



Preface

“Hydrology education in a changing world”

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Society is faced with a rapidly increasing risk of water insecurity due to a changing climate, growing population pressure and related increases in industrial productivity and food production. Particularly less developed countries with low levels of resilience are faced with serious direct or indirect consequences of human-caused climate and land use change as well as growing water demand and an increasing exposure of humans and their property to floods and other hydro-meteorological extremes. Tasks such as the estimation of design floods, the quantification of available water resources or the assessments of the environmental status of rivers become both highly important and increasingly challenging. Adequate hydrology education is needed to address these questions, but is generally not yet available (e.g. Wagener et al., 2007). Hence, there is an increasing interest in water education at the university level and in the continuous development of water professionals.

This increasing interest is demonstrated by the wide range of contributions to this special issue of HESS on “Hydrology education in a changing world” (Fig. 1). Papers range from concrete examples of how to teach physical processes (Rodhe, 2012) to calls for integrative curricula (Blöschl et al., 2012), from natural science education (Gleeson et al., 2012) to addressing socioeconomic aspects of water (Douven et al., 2012), and from education at the secondary school level (Reinfried et al., 2012) to continued learning for practitioners (Kaspersma et al., 2012) (Fig. 2, Table 1). The large number of interesting contributions to this special issue clearly demonstrates the high motivation and interest of researchers

and teachers in hydrology and water resource management in providing the best possible education and to advance the discussion on how to achieve it where it is not yet available.

Teaching hydrology, at undergraduate level, graduate level and in a life-long learning context, has always been a long-standing challenge for educators (Nash et al., 1990), and many of the problems discussed in historical papers still remain (Wagener et al., 2007). Challenging aspects include the heterogeneity of hydrologic entities such as the catchments and hillslopes we study and the diversity of the students we teach. Students entering hydrology programs come from both engineering and science backgrounds with very different educational foci and strengths as well as weaknesses. The heterogeneity of catchments and hydrological systems around the world is staggering and limits our ability to easily convey how general theories have to be tailored to local conditions. The educational system that supports the teaching of hydrology must undergo a paradigm shift away from the current practice of imparting a narrow set of basic concepts and a disciplinary set of skills to engineers and scientists with little consideration for the real needs of the area of hydrology, especially when considering the increasing impact of global and local environmental change (Wagener et al., 2010). How do we balance the need for hydrology students to have strong disciplinary skills in basic subjects (like maths, physics, soil science) (Kavetski and Clark, 2011), with field and laboratory work (Kleinhans et al., 2010; Nash et al., 1990), while also developing the higher level skills of connecting across disciplines and across places? Given the great complexity of

Table 1. The papers included in this special issue are grouped into four different categories (for each paper the authors, titles and main message are given).

Competences, continuing education and networks		
D. A. Hughes	Hydrological education and training needs in sub-Saharan Africa: requirements, constraints and progress	The development of local expertise is fundamental and desperately needed to sustain educational and practical hydrological knowledge for water management in sub-Saharan Africa. Increasing regional networking, the exchange of information, tools and institutional support should facilitate achieving this goal.
S. Reinfried, S. Tempelmann, and U. Aeschbacher	Addressing secondary school students' everyday ideas about freshwater springs in order to develop an instructional tool to promote conceptual reconstruction	Simplified exemplary hydrological models which only contain the most relevant elements can be a helpful tool to change the preconceived (often incorrect) ideas about hydrological concepts of students at the secondary school level. Such models enable deep learning and a sustainable change of misconceptions.
M. E. McClain, L. Chícharo, N. Fohrer, M. Gaviño Novillo, W. Windhorst, and M. Zalewski	Training hydrologists to be ecohydrologists and play a leading role in environmental problem solving	Ecohydrological education should promote professional and personal competences during and after the master's level. As a consequence, in depth knowledge of ecohydrological processes and systems, technical skills and competences such as creative thinking, cooperation, communication and leadership need to be addressed during the studies.
J. M. Kaspersma, G. J. Alaerts, and J. H. Slinger	Competence formation and post-graduate education in the public water sector in Indonesia	For work in the public water sector the three aggregate competences for technical issues, management and governance, and the meta-competence for continuous learning and innovation are particularly relevant. A T-shaped competence profile can help to organize the different competences.
G. Blöschl, G. Carr, C. Bucher, A. H. Farnleitner, H. Rechberger, W. Wagner, and M. Zessner	Promoting interdisciplinary education – the Vienna Doctoral Programme on Water Resource Systems	Facing future challenges in water resource management considering the holistic catchment management paradigm requires an interdisciplinary approach. This includes a broad understanding of processes relevant in water resources systems and soft skills that enable an interdisciplinary communication.
S. Uhlenbrook and E. de Jong	T-shaped competency profile for water professionals of the future	The understanding and managing of global changes in the environment implies cognitive, functional, personal and human values competences as well as meta-competences; therefore a T-shaped competence profile that can guide the education is suggested. The required competences change during the professional development. An open attitude towards learning, continuous professional development and integrative and team working skills are therefore crucial.
L. Jonker, P. van der Zaag, B. Gumbo, J. Rockström, D. Love, and H. H. G. Savenije	A regional and multi-faceted approach to postgraduate water education – the WaterNet experience in Southern Africa	The organization of postgraduate education and research on water resources on a regional scale is beneficial for many reasons. Experiences from WaterNet in Southern Africa provide a good example for a regional network approach that contributes effectively to capacity building for both water management and research.
W. Douven, M. L. Mul, B. Fernández-Álvarez, S. Lam Hung, N. Bakker, G. Radosevich, and P. van der Zaag	Enhancing capacities of riparian professionals to address and resolve transboundary issues in international river basins: experiences from the Lower Mekong River Basin	A capacity program for trans-boundary water issues needs to address a wide spectrum of topics that can be understood by a wide range of professionals from different sectors. The program should consider the three levels of capacity building (enabling environment, organizations and individual staff) and involve both national and regional education/knowledge institutes.

Table 1. Continued.

Curriculum and classroom		
T. Gleeson, D. M. Allen, and G. Ferguson	Teaching hydrogeology: a review of current practice	New pedagogical findings indicate that in addition to the classroom, the field and the laboratory are important places for learning. The ideal balance of these three components results in an increased motivation and progress in theoretical and professional hydrological knowledge and understanding.
T. Wagener, C. Kelleher, M. Weiler, B. McGlynn, M. Gooseff, L. Marshall, T. Meixner, K. McGuire, S. Gregg, P. Sharma, and S. Zappe	It takes a community to raise a hydrologist: the Modular Curriculum for Hydrologic Advancement (MOCHA)	Climate change and increasing population pressure are an upcoming challenge for hydrologists. Since the current hydrological education is not yet prepared to deal with this challenge, a Modular Curriculum for Hydrologic Advancement (MOCHA) that is intended to be a basis for developing a community-driven hydrological education was developed.
J. A. Marshall, A. J. Castillo, and M. B. Cardenas	Assessing student understanding of physical hydrology	Careful assessment of student understanding can increase the awareness and dialogue on student learning in hydrology. Such an assessment can evaluate to which degree students move from being aware of hydrological concepts from a non-physical perspective to a understanding of physical processes during a hydrology course.
I. Popescu, A. Jonoski, and B. Bhattacharya	Experiences from online and classroom education in hydroinformatics	Experiences from online and classroom education at university level show that online education has a significant potential for the future. Since temporary water problems need an up-to-date expertise, online modules can offer lifelong learning services and online educational support.
S. B. Shaw and M. T. Walter	Using comparative analysis to teach about the nature of nonstationarity in future flood predictions	By visually comparing hydrographs of different catchments and places, the physical understanding of flood events can be improved. In combination with information on the predictability of hydroclimatic drivers in a changing climate, students learn how and when to modify statistical models under non-stationary conditions.
S. W. Lyon, M. T. Walter, E. J. Jantze, and J. A. Archibald	Training hydrologists to be ecohydrologists: a “how-you-can-do-it” example leveraging an active learning environment for studying plant–water interaction	Ecohydrology courses include significant cross- and inter-disciplinary aspects and, thus, consideration of active learning approaches is advantageous. A case study demonstrates that students recognize the value of such approaches compared to traditional, lecture-based courses.
S. E. Thompson, I. Ngambeki, P. A. Troch, M. Sivapalan, and D. Evangelou	Incorporating student-centered approaches into catchment hydrology teaching: a review and synthesis	In hydrology, like in many other disciplines, there is a tradition of teacher-centered teaching. A review of the theoretical background and empirical literature on adopting student-centered approaches demonstrates how these approaches can improve hydrology education.
A. Pathirana, J. H. Koster, E. de Jong, and S. Uhlenbrook	On teaching styles of water educators and the impact of didactic training	To promote creative thinking and trans-disciplinary approaches, the role of the lecturer should change from expert traits towards delegator/facilitator traits. A didactic program for lecturers carried out by the UNESCO-IHE led to a significant change and improvements of the teaching style and learning outcomes.
E. G. King, F. C. O’Donnell, and K. K. Caylor	Reframing hydrology education to solve coupled human and environmental problems	Hydrological problems often require the knowledge of coupled human-environmental systems. It is therefore necessary that students are confronted with the complex dynamic interactions between human and physical environments during their hydrological education.

Table 1. Continued.

Software and online resources		
J. Seibert and M. J. P. Vis	Teaching hydrological modeling with a user-friendly catchment-runoff-model software package	Conceptual computer models for catchment hydrology are often used in the classroom. A version of the HBV model was further developed particularly to be suitable for teaching. A series of suggested exercises promote the understanding of general model concepts.
A. AghaKouchak, N. Nakhjiri, and E. Habib	An educational model for ensemble streamflow simulation and uncertainty analysis	Uncertainty analysis is an important aspect in modeling. Toolboxes, which are designed for use in teaching such as the HBV-Ensembles presented here, can support students to obtain an understanding of uncertainty concepts in hydrological modeling.
E. Habib, Y. Ma, D. Williams, H. O. Sharif, and F. Hossain	HydroViz: design and evaluation of a Web-based tool for improving hydrology education	HydroViz is a web-based tool, which enables active learning in the field of engineering hydrology. Learning is based on data and simulations, using real-world natural hydrologic systems and freely available geospatial and visualization resources. HydroViz offers several course modules for different stages of the curriculum.
V. Merwade and B. L. Ruddell	Moving university hydrology education forward with community-based geoinformatics, data and modeling resources	Data and modeling driven geoscience cyber-education (DMDGC) approaches should support conceptual learning and complement existing lectures. Currently, only the most basic modeling and visualization tools are widespread. It is necessary that the community develops the potential for DMDGC at universities by particularly developing and publishing curriculum materials.
A. Pathirana, B. Gersonius, and M. Radhakrishnan	Web 2.0 collaboration tool to support student research in hydrology – an opinion	The use of Wiki (a popular Web 2.0 technology) as a personal learning environment for supporting thesis research facilitates knowledge construction and peer-communication within and between groups, and stimulates learning. Wiki offers additional advantages compared to traditional learning management systems for supporting non-classroom education activities.
J. Seibert and M. J. P. Vis	Irrigania – a web-based game about sharing water resources	Irrigania is a web based game intending to demonstrate and simulate water conflicts between different actors in a simplified way. The use of Irrigania in classrooms showed that interesting patterns can evolve during the game, which can later be used to discuss the limitations of the game for representing water conflicts and to discuss ways to deal with them.
M. Rusca, J. Heun, and K. Schwartz	Water management simulation games and the construction of knowledge	Simulation games support experience-based learning and can stimulate negotiating skills, consensus building and working in teams. Since learning with games is usually case-based and underemphasizes conceptualization, simulation games should be seen to be complementary to traditional teaching methods.
A. Y. Hoekstra	Computer-supported games and role plays in teaching water management	Computer-supported games such as the River Basin Game and the Globalization of Water Role Play facilitate the development of an integrated understanding of water systems by encouraging the participants to think about the system as a whole. During the game both the uncertainties about the system and the different opinions of the participants play a central role.

Table 1. Continued.

Field and lab experiments		
D. G. Kingston, W. J. Eastwood, P. I. Jones, R. Johnson, S. Marshall, and D. M. Hannah	Experiences of using mobile technologies and virtual field tours in Physical Geography: implications for hydrology education	Mobile technology-based field exercises and virtual field tours are especially popular with students because they allow for increased interactivity and peer learning. The development of such exercises is not trivial, because of high start up costs, the need for technical support and the continuous improvement of the exercises.
A. Rodhe	Physical models for classroom teaching in hydrology	Many hydrological processes can be demonstrated and explained using simple physical models such as a sandbox. The use of such models in the classroom generates curiosity, provokes discussion and deepens the understanding of the fundamental hydrological processes.
V. Hakoun, N. Mazzilli, S. Pistre, and H. Jourde	Teaching groundwater dynamics: connecting classroom to practical and field classes	Integrating lectures, classroom experiments and field work promotes active learning. This is exemplified for a course on groundwater dynamics student activities. Detailed appendices describe possible student activities.

face. There is much to be gained from an enhanced exchange of teaching methods, experiences and ideas, both regarding concrete teaching activities as well as regarding our general approach to hydrology education. We hope that this special issue can contribute to this advancement for the benefit of educating future hydrologists, water managers and others working with water-related issues.

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