply in practice.

Minimizing Divergence to Improve Accuracy

A 100 % accurate measurement is not possible with any scientific method. In analytical measurements, accuracy refers to how close a measured value is to the true or accepted value, while precision indicates how close multiple measurements are to each other. Measurement error, the difference between the measured value and the true value, is affected by systematic (determinate) errors that primarily affect accuracy, while random errors (indeterminate) primarily affect precision. Systematic errors have a consistent bias in one direction (always high/low), while random errors are unpredictable across different measurements. Instrument errors like faulty calibration, methodical errors like incorrect procedures, and personal errors like misreading of instruments are sources of systematic errors. Calibrating instruments regularly, using proper procedures, and training personnel reduces systematic errors. Fluctuations in experimental conditions (temperature/pressure), limitations of measuring instruments, and human errors are common sources of random errors. They cannot be eliminated, but can be reduced by taking multiple measurements and averaging the results. Increasing the number of measurements, controlling environmental conditions, and using statistical methods for analysis reduces the impact of random errors. Good accuracy implies convergence to the true value, and good precision may converge or diverge from the true value. Thus, errors in analysis can lead to divergence (measurements moving away from the true value) or convergence (measurements approaching the true value). Divergence from the true value is usually associated with systematic errors, while random errors cause scatter and affect precision, potentially leading to divergence or convergence depending on the specific error. By understanding the nature of accuracy, precision, and the various types of errors, analysts can take steps to minimize these errors and improve the reliability of their measurements (Leamer, 1993; Taylor, 2022; Liese & Vajda, 2006).

Concluding Comments

The relationship between scientific theory and practice in higher education is a dynamic and continuous process, characterized by both convergence and divergence. Qualitative research provides valuable insights into the challenges and opportunities for bridging the gap between theory and practice, improving educational outcomes. Learners' lived experiences and the theoretical frameworks create a thinking framework that shapes their worldview. The joint application of theory and experimentation in higher science education and research institutes/ universities shapes our understanding of how we view our multiverse. Qualitative observations and quantitative analyses using modern, sophisticated instruments should become a very important part of society, projecting symbolic or economic value. However, academic guidance, updated curricula, physical and intellectual infrastructure, structured learning materials, in-service teacher training, modern science laboratories, smart digital classrooms, institute-industry partnerships, AI-driven microlearning platforms, research incentives, and other operational challenges remain (Jia et al., 2024; Good, 1987; Zawacki-Richter et al., 2019; Almasri, 2024). Scientific techniques should become extremely important in deciding the quality of commodities sold in the market. It is essential to lower atmospheric carbon dioxide/methane concentrations to provide climate justice by creating environmental awareness among youngsters through education. Further scientific research on sustainable agricultural practices, multiple approaches to predict droughts and downpours, breakthrough sustainable innovations that are transformative of the scientific landscape, technology development, skill-based manufacturing, and socially useful products/processes will go a long way in creating a sustainable global community. The potential of artificial intelligence (AI) as a collaborator in higher education and applied research is enormous, and the future belongs to those who combine deep expertise with generalist flexibility. Interdisciplinary/transdisciplinary/multidisciplinary higher education and advanced theoretical and practical research must be promoted to create a world with a multipolar and inclusive order and balanced global growth.

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