Opportunities and challenges in Teaching Structural Geology and Tectonics

A summary of findings from the TeachSGT21 workshop held in Wolkersdorf/Weinviertel on April 5-7, 2019

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Motivation

In most university geosciences curricula, structural geology and tectonics (SGT) form a core part. Our understanding of SGT has evolved over the years, and industrial applications have changed with the emergence of novel tools and data, and as a consequence we must develop our teaching to reflect these advances. Such a development is encouraged by new teaching approaches, technologies and methods. At the same time, our students, and the ways in which they learn, are changing, and classical ex-cathedra teaching often fails to excite them.

The workshop brought together experienced university-level SGT educators from three continents in order to learn and discuss about strengths and weaknesses of current SGT curricula in Europe and beyond. The goal of our meeting was to outline an SGT teaching vision for the next decade. We learned about the educational demands from industry and research and discussed a common position on the role and significance of field training. We debated a range of efforts to establish a community-supported teaching platform.

Progress through technology?

Several experts presented innovative teaching approaches and tools, including virtual landscapes, augmented and virtual reality, digital microscopy and others. The pros and cons of these were explored. *The Covid-19 crisis has rendered this discussion more urgent and, since the workshop, significant web-based resources have become available. The long-term effects on classical teaching remain to be assessed, but the developments have definitely been accelerated*.

Virtual microscopy (J Urai)

Pros: Accessibility, cheap, standardisation, interactivity (image analysis/annotation), can be used in exams
Cons: Potentially less basic light microscopy, hardware-intensive
Status: Several platforms available for use
How accessible? Very good
Vision? Thin section database with background information on samples
www.ged.rwth-aachen.de/index.php?cat=Virtual_Microscope

Augmented/mixed reality (F Hawemann)

Pros: Immersive, providing additional information, use in field classes AND labs, contributes to spatial understanding
Cons: Preselection of information
Status: Some apps available
How accessible? Very good
Vision? Significant potential
https://meetingorganizer.copernicus.org/EGU2017/EGU2017-13655-1.pdf

Hardcopy 3D (M Ketterman) (3D printed outcrop models)

Pros: Tactile and haptic, supports 3D understanding, cheap, bridges gap between VR and field
Cons: Accessibility, potentially expensive
Status: Just starting
How accessible? Not very, depending on data and printers
Vision? Coupling with virtual outcrops

Unmanned Aerial Vehicles - UAVs (B Grasemann)

Pros: Fast and efficient method to capture high resolution photographic data; straightforward generation of structure from motion models; digital preservation of short-lived outcrops; sharing of virtual outcrops
Cons: Legal restriction of flying drones; run-time and computational overhead of high-resolution 3D models
Status: Getting more and more popular especially in connection with virtual field trips
How accessible? Very good; cheap drones with high resolution cameras; cloud service for 3D models
Vision? Implementation of other sensors like radar, multispectral, infrared, LIDAR

Digital input devices (in the field) (V Toy)

Pros: Lots of data, better statistics, cheaper, faster, more efficient, works with magnetic rocks, good in bad weather, integration with photos and GPS, instant analysis, sharing, assessment
Cons: Data quality, battery life, accuracy, reduced 3D understanding, distractions, not good for foundation classes
Status: Already widely used
How accessible? Very good, good devices expensive though
Vision? Advanced sensors for improved accuracy

Virtual Field Training (J Houghton)

Pros: Inclusive, accessible, cheap, providing additional information, easy to give feedback even during classes, many additional sources and tools
Cons: Disengagement, loss of social component, lack of direct contact, perceived as extra work
Status: Widely used to various degrees
How accessible? Very good
Virtual Landscapes

Virtual reality (J Lamarche)

Pros: Immersive, seasonal independence, interactive data manipulation, aids 3D understanding, intuitive
Cons: Triggers seasickness in some users
Issues: Disconnects from haptics
Status: Already in use for visualization
How accessible? Available for phones
Vision? Significant potential

3D virtual outcrops (A Cawood)

Pros: low carbon footprint, safety/accessibility, efficiency, repeatability, motivation
Cons: distraction, resilience, user difficulties, lack of uniqueness and haptic feedback
Issues: People not sharing their data, risk of replacing actual field work
Status: Growing, but databases still small
How accessible? Through abundant freeware
Vision? Integrate students in data acquisition, a unified database
erock: Home

Industry perspectives

Structural geologists from Shell, OMV, Nagra and the British Geological Survey outlined skills and knowledge they consider important/helpful:

While the specific skills and knowledge needed by the represented industries vary slightly, all of the participants from industry agreed on the skills and knowledge outlined below.

The need for good **observational, descriptive and documentation (including mapping) skills** that form the basis of all interpretation is generally acknowledged. A wide exposure to different rocks and structures on the micro-, meso- and regional scales is considered critical for accumulating the experience needed to interpret geological and geophysical data. Students need to have seen different structural styles, geometries and interpretations; with this comes an appreciation of the complexity of geological reality and the processes that shape it in space and time.

Students should also have a solid **background knowledge** in geodynamics, the different tectonic regimes and the associated structures. An in-depth understanding of rock physics and the concepts of stress, strain, strain rate, rheology and mechanical anisotropy on local and regional scales is considered important to evaluate the underlying mechanics, as is an understanding of the evolution of rock properties during deformation. Knowledge of the principles of faults and faulting in different tectonic settings should lead to the capability to predict possible structures in complex extensional, compressional, strike-slip, transtension and transpression tectonics.

Seeing and drawing from similarities with world-wide analogues, (sandbox) models and numerical simulations is very useful, as is a basic knowledge in balancing/restoration. Ultimately, this translates into the ability to think in 4 dimensions, and analyse the evolution of faults and folds, and their interaction in a kinematic context. This should include an assessment of the complex interactions between structural elements, fault reactivation, structural inheritance and also sedimentation and tectonostratigraphy. An appreciation of uncertainties and how to deal with them using statistics and probability is important.

The employers also identified a range of **desirable soft-skills**, which are often undervalued in the syllabus but important in employment and recruitment. These include strategies for problem solving and work ethics that can be trained in practicals and simulation exercises. Effective communication training should enable students to articulate their thought process clearly, using specialist vocabulary, and should include presentation- and writing skills in various formats. In SGT, communication skills include the creation of clear and high quality diagrams, drawings, sections and maps.

SWOT Analysis

As part of our discussion, we conducted a **Strength-Weakness- Opportunities-Threats analysis of current SGT teaching.**

Strengths

As perceived at degree level at individual universities:

- Well-funded, good industry links (internships, data), travelling opportunities, high employment rates, good collection of experts
- SGT core to curriculum, very hands-on, focus towards skills required for independent mapping
- Back-to-basics: Focus on basic mapping skills and geometrical analysis, consistent learning track
- Strong focus on field studies
- Integration of high-end labs into teaching, teaching collaboration across departments, short travel distance to good outcrops
- Research-focussed curriculum, recognized excellence of staff, focus on issues of societal relevance
- Training in research skills
- Excellent staffing, very applied education, good job prospects

...of SGT teaching in general (panel discussion)

- 3D/4D thinking, integrating spatial and temporal information
- Multi-scale understanding
- Model building from limited datasets, abstraction
- Pattern recognition in complex data
- Dealing with complex systems and uncertainties
- Pencil and paper approach - careful observation
- Interpreting the past to forecast the future

Weakness

As perceived at degree level at individual universities:

- Dependence on oil industry, very compartmentalized knowledge-transfer, no independent field work in BSc, outdated introductory courses
- Learning advanced concepts is optional, increasing struggle with numeracy and 4D thinking
- No tectonics/geodynamics or advanced structural geology
- Many different courses prevent focus
- little independent mapping
- No teaching in English, weak integration between SGT staff
- Inefficient in terms of number of graduates
- No money available to invest in teaching, Bologna process weakened curriculum, foundation courses taught by many different departments, great diversity among international students can be challenging.

...of SGT teaching in general (panel discussion)

- Traditional format for teaching traditional tools
- Linear SGT teaching teaches complex concepts with little context
- New technological approaches bear the risk of data overload
- Do we really understand our students, and are we using their skills properly?
- Teaching the teachers - how do we train ourselves?

Opportunities

As perceived at degree level at individual universities:

- Opportunities arising from renewables, civil engineering
- Develop problem-based approach, further integration of theory with field work, virtual and augmented reality, digital data capture, analysis and modeling
- Strengthen BSc with tectonics and MSc with microtectonics
- Start teaching MSc in English to attract international students
- Integrate technological advances into teaching

...for SGT teaching in general (panel discussion)

- Learn more about the way our students learn best, embrace new teaching techniques and technologies
- Become more inclusive
- Embrace new employment opportunities for students
- Transform tradition (provide context for content, highlight benefits of careful observation before interpretation, integrate big data, teach complexity/uncertainty more explicitly)
  - Master competition between teaching in depths vs sharing recipes/resources
  - Mentoring schemes for improving teaching abilities
  - Sharing experiences/resources/best practices among educators

Threats

As perceived at degree level at individual universities:

- Slump in oil price/societal and technological shift away from hydrocarbons, fieldwork healt and safety needs more weight
- Declining student numbers (-30% in past years), drive to reduce number of optional modules, funding for fieldwork, investment in technology and software, changing employment market
- Budget for fieldwork, program director with little enthusiasm for SGT
- Constant reduction of financial support for field work and excursions
- Department closure!
- Energy transition

...to SGT teaching in general (panel discussion)

- Risk of focussing on latest techniques and forgetting the basics
- Sinking student numbers threaten existence if departments
- Increasing concerns from health and safety perspective, especially regarding field work
- Shrinking budgets threaten field education and investment in modern teaching technologies
- Competition between universities, with the best getting the best professors and students
- Financial pressure on students
- Limitations brought by Bologna system

Further participants from U French West Indies (Guadeloupe), U Ottawa (Canada), Hamilton C (USA)

We debated the **value and significance of (independent)** **Field Work** **and excursions** in geology degrees.

Why is field work important?

- Structural geologists contribute to our understanding of natural resources and geohazard. The **complex environments** from which the necessary data need to be collected are **best confronted in the field**.
- The **ability to think in 3D and 4D** is a fundamental skill of a geologist. Field work and mapping offer a multisensory experience that develops cognitive and psychomotor skills in ways that are not possible in other learning environments. While VR/AR enhance this understanding, they cannot replicate the full complexity of nature.
- **Specific techniques** such as context-based sampling are **best trained in the field**. This includes identification and documentation of the relative timing of structures (and associated kinematics) through observation, description and interpretation of incomplete, spatially distributed data, orientation and cross-cutting relationships.
- **Field work is a very efficient means of teaching**, with immersive fieldwork experiences enhancing learning.
- Systematic and problem-based **fieldwork develops student's decision making and time management**. They are challenged to consider uncertainty and alternative models based on their own observations and data collection. This can be developed through team-based approaches but is perhaps most effectively learned during independent field projects, including mapping.
- **Field work develops a wide range of transferable skills** (social, collaborative, organisational, health and safety) that are highly relevant.
- **Field work creates a sense of identity** in students and helps in cohort building.
- **Accreditation** by professional bodies such as the Geological Society of London.

What are problematic aspects?

- **Inclusivity and diversity remain challenges** for fieldwork for both students and staff. Fieldwork practices and approaches need to be re-evaluated in order to maximise all aspects of inclusion and thereby enhancing the overall fieldwork experience.
- **Approaches to health and safety are variable.** A risk-based approach is taken by many but training is patchy and training to prove competences limited.

What opportunities are there?

- **Shared resources for field work** covering selected locations around Europe/world, organized by key structural styles (e.g., fracture patterns, shear zones, magmatic etc). Such online resources also have a role in geoconservation. Online resources could include VR models that would help with accessible fieldwork. VR provides opportunity to map in great detail and cover structures and textures at an intermediary scale.
- **Shared field teaching** between different universities across Europe/world at different levels. Increases range of fieldwork opportunities for students and staff with limited extra effort and cost and promotes cultural exchange. This could possibly include summers school and be facilitated through EU programmes.

What threatens field teaching?

- **Virtual Reality** (VR) is a valuable enhancement but **could be regarded as a replacement** for field work should non-educational factors be given higher significance.
- With an increased focus on reduction in student contact time **the opportunities for fieldwork may reduce** and, in particular, desirable opportunities for students to make mistakes and learn from these could be lost.
- A **reduction in the available funding** may lead to field days being cut, or budget may become the primary factor in choosing locations.
- Justified **demands to reduce our CO_2 footprint** will force a rethink of overseas travel.
- Unforeseen **consequences of increasing regulation of higher education** (local, national and international). Not only could this limit the scope of fieldwork but it also has consequences in terms of student expectations and blurs the distinction between staff and student responsibilities.
- There is an **increased reluctance**, for a variety of reasons (including research specialisms), **of staff to undertake fieldwork** activities, especially residential fieldwork.
- *The wide range of online alternatives to field teaching that is becoming available to mitigate the effects of the Covid-19 restrictions might permanently replace field activities in some universities without its effect being evaluated properly.*

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