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Lab-in-a-Bag

This paper presents an integral knowledge exchange project within the framework of an experience-based teaching concept on water, a topic that is gaining more and more urgency and relevance worldwide. In doing so, the importance of a sound university education in hydraulics, hydraulic engineering and urban water management is derived via the central role that water plays in global warming processes. The focus of this article is on the DAAD-funded exchange project "Lab-in-a-Bag", on which partners from Tanzania and Germany have been working since April 2021.

Keywords:
Water - climate change - knowledge exchange - experience-based teaching - mobile teaching labs - hydraulics - hydraulic engineering - urban water management

Lab-in-a-Bag

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1. Introduction

Since time immemorial, people have settled near water because it provides them with everything they need to live. Besides drinking water, the food supply from aquatic life was significant. Later, the irrigation of fields, process water for tanneries, for example, and the receiving water for wastewater were added as important factors. Thus, the first advanced civilisations emerged precisely where water was not abundant, but had to be managed intelligently: in the so-called Fertile Crescent. The dynasty of the pharaohs, for example, emerged from district rulers who managed the irrigation canals along the Nile. Further examples from Asia and South America will not be given here.

At the latest with industrialisation and the use of large quantities of (cooling) water for power plants and factories and the trades routes spreading over the waters – especially also for fossil fuels – the access to the world's rivers and oceans was a strategic advantage in the development of metropolises. As settlement pressure increased, rivers were controlled more and more, their flood plains straightened and trimmed. Protection against flooding and the extraction of groundwater moved to the forefront of "cultural hydraulic engineering".

With climate change and the associated rise in sea levels, concerns grew, especially for coastal agglomerations. But after the major flood disasters that occurred in Germany in 2021, the question is being asked more generally: "Is it still safe to live by the water?".[1]

The connection between climate change and river gauges has been evident for a long time.[2] In recent years, the focus has rather been on the ever decreasing precipitation, as the title "Germany's soils are thirsty" shows.[3] While the effects are now causing a media outcry even in the climatically moderate, industrialised Germany, the catastrophic consequences in the poorer, drier regions of the world go almost unnoticed. However, the developments were anticipated by the Intergovernmental Panel on Climate Change (IPCC) as early as 2007.[4] For the anthropogenic temperature increase of 1°C in 2020, the authors of the report predicted that an additional 400-800 million people worldwide would live in water-deficient areas. In 2050, with a temperature rise of 1°C to 2°C, there will be 1.5 billion people, with a temperature rise of 2.5°C, 2.4 to 3.5 billion people living without access to clean water.[5]

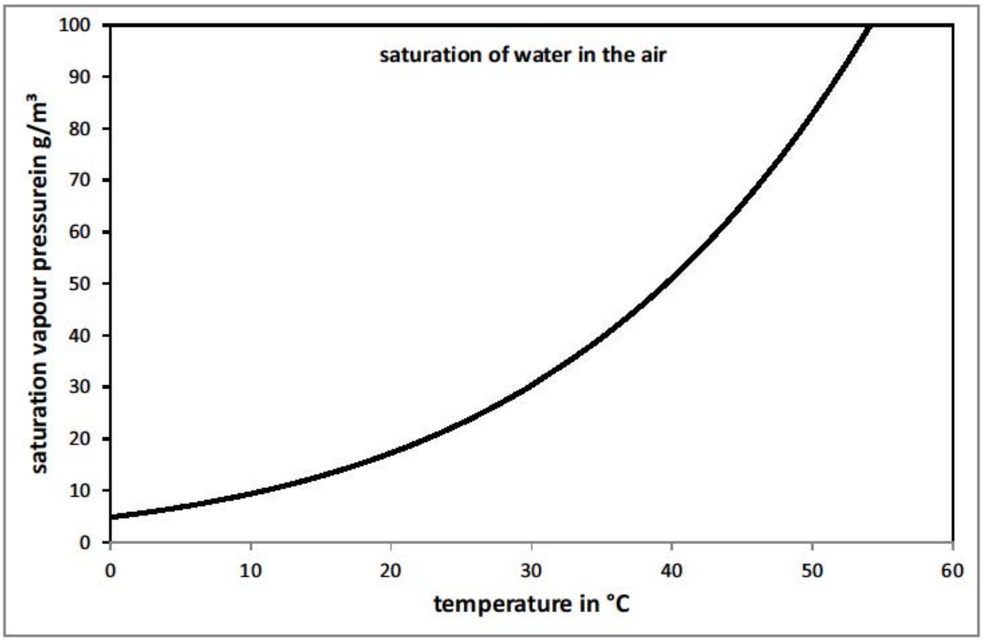
It should not be forgotten that water is the climate change element par excellence. Water in its three phases – gaseous (0.001%, i.e. water vapour), liquid (97% salt water and 0.7% fresh water) and solid (2.3% ice) – has a significant influence on the climate of our planet, not only because it covers 71 per cent of its surface.[6] The oceans absorb a large amount of CO_2 and have warmed by about 0.011°C since industrialisation – which saved the atmosphere a warming of 11°C – water vapour is the number one greenhouse gas (also with a rebound effect[7], see below)[8] and the ice albedo effect, i.e. the reduced reflection of sunlight due to melted glaciers, is a major rebound effect.

Rising temperatures will lead to less frequent, but much heavier precipitation due to the higher saturation vapour pressure (exponential function) (see Figure 1). This is because precipitation does not occur until the saturation vapour pressure is reached. The cold, Siberian air is dry; humid, warm air leads to tropical rainfall.

just as Antoine Lavoisier once discovered in 1783: Water consists of one part "vital air" and two parts "inflammable air".

Water thus plays a central role in climate change and adaptation. To meet the challenges, humanity will need the creativity of many well-trained engineers and scientists in this field. One approach to meeting this need is described in this paper.

Figure 1. Saturation of water in the air



Source: Created by the authors

Especially if the local effects are considered (e.g. a global warming of 2°C affects the Mediterranean region with a temperature increase of 4°C), one can imagine the consequences. Locally, the "distribution systems" must then also be questioned. One of these circulation systems, the AMOC (Atlantic Meridional Overturning Circulation), known to us as the Gulf Stream, is in danger of collapsing due to the melting Greenland glaciers, according to recent findings.[9]

Water also plays the central role in solving the climate crisis: after all, 17 percent of the world's electricity consumption is supplied by hydropower. And in future, H_2O is to be split into its atoms by electrolysis and the hydrogen extracted in this way is to be used as an energy carrier. Its combustion releases energy, water is created and the cycle is closed,

2. Knowledge Exchange

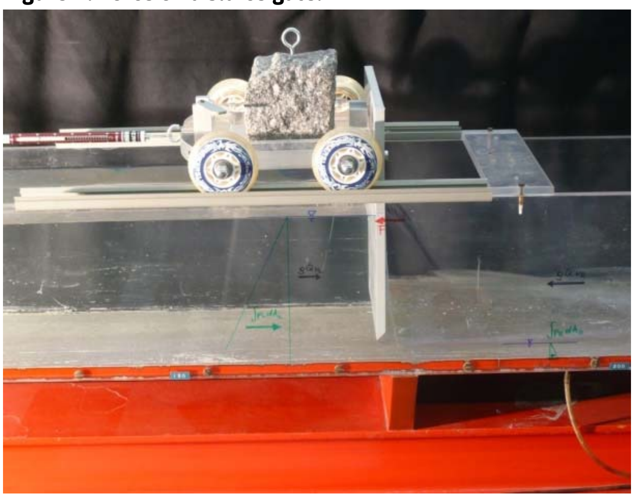
It is evident that knowledge is the basis of development. In a massively digitalised and networked world, it seems easy to exchange knowledge. With the permanent increase in knowledge, the degree of complexity in application also increases. This means that responsible tasks can often only be taken on by well-trained experts who have internalised the knowledge. Therefore, learners need to understand and fully grasp the subject matter.

The basis for this is primary education, which, according to the United Nations Sustainable Development Goals, should be made possible for all citizens of the world.[10] However, it must not be forgotten that education at secondary schools and universities for an appropriate proportion of the population (for the smartest, not for the richest) is elementary for the sustainable development of good living conditions. In all educational institutions, those imparting knowledge have to ensure that the facts are prepared, explained and placed in the right context. Enthusiastic knowledge transfer by passionate educators is essential for successful learning.

Currently, however, the education of these engineers, especially in developing countries, often does not meet these requirements. Complex physical and chemical contexts are usually only discussed or read out in books and taught in front-of-class at colleges and universities. At best, commercial physical experiments or software are used in teaching and black-box results are generated; which does not leave any space for creativity. Exams are mostly about reproducing, not projecting the actually understood content onto new questions, i.e. applying it. The engineers are thus often inadequately prepared for the requirements and questions of their future work. They are often unable to question given situations, which leads to the impediment of innovation and ultimately the development of societies.

A teaching concept was developed in the hydraulics department at the Technical University of Munich and has been used for years at teaching institutions abroad. It is based on the idea that learners follow the same path that the researcher of the phenomenon has followed.[11]

Figure 2: Force on a sluice gate.



Source: Rapp/Springer

Observe → Understand → Conclude → Challenge → Apply

This idea is illustrated by the following example of determining the flow force on a sluice gate, as it is used millions of times worldwide (see Figure 2).

Observe

A sluice gate is attached to a trolley which is placed on a Plexiglas channel; this trolley is held in the horizontal direction with a spring balance. When the flow in the laboratory flume is started and the amount of water is increased, the flow depth in the flume increases, causing a build-up by the sluice gate. It can be observed that the carriage initially moves in the direction of flow until it finally stops. The movement of the carriage has stretched the spring balance; a force can be read directly from it.

Comprehend

So there must be a balance between the flow forces and the holding force of the spring balance. The students can feel from this experiment that a dynamic force, the so-called impulse current, also prevails. The flow depth upstream of the sluice gate is large and small directly downstream; the flow depths can be marked on the Plexiglas wall. Since the flow as a product of flow cross-section and velocity is the same upstream and downstream due to mass conservation, it is obvious that the flow velocity downstream of the sluice gate must be much greater than upstream. So if you hold your hand in the channel up- and downstream of the sluice gate, you can feel that the impulse current, the product of flow, velocity and density, is much smaller upstream of the sluice gate than downstream.

Conclude

Obviously, there is an imbalance between the sum of hydrostatic pressure force and impulse current (together supporting force) upstream and downstream of the sluice gate, which is compensated by the force of the spring balance.

Challenge

The so-called momentum theorem, which theoretically describes the prevailing forces, can be easily derived for a fluid volume fixed in space. The result from the equation can then be compared with the measurement result of the spring balance. Slight deviations in the results from theory and practice can be explained by the friction force that is included in the horizontal reaction force – and not measured by the spring balance of course; however, this is quite noticeable on the test rig. The relationships must be further questioned on the basis of examples and experiments.

Apply

Applying knowledge to new tasks is an important part of the learning process. There are various interesting questions to be asked. This illustrative teaching method was implemented in the spirit of von Humboldt's principle – the connection between science and teaching – at various universities in Africa and Latin America through the "Verein zur Förderung des internationalen Wissensaustauschs e.V." (Association for the Promotion of International Knowledge Exchange). In Mozambique and Tanzania, teaching laboratories were set up and teaching materials were designed to support experience-based knowledge transfer (see Figure 3). In this context, a textbook was published in 2017 by Springer-Verlag titled: Hydraulics for Engineers and Scientists – a Course with Experiments and Open Source Codes[12], which has since been reprinted.[13] The book has been translated into English and will be made available worldwide, digitally and free of charge. The textbook is flanked by open source codes and simple and inexpensive experiments. These are now to be developed in cooperation with the University of Applied Sciences Erfurt and the Arusha Technical College in a way, that they can be packed into bags.

Figure 3: Experiments on pipe hydraulics (Karume Institute of Science and Technology, Zanzibar, 2013)

Source: Rapp/Springer

2. Lab in a Bag

As part of the project – which is funded by the DAAD (German Academic Exchange Service) –, staff and students from Erfurt University of Applied Sciences, Arusha Technical College, the associated Kikuletwa Renewable Energies Training and Research Center and the Verein zur Förderung des internationalen Wissensaustauschs e.V. (Association for the Promotion of International Knowledge Exchange) are developing mobile water teaching laboratories that can be used not only in developing countries. With the help of the experiments, complex relationships are to be presented in a simple way and brought closer to the students. The teaching concepts for the cases will also be developed jointly and included in the curricula of the participating universities.

2.1 Concept

The experiments cover hydraulics (fluid mechanics of water), hydraulic engineering and water quality or wastewater treatment. Accompanying instructions are created, videos of the experiments are shot and made freely available via Massive Open Online Courses (MOOCs). Furthermore, open source codes for calculations of hydrodynamic issues round out the open approach of the project, which is expected to have a positive effect beyond the participating partners (Codes are available through github: https://github.com/christophrapp).

Following the project, the water teaching labs are to be produced by a start-up in a developing country and distributed worldwide; it is planned that the start-up uses the associated Kikuletwa Renewable Energy Training and Research Center as a hub.

Ultimately, the aim is to encourage students to think independently in a subject area that presents one of the major challenges of the future, not only in developing countries. With the open-source approach, other target groups can be reached as well, as in principle anyone interested can replicate and expand the Lab-in-a-Bag. Since, in addition to appropriate public documentation, MOOCs are intended to create access to the subject matter, this is not limited to universities, but environmental organisations, water supply and disposal companies, authorities, etc. can also benefit from the training materials and courses.

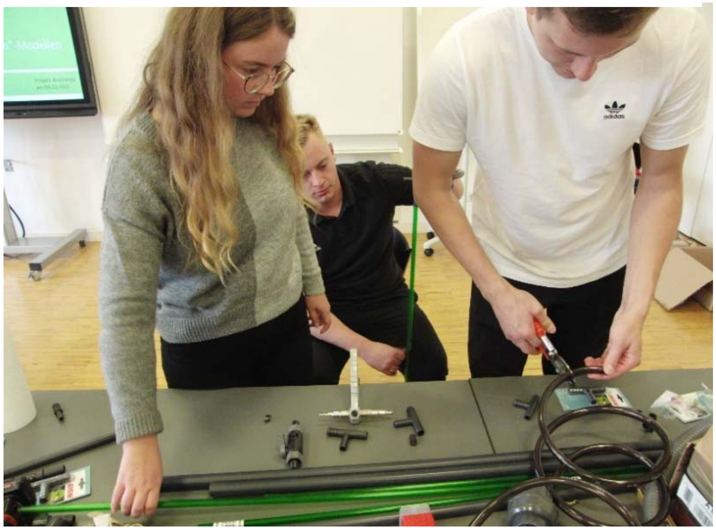
There are several conditions for the durability and practicability of these teaching materials: The materials to be used should be available on the market, also in developing countries, in an as standardised way as possible. This also means that the contents of the case must have an as low monetary value as possible so that parts can be easily replaced. Furthermore, the parts should be used as singularly as possible for the experiments in order to prevent misuse.

2.2 Implementation

The teaching materials are developed jointly by all project participants. In order to create sufficient space for discussions, scientific presentations, the preparation of scientific publications and the joint work on the teaching concepts, so-called retreats take place with five participating persons (teachers, doctoral students, students) from each university.

The retreats are arranged thematically along the project process; during the first retreat, which only allowed a virtual exchange between the partners due to COVID-19, the focus was on hydraulics or hydraulic engineering and modern teaching concepts (incl. digital applications) (see Figure 4).

Figure 4: Retreat in Erfurt - without the partners from Tanzania due to COVID-19.



Source: Rapp/Springer

At the second retreat, which will hopefully take place in Tanzania in spring 2022, parts of the Lab-in-a-Bag prototype will be tested by students and lecturers. Furthermore, documentation and accompanying documents will be discussed. The third retreat will then focus on urban water management and with it the second "Lab-in-a-Bag". An essential part of the cooperation between the project partners is the exchange of students and doctoral candidates. Stays of up to two months are intended to enable joint work, but also to create understanding as a prerequisite for genuine knowledge exchange in both directions. In detail, Tanzanian students and doctoral candidates will have access to the facilities of the University of Applied Sciences Erfurt and will be able to carry out internships with partners in industry and public enterprises. German students will have access to the facilities in Tanzania.

Figure 5: Wind water tower in Michamvi, Zanzibar

Source: Markus Heinsdorff

Ultimately, a large part of the development of the "Labs-in-aBag" and the associated teaching materials, concepts and videos is to be created or supported through student participation. To this end, it is also planned that the exchange participants will be involved in teaching at the respective partner universities. Since the start of the project, four students from Germany have already been recruited to write their theses within the framework of the project.

In addition to the assignment at the partner universities, visits to other universities are planned where the "Labs-in-a-Bag" will be presented with the associated teaching concepts.

3. Outlook

As part of a research project – and parallel to this project – Markus Heinsdorff (www.heinsdorff.de) plans to construct a simple laboratory building from regional, low-cost recyclable materials (e.g. cleaned waste) at the Kikuletwa Renewable Energies Research and Training Centre in order to test the simplest construction forms with locally available resources. The projects will be coordinated in order to leverage synergies among the professors and students involved and to be able to provide the "Lab-in-a-Bag" with a cost-effective space at each location. This cooperation is based on the joint experiences in a GIZ-funded PPP project in Zanzibar (see Figure 5).[14]

|| Christoph Rapp

Dr. Christoph Rapp was an assistant at the Department of Hydromechanics at the Technical University of Munich and, after receiving his doctorate, became head of the laboratory. In addition to experimental research into complex flows, he also devoted himself to descriptive teaching, for which he received several prizes, including the Ernst Otto Fischer Teaching Prize for an innovative teaching concept. He works for an energy supplier and is the managing director of a hydropower company. He also currently teaches at universities in developing countries through the Verein zur Förderung des internationalen Wissensaustauschs e.V. (Association for the Promotion of International Knowledge Exchange), which he founded, and as a lecturer at the Bauhaus University Weimar.

|| **Christian Springer**

Prof. Dr. Christian Springer worked at the Bauhaus Institute for Future-Oriented Infrastructure Systems (b.is) at Bauhaus University Weimar and has been working on theoretical, experimental and practical issues in environmental and wastewater technology for many years. He has long-standing experience in the management of research projects as well as technology development. As head of the distance learning programme “Water and Environment” at Bauhaus University Weimar, Prof. Springer has also been able to gain experience with various forms of online teaching since 2015. He is currently successfully using 360° excursions and a quiz app in regular teaching at UAS Erfurt. His professorship of Urban Water Management and Environmental Engineering at the UAS Erfurt has a laboratory for water analysis and a workshop for the production and construction of test rigs.

NOTES

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