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Hydrology and Earth System Sciences Discussions

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It takes a community to raise a hydrologist: the Modular Curriculum for Hydrologic Advancement (MOCHA)

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Abstract

Protection from hydrological extremes and the sustainable supply of hydrological services in the presence of climate change and increasing population pressure are the defining societal challenges for hydrology in the 21st century. A review of the existing literature shows that these challenges and their educational consequences for hydrology were foreseeable and were predicted by some. Surveys of the current educational basis, however, also clearly demonstrate that hydrology education is not yet prepared to deal with this challenge. We present our own vision of the necessary future evolution of hydrology education, which we implemented in the Modular Curriculum for Hydrologic Advancement (MOCHA). The MOCHA project is directly aimed at developing a community-driven basis for hydrology education. In this paper we combine literature review, surveys, discussion and assessment to provide a holistic baseline for future hydrology education.

1 Introduction

1.1 From hydrology to hydrologist skill needs

Hydrology deals with the occurrence, circulation and distribution of water on earth, including its chemical and physical properties investigates the spatio-temporal storages and fluxes of water (in all its forms) in the terrestrial, oceanic, and atmospheric components of the global water system (US National Research Council, 1991; Dingman, 2002). Hydrology started as an engineering discipline mainly focused on problems such as estimating extremes for hydrologic design applications (Chow et al., 1988). The role of hydrology expanded with time, not only due to increasingly larger scales of study, but also due to the necessary inclusion of chemical and biological aspects of the hydrological cycle to deal with topics such as water quality and ecosystem functioning (Eaglson, 1970, 2005; Dunne and Leopold, 1978; Mollinga, 2009). Today, the societal need for water, human security, and ecosystem function in a rapidly changing world can

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only succeed through quantitative hydrological understanding that creates the necessary predictive capability across space- and time-scales (Milly et al., 2008; Wagener et al., 2010). This wide range of scales and the importance of understanding the role of water in the context of societally relevant endpoints, e.g., water supply for energy or food production, further highlight the interdisciplinary nature of our field (Hendrick, 1962). The societal importance of water is likely to attract students from widely different backgrounds to the field of hydrology (Eagleson et al., 1991), either as a major field of study, or in support of a related discipline such as ecology, meteorology or soil science. Nash and colleagues already described the role of water as a connector and hence the need for hydrologists to be central in interdisciplinary teams.

"It is likely that, for the foreseeable future, major problems involving the interaction of man with the hydrological environment on the global scale will increasingly require the attention of teams of scientists from many disciplines, including that of the scientifically trained hydrologist" (Nash et al., 1990).

Societal demands on hydrologic inquiry and problem solving will continue to erode the separation between science and engineering approaches to hydrology. Engineering solutions to hydrological problems in a nonstationary world will increasingly rely on mechanistic solutions, rather than empirical ones that depend on the assumption of stationarity (e.g., Milly et al., 2008). At the same time, scientists working in the field of hydrology will increasingly be pushed towards inquiry that is relevant to societal issues, which has important consequences such as the relevant scale of inquiry. *"Research topics come from societal needs as much as they come from the flow of scientific ideas and technological breakthroughs"* (Eagleson et al., 1991). Similar sentiments have been discussed more recently (LeDee et al., 2011).

1.2 From hydrology skill needs to hydrology education

Hydrology escaped the dominance of empiricism and developed a more scientific basis in the second half of the twentieth century when it became clear that deeper scientific understanding was needed to solve water resources questions (Eagleson,

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1970; Dunne and Leopold, 1978), and that a consideration of bio-geochemical cycles was needed to look at water quality issues (Sopper and Lull, 1965; see discussion in McGuire and Likens, 2011). Viewing hydrology as a geo- and environmental science, rather than an engineering problem-solving discipline, provided an impetus for the study of hydrology as a unified field of natural science (Nash et al., 1990). Scientific hydrology as such has three major stages: (1) careful observation of a phenomenon, (2) quantification and conceptualization, and (3) quantitative prediction (Nash et al., 1990).

A hydrologist who is to master all three aspects of scientific hydrology has to be well equipped with practical experience in observing and measuring hydrological variables, with in-depth process understanding and the knowledge to translate this into quantitative theory, and finally, he or she needs to be able to build and utilize models to make actual predictions. Training such a holistic hydrologist requires a coherent and comprehensive science (Nash et al., 1990). Hydrology does not generally present itself in such a coherent way though, leading to hydrologists with a restricted or uneven background. Wagener et al. (2007) surveyed the approaches and opinions of hydrology educators and concluded that this lack of coherence is still very present. Even if such a coherent image could be find at this time, the increasing impact of climate change (largely propagated to society through the hydrological cycle) and the deepening footprint of human activity force us to re-evaluate the suitability of many of our methods and therefore create an exceptional opportunity to advance the education of hydrologists (Firth, 1999; Wagener et al., 2010; LeDee et al., 2011). An older statement that *"the present structure of hydrological education, generally tailored to the needs of specialized non-hydrological disciplines, is ill-fitted to cope with present and future requirements "* (Nash et al., 1990), seems to still hold true. *"Hence, if we are not paying merely lip service to the science of hydrology, we should make an effort to provide it with an adequate educational basis"*... (Klemes quote in Nash et al., 1990). So how do we achieve a coherent image of hydrology as an educational subject in the presence of new demands?

1.3 Opportunities through open education

In addition to the societal needs discussed above, there are opportunities and developments outside the field of hydrology that make this an opportune moment to advance and revitalize standards for hydrology education. Hydrology education could become a trendsetter in educational advancement due its cross disciplinary and problem-driven nature, which demand educational advancement more than other fields of study, if opportunities are utilized. Two important developments provide such opportunities: (1) the move towards more interdisciplinary research, and (2) the advancement of open education.

Current societal problems such as climate change demand integrated interdisciplinary solutions that enable us to understand the complex interaction of drivers and responses at scales relevant for decision-making. While it is easy to demand interdisciplinary science, it is practically difficult to achieve, for example because it is often not supported by the current reward structure at many universities (Rhoten, 2004; Rhoten and Parker, 2004). Hydrology has a long tradition in interdisciplinary research (e.g., Sorooshian et al., 2002; Sivapalan et al., 2003; Wagener et al., 2010) and interdisciplinary teams now even approach problems previously considered the domain of hydrology alone, e.g., hillslope hydrology (e.g., Brooks et al., 2010). Much historical advancement in hydrology came from the adaptation of methods from other disciplines, e.g., from sanitation (Darcy, 1856), from linear systems theory (Dooge, 1973) or from geochemistry (Libby, 1953; Sklash et al., 1976; Pinder and Jones, 1969). In the future, this trend could also be reversed. Other fields such as climate science, ecology, or pedology strongly intersect hydrology based on the realization that water is either an important driver or a relevant endpoint for predictions. Hydrology education must include the knowledge to work at such interfaces.

The second relevant advancement that has to be considered for the evolution of hydrology education is the strong push for open education (Mogk and Lee, 1997; Muramatsu, 2000; Muramatsu et al., 2000; Manduca et al., 2001; Baraniuk et al.,

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2002, 2004). Projects such as Connexions, MERLOT, MIT Open Courseware, DLESE, NSDL, NEEDS or the NWS COMET program offer freely available course material that can be downloaded by everybody. However, availability of material does not equal uptake and utilization. Hydrology material might often only represent a small component of a large database of teaching materials, often produced for a specific type of student (e.g., geology), developed by an instructor with particular training and preferences etc. For improved hydrologic education standards, scientific community use, constructive criticism and refinement of such material is critical. Many successful examples of actual community developed tools and materials already exist. One interesting community (bottom-up) developments is the LINUX operating system. The community-based development of this software through criticism and error correction brought about one of the most widely used operating systems in the world (Lee and Cole, 2003). While everybody can contribute software to advance LINUX, each contribution is carefully reviewed to ensure high quality. How can such a controlled community-development approach be transferred to hydrology education?

1.4 Objectives and scope

In this paper we review the current state of hydrology education based on community surveys as well as on our own personal experiences. We identify shortcomings and opportunities, and outline a way forward in which education can facilitate the advancement of hydrology in both research and practice. We support this vision with practical examples of our Modular Curriculum for Hydrologic Advancement (MOCHA) project in which we implement and test the proposed way forward.

2 Historical evolution and current state of hydrology education

The state of hydrology education has been reviewed multiple times in past (incl. Wilm, 1957; UNESCO, 1972, 1974; Nash et al., 1990; Eagleson et al., 1991; MacDonald,

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1993, James, 1993). One of the most prominent reviews of hydrology as a whole can be found in the so-called Blue Book from 1991. In it, Eagleson et al. (1991) identified the following needs for hydrology education:

- Organization of a solid (perhaps senior-level) undergraduate course in scientific hydrology.
- Define hydrology education of a unified field of natural sciences.
- The need for a coherent and comprehensive science in its educational image.
- The inclusion of human activity into hydrology.
- More field and laboratory experience.

We do not believe that these needs have yet been fulfilled, but rather that some of the issues have become more rather than less problematic. With respect to their last point, Eagleson and colleagues were of the opinion that that lack of field and laboratory experience had already *"reached crisis proportions in many universities"* (Nash et al., 1990; see also Philip, 1992; Trop et al., 2000; and Pearce et al., 2010). The value of field research for enhancing scientific understanding in hydrology is undisputed and has been demonstrated through a wide range of educational studies (Carlso, 1999; de Wet, 1994; Dunnivant et al., 1999; Hudak, 1999; Trop et al., 2000), but decreasing funding and increasing student numbers have further reduced the availability of hands-on experience during college education at many universities. The subsequent discussion below and our own work has been focus on advancing the other four points though.

Recent surveys (Bourget, 2006; Wagener et al., 2007) demonstrate the confused self-image of hydrology education at this time. Bourget (2006) reviewed the Integrated Water Resources Management (IWRM) curriculum in the United States using a survey to which over 600 people from academia, government and consultancy responded.

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While everybody agreed that the interest in IWRM is high, there was a lack of agreement among survey participants regarding what constitutes an appropriate curriculum and in which discipline it should be housed. In this particular survey, watershed hydrology and watershed modeling were seen as the dominant area of education/training interest, since they were selected by 86 % of the respondents.

Purely focusing on hydrology, Wagener et al. (2007) surveyed over 150 hydrology educators at Universities in the US (71 %) and in Europe. About 35 % of educators surveyed where at the time teaching in engineering and the rest in science departments. 43 % reported engineering as their highest degree, while the others reported various science degrees. The survey results can be summarized as: (1) class characteristics (Fig. 1a): most survey participants taught relatively small classes with up to 25 students (54 %). Only 9 % of all instructors taught classes larger than 50 students. Participants described their classes as fitting into one of four categories: general hydrology (43 %), surface water hydrology (30 %), groundwater hydrology (17 %), and water resources management (10 %). With respect to the materials used for their classes, about 40 % of all survey participants reported that they not use any textbook as a class resource. In general, all survey participants used a wide range of material to create their lectures, and 68 % of the participants, who did use a primary textbook, took 50 % or less of their material from their primary text. (2) Preparation time (Fig. 1b): most participants in the survey stated that they spent 3–5 h to prepare 1 h of actual lecture time when teaching a course for the first time. A large number of respondents still spend 1–2 h of preparation per lecture when teaching the course subsequently. The variability in material used, and the extensive preparation time needed suggests that hydrology does not yet posses a common basis that would make preparing such a course easy. *"Hydrology educators are challenged to identify common principles, core knowledge, and approaches that should be included, in addition to areas where clear consensus is lacking"* (Wagener et al., 2007).

3 Current limitations in hydrology education

3.1 Hydrology education assessment

Most students have their first encounter with the hydrologic or water cycle for the first time in high school, if not earlier. The perception of the water cycle in the mind of many high school students lacks its dynamic, cyclic and systemic aspects, is incomplete and will include misconceptions (Ben-zvi-Assarf and Orion, 2005; Dickerson et al., 2006). Ben-zvi-Assarf and Orion (2005) concluded that this was a consequence of the traditional disciplinary approach to science teaching after questioning 1000 junior high school students (7th–9th grade) from six urban schools in Israel. Some of these misconceptions prevail even for university students (Dickerson et al., 2005), and/or may be enhanced due to errors of incomplete representations in general geoscience textbooks (Wampler, 1997, 2000). The starting point for hydrology education at the university level is therefore at best an incomplete picture of the hydrological cycle. However, the increasing coverage of water-driven issues in the news (floods, droughts, impacts of climate change, pollution), and personal interaction with the hydrologic cycle (particularly extremes) have enhanced the public's appreciation for water security.

At the same time there seems to be an increasing interest in hydrology education research (Kastens et al., 2009). Some studies have for example assessed the value of computing in conveying concepts of data analysis or modeling in hydrology (Elshorbagy, 2005; Hossain and Huddleston, 2007; Wagener and McIntyre, 2007; Schwenk et al., 2009; Aghakouchak and Emad, 2010), which is less straightforward than it might appear (Whiteman and Nygren, 2000). Others have attempted to use watersheds as an integration scale even outside hydrology (Salvage et al., 2004). Additionally, there is an increasing societal recognition of water related issues and threats, as well as opportunities to enhance hydrology education through linking it to popular concepts such as sustainability or millennium development goals including access to clean water (Mihelcic et al., 2008), or risk in regard to natural hazards (Boynton and Hossain, 2010). Despite these opportunities there are continued calls for changes in

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hydrology education (Clifford, 2005; Ledley, 2008; Loucks, 2008; Manduca et al., 2008; Stakhiv, 2008; Wagener et al., 2010; Thompson et al., 2011), to satisfy the demands of a strong job market for hydrologists (van Vuren et al., 2009; Zimmerman, 2009; Milano, 2010).

So what is lacking in hydrology education today? The strong separation between science and engineering approaches to hydrology education has already been mentioned. We are convinced that an integration of qualitative and quantitative aspects into a holistic teaching approach to hydrology will continue to propagate through the educational system. There are other basic issues, such as a lack of a well-grounded applied mathematical understanding of many (even engineering) students in hydrology (Clark and Kavetski, 2011), and the problem of field-based teaching so students' develop the ability to measure and observe in a time of increasing class sizes and decreasing funds. Hydrology education, especially in engineering departments, has historically focused on teaching established and sometimes even outdated solutions to current (and sometimes past) problems. There is, however, an urgent need to focus on teaching an evolving skill set with a strong scientific basis that can be adapted to solving new problems with new tools and to understanding new phenomena (Wagener et al., 2010). New interdisciplinary approaches to education are required and we need the material to support such an education inside and outside the classroom.

3.2 Practical teaching problems in hydrology

Hydrology is commonly taught in different departments across campuses though a few departments fully focus on hydrology and water resources education for undergraduate students. The generally small number of undergraduate students enrolled in these programs indicates that the majority of hydrologists are educated within some other primary discipline. One consequence of this fact is that students are likely to encounter only a single hydrology class during their undergraduate studies. This limited exposure means that much has to be achieved – in terms of introducing an interdisciplinary field – in a single course.

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Typically, this course will be biased towards the instructor's expertise (How was he/she taught and his/her research field?), towards the department (What are the course pre-requisites and traditions? How does the course connect to other courses, e.g. a capstone class? Do the students have a more qualitative or quantitative background?), and towards the material used (Who wrote the textbook, with what kind of background and for whom?). As a result, the focus of the class is typically not consistent with the needs of an inherently interdisciplinary subject. Educators who want to break this cycle face a monumental task that includes the collection and preparation of material from multiple textbooks and from different disciplines. Following this, any hydrology educator has to educate himself/herself on multiple new topics before they can be integrated into the course. Furthermore, it is also valuable to continually modify class materials by including new discoveries or changes to hydrologic science as they are published and used by the broader hydrologic community. This is more difficult than it seems at first glance because it takes significant time and effort to learn the key material and concepts outside of our immediate sub-disciplines. The successful execution of such a task is especially infeasible for most new faculty, since effort has to be balanced with the writing of papers and proposals, the supervision of students, and other demands on young tenure track faculty.

This problem exists despite the fact that a variety of excellent hydrology textbooks are available. Examples of popular textbooks include Dingman (2002), Hornberger et al. (1999), Bras (1990), Beven (2000, 2010), Dunne and Leopold (1979), Brooks et al. (2003), Hewlett (1982), Ward and Trimble (2003), Chow et al. (1988), Brutsaert (2005), Shaw et al. (2010), and Hendricks (2010). However, none of these satisfy the broad requirements discussed above, because the authors typically have the same subject specific bias mentioned above, and because textbooks are typically static and do not evolve to integrate new research results, new measurement techniques, new exercises, or new topics – a problem that is significant in the quickly evolving field of hydrology.

We summarize our view of the limitations of currently available material for hydrology education and their consequences on teaching below:

- The time consuming task of finding and incorporating material into lectures leads to an unwanted focus on material preparation. This time is taken away from time that could be spent on actual teaching preparation (how best to teach the material to a specific group of students). While the internet has made finding new material a quicker process (especially multi-media material), McMartin et al. (2008) found that faculty have difficulty using internet resources in their teaching, specifically because of: lack of time to learn about the material, difficulties of finding usable material, and lack of training on how to use the material. There is also typically a lack of background information on and description of the material one finds on the web.

- Information is rarely available about how to best convey this particular knowledge to students in the classroom. Pedagogical guidelines and standards often do not accompany available course materials and are vital for new educators.

- No single suitable textbook exists that can accommodate the interdisciplinary nature of hydrology. A large number of textbooks have to be distilled and it is often daunting to extract the relevant information. Our survey (Wagener et al., 2007) shows that common textbooks used by faculty do not just include different hydrology texts, but books on meteorology, soil science, probability/statistics, fluid mechanics and others.

- A collage approach of collecting material leads to a lack of continuity in the material presented to the students. Hydrology courses include teaching a wide variety of processes and their mathematical descriptions.

Should the instructor decide to adopt a single (main) textbook (despite the above mentioned problems), so students can read the relevant chapter before (or after) a certain topic is covered, other limitations become imminent, mainly the need to (reasonably) follow the linear structure provided by the textbook.

4 Hydrology education 2.0 – the Modular Curriculum for Hydrologic Advancement (MOCHA)

The Modular Curriculum for Hydrologic Advancement (MOCHA) is establishing an online faculty learning community for hydrology education and a modular hydrology curriculum based on modern pedagogical standards. MOCHA has currently (November 2011) 384 members from 43 countries. The majority of users are from the USA (39 %) and Europe (42 %), though 10 % of members are from Asia or Africa. *"The purpose of creating faculty-learning communities is to provide colleagues with a means to learn from one another unconstrained by barriers of time, distance, technology, and geographic location"* (Puzniak et al., 2000). A community can be defined as *"a dynamic whole that emerges when a group of people share common practices, are independent, make decisions jointly, identify themselves with something larger than the sum of their individual relationships, and make long-term commitments to the well-being of the group"* (Shaffer and Anundsen, 1993). The overall objective of the MOCHA module development activity is to create a continuously evolving core curriculum that overcomes traditional disciplinary biases and is freely available to, developed, and reviewed by the worldwide hydrologic community. This project is implemented using a web-portal to support this community-driven curriculum development.

MOCHA is advancing educators' abilities to challenge students to address complex and interdisciplinary problems across the field of hydrology. MOCHA provides hydrology educators with the tools and materials to be efficient and successful teachers, while enabling students to gain (in-class) access to current, peer-reviewed, high quality education resources. Diverse contributors are working collaboratively to create material that addresses a wide range of student learning styles and needs (Fig. 2). Furthermore, MOCHA is creating and institutionalizing an interdisciplinary hydrology learning

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community that can serve as a model for other STEM (science, technology, engineering, and mathematics) fields.

Creating the material to teach a hydrology course is a very time intensive activity. Many topical areas have to be covered while the instructor generally only has research experience in a few of those areas of study. Thus, certain parts of a hydrology course may be very strong, and others sub-optimal because one has to cumbersomely collect material from textbooks, the web etc. Additionally, implementing good classroom practice involving active learning through creation of like case studies, or through co-operative and problem-based learning is time consuming (Lynn, 1999; Smith et al., 2005). The MOCHA project directly addresses these issues by providing the hydrological community with free teaching material available in an easily accessible and classroom friendly format. The community development of material facilitated through MOCHA provides us with an opportunity to inquire about what could be achieved. How good could a watershed hydrology course be if all aspects of the course would be covered by one or more experts in this particular aspect of hydrology, rather than having the whole course created by a single hydrologist? How holistic would the approach to hydrology education be if both scientists and engineers jointly cover both the qualitative and quantitative aspects of watershed hydrology? How much improvement would be possible if basic pedagogical guidelines would be followed throughout a course?

4.1 Control volume approach as integrating principle

Students often perceive hydrology as a random collection of empirical equations to describe a wide range of different processes. This lack of coherence hinders their development of a holistic picture of the field of hydrology and often leads to a dislike of the field, certainly in engineering students. Rather than offering a consistent approach to solve hydrological problems, most classes and textbooks demand that the students learns individual solutions for a specific problem. Few textbooks provide a consistent approach for deriving equations describing different hydrological processes. Chow et al. (1988) is the first hydrology textbook (to our knowledge) that does

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offer a consistent approach by using a control volume approach throughout. Despite its age, it remains a widely used hydrology textbook (Wagener et al., 2007). We propose, similar to Chow et al. (1988), to use a Control Volume (CV) approach to achieve consistency (Fig. 2a), and to use the Reynolds transport theorem as the analytical starting point to describe fluxes in this CV context. Engineering students will be familiar with CV theory from their fluid mechanics class, which is typically a prerequisite for hydrology. Using the same CV approach in hydrology creates a consistency, which helps the students to see that the same physical principles rule hydrology and that the simplifying assumptions made in the derivation of equations for different processes leads to the diversity of solutions found. The simple conceptual basis of the CV approach makes it also a very suitable tool to teach hydrology to students are more restricted than engineering students in their mathematical abilities. There is not need to start with Reynolds Transport Theorem for non-engineering students, because the basic idea that the change in storage equals input minus output can still be conveyed.

4.2 Pedagogical guidelines for lesson design

At many universities there will be no lack of opportunity for young faculty members to receive training in teaching. Alternatively there might be general programs that offer such guidance, like the ExCEEd program of the American Society of Civil Engineers (ASCE) (http://www.asce.org/exceed/). However, time constraints (a major issue for junior faculty who are trying to get their research program started) or lack of general infrastructure to support university teaching in less developed countries (Hughes, 2011) might still limit training opportunities. We therefore believe that it is crucial for an education initiative such as MOCHA to propose a set of basic (but important) pedagogical guidelines to provide a foundation for hydrology educators everywhere.

As a first step toward addressing the need for guidelines, we list 16 pedagogical guidelines, as an *ABCD of lesson design* (Fig. 2b). The lettering refers to the time period when the guidelines are valuable for the instructor in the teaching process: (A) planning the lesson. (B) Beginning the lesson. (C) During the lesson. (D) Ending

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the lesson. Table 2 lists the main points for good lesson design. These points are not specific to hydrology education, but provide a general reminder of good practice for instructors who previously received training; or provide a starting point for further reading if the instructor has not had such an opportunity.

Another important pedagogical tool included in every module is the specific listing of *learning objectives*. The learning objectives have to be specific by the module developer for the students. Module developers are also required to add statements about how the students should go about testing whether they have achieved the learning objectives.

4.3 Teaching notes to share how we teach

General pedagogical guidelines are helpful and a wide range of sources for guidance is available. More problematic, and generally unavailable, is access to specific guidance on how to teach the material at hand. The support needed here goes beyond reading textbook discussions of the material covered. While one could easily assume that the problem of finding suitable teaching material has gone away with the advancements made in Google web searches, this is not correct as stated in Sect. 3.2 (McMartin et al., 2008). Simply providing access to the material is insufficient. The time and effort needed to turn this material into an actual, effective lecture or into other types of learning material is still very high (see Wagener et al., 2007, and Fig. 1 in this paper).

In addition to providing the material to be used in class, we need to educate the instructor (where needed) on how to use the material! Teaching notes are the chosen solution to this problem in MOCHA (Fig. 2c). All MOCHA modules include teaching notes (in the notes section of PPT), which provide suggestions on how to convey the material presented on each slide. Such teaching notes allow the instructor to benefit from the experience gained by the module creators. Teaching notes might include an opening question to a figure or a graph, a strategy to explain a difficult aspect of the material, or it could discuss a common stumbling block for the students to understand the material. The notes section of each slide also includes references with information

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about the information presented on the slide, so that instructors may refer to material sources when in search of information beyond the teaching notes.

4.4 Power Point design based on education research

Microsoft PowerPoint (PPT) is the most widely used presentation package and therefore our software of choice. We developed a general PPT template, which is the basis for each MOCHA module (Fig. 2d). In this way we achieve seamless connectivity between modules through a common template; and a common look and feel that lets any collection of modules used in class appear as a single coherent set of lectures. It also enforces some of the pedagogical guidelines, through inclusion of learning objectives, interactive activities for students, etc.

The use of PPT has often been widely criticized, *... PowerPoint has a dark side. It squeezes ideas into a preconceived format, organizing and condensing not only your material but – inevitably, it seems – your way of thinking about and looking at that material* (Keller, 2004). The issue of how PPT shapes your style of presenting and how this limits communication has been discussed in detail by Tufte (2003), who concludes: *"In particular, the popular PowerPoint templates (ready-made designs) usually weaken verbal and spatial reasoning, and almost always corrupt statistical analysis"*. There are remedies to some of these issues and we utilize some that have been shown to significantly enhance memorization and learning using PPT (Alley, 2003). A main problem with PPT slides is that the design defaults tends to oversimplify and fragment the subject matter at hand. As a remedy for these problems we use an assertion-evidence structure. In the assertion-evidence design, a statement, assertion or headline is placed at the topic of the slide, in the area usually reserved for a short topic. Evidence to support this assertion is then placed in the body of the slide. This evidence should be visual whenever possible (e.g., images or graphs). For example, bulleted text can often be reduced to keywords supported by photographs or graphics. This is more interesting while it should not limit our ability to memorize the content, since we generally remember keywords, rather than full sentences. Alley and colleagues have

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shown in multiple studies that such design, and some additional design guidelines related to organization, typography and layout, significantly increase audience interest and material retention (Alley and Neeley, 2005; Alley et al., 2007; Garner et al., 2009, 2011).

4.5 In-depth PPT slides for higher-level material

It is not sensible to even attempt to develop a single set of PPT slides suitable for all instructors and all types of students (engineering or science, junior or senior etc.). Providing material that is sufficiently rich and diverse so that it can be easily adapted to a wide range of course, without being overwhelming in total volume. This step is crucial if wide scale adoption of MOCHA is the objective! Any MOCHA module therefore contains more slides than an individual instructor is likely to use (or even should use). The level of depth that instructors choose to their students will depend on a range of considerations, including: their background, their familiarity with the material, their degree department (science or engineering?), and their undergraduate year standing. If each MOCHA module includes excess material, then it is sensible to provide instructors with guidance on how to select the appropriate material for the students in their class.

MOCHA modules include so-called in-depth slides so that instructors can tailor the material to the specific needs and abilities of their students. For example, a derivation of Richard's equation might be something to be included in some engineering or physics-based courses, while it may not be appropriate for science students. On the other hand, science students might want to gain more in-depth understanding about underlying processes. In-depth slides are visually marked by whether they refer to in-depth study of theory or processes (Fig. 2e). The ease with which modules can be adjusted also supports the module use for course in which hydrology is only a side-topic, rather than the main focus.

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4.6 Classification of PPT slides by spatial scale and focus

Differences in the preferred course structure and teaching style between instructors became apparent during the development of the first MOCHA modules. Subsequent discussions highlighted very quickly that the order in which instructors present material to their students varies widely, in addition to what is presented in the first place as discussed in the previous section. In their courses, some instructors started with a discussion of processes and observations, and then added the mathematical treatment and the solving of problems, while others moved from local, to plot to catchment scale. We therefore strived to develop material that allows for an easy adaptation to different teaching structures. While it is generally accepted that different students have different preferred learning styles (Felder and Brent, 2005), different instructors also have different approaches to teaching (Felder and Silverman, 1988; Prince and Felder, 2006). The MOCHA material should therefore accommodate different teaching styles. Each MOCHA slide is therefore classified in two ways. First, we classified slides by the spatial scale (point, plot or catchment) to which the material on the slide refers. In addition, each slide is marked as whether it relates to theory, processes or observations. This information makes it easy for instructors to organize slides by scale or by focus, hence adapting the material to their own preferred style. This slide classification allows instructors to organize their lectures in PPT "Slide Sorter View" with very little effort (Fig. 2f), building additional efficiency into the lecture generating process.

5 Initial assessment of MOCHA

Some preliminary assessment of the MOCHA modules has already taken place. The *Infiltration* module was first assessed in three courses across the United States during the fall of 2008 to gain feedback from professors and students. Modules were taught in three different departments, Land Resources and Environmental Sciences (Montana State), Civil and Environmental Engineering (Penn State), and Environmental Sciences

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and Policy (Plymouth State), to evaluate a cross-section of student and professor backgrounds. Following classroom use, students were referred to a website with a series of questions about their background and their opinions on the module.

Student backgrounds ranged across several engineering and science disciplines (Fig. 3) and class years, including both graduate and undergraduate students. A total of 110 students were surveyed. On the whole, students responded positively to the modules. Results from the three different courses were combined, and are presented in Fig. 4. The majority of students found module material to be interesting (Fig. 4a) and indicated that they understood module material (Fig. 4b). To assess the module pedagogy, specifically the learning objectives, we asked students if what they were supposed to learn from the module was clear. Figure 4c shows that students responded positively, with 74 % in agreement. Another interesting result of the assessment was that 90 % of the students (Fig. 4d) also agreed that their instructor was comfortable using the module despite a large proportion of the material not being directly linked to their own research topics and education.

Tracking of downloads indicates that over 50 % of MOCHA members have downloaded the *Hydro-Ecology* and *Infiltration* modules and the Pedagogical Guidelines for designing a good lesson. During the fall of 2009, we polled the MOCHA community to gage whether and how modules were being used in the classroom. Responses indicated that the majority of professors were tailoring the module materials to their specific classes, using parts of the module to augment their own material.

6 From MOCHA to a faculty learning community

The current focus of MOCHA is the development of a modular curriculum for an upper level undergraduate course in hydrology – suitable for both science and engineering students. Such a course, developed, reviewed and evolved by a large number of diverse hydrology educators would represent a first milestone towards the creation of an online faculty learning community in hydrology. Future activities will include the development of a web-portal that can facilitate review, assessment, and updating of modules; host multi-media elements to support different topics; provide meta-data for the modules present etc. Such cyber infrastructure will be crucial for the longevity of the project. Especially this portal should host:

- Case studies that can be given to the students as homework assignments – individually or as groups. These should cover very different hydrologic applications (e.g., flood frequency analysis or the characterization of the hydrologic function of a catchment) and very different regions of the world.

- Multi-media elements that provide additional insight into measurement methods, into the diversity of catchments found around the world, or into more advanced guidance for programming models or data analysis algorithms.

- Stand-alone modules (potentially even online modules), which contain material that the students should not study in the classroom, but by themselves. This material could for example include reviews of material that should have been covered elsewhere, e.g., basic statistics or mathematics.

- A model base with algorithms that the students can download and use to support their homework assignments or in term projects (Wagener et al., 2004). Such algorithms need to be accompanied by sufficient documentation and data examples.

- Examples of how to teach students in the field using adequate observation and measuring techniques.

Ultimately MOCHA could provide: (1) a global baseline for hydrology education, (2) an overview over existing knowledge and knowledge gaps in hydrology, and (3) a place for discussions on hydrology education advancement.

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7 Conclusions and outlook

The changing demands on hydrology as a science and as an engineering discipline offer an exceptional opportunity to advance hydrology education (Wagener et al., 2010). We need to enable the education of researchers and practitioners *"who can better address the complex interactions within natural systems and between humans and the environment "* (NSF AC-ERE, 2005). We need integrative educational platforms to span the bridge traditional disciplinary boundaries. In this paper, we review educational developments in hydrology up to now, take a look into the future, and present a community-based framework in which we establish a faculty learning community centered around a modular hydrology curriculum (MOCHA).

We believe that such a project can have direct and significant implications for global hydrology education, as well as broader implications for our field as a whole. We see hydrology education as an opportunity to: (1) create a baseline (even if it is shifting) by organizing our knowledge, (2) identify our knowledge gaps, and (3) create a faculty learning community in which we collaboratively create the interdisciplinary education hydrology demands. We have made the first steps towards achieving these goals. However, seeding an idea is only the beginning. Many good ideas in the area of education never achieve large-scale adoption (Baker, 2007; Henderson and Dancy, 2010). We believe that we have built the momentum to overcome this problem and the increasing number of MOCHA community members is supporting this opinion, but an active collaboration and interaction among the members will be a requirement to fulfill this goal.

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Table 1. The ABCD of lesson design (http://www.mocha.psu.edu/lesson-design).

A. Planning the lesson
(1) Identify the skills and knowledge your students are coming in with so you can address the appropriate level of content.
(2) Plan your lesson in approximately 20 min chunks of lecturing, interspersed with 5–10 min of activity (e.g., discussion or problem) to keep the students refreshed and engaged.
(3) Ensure that your slides and presentation materials are well designed and clear (see MOCHA template).
B. Beginning the lesson
(4) Begin every module/unit/lesson with a list of objectives for the lesson. Objectives help students to focus on what they have to learn and also provide a goal for the session.
(5) Objectives should be short, clear statements about what a student will be able to do at the end of a lesson. E.g., "Students will apply available measurement techniques (for properties, fluxes and states) including their limitations".
(6) Phrase objectives in **SMART*** terms – i.e., so that they are: (a) **S**pecific – Avoid using words like understand or appreciate. Use an active verb that describes what students can do as a result of learning (b) **M**easurable – Use concrete outcomes to frame student learning, i.e., "students will accurately describe problems related to XXX", as opposed to "students will appreciate problems related to XXX". (c) **A**chievable – Ensure that the objectives are achievable within the scope of the lesson, i.e., "students will solve problems related to XXX", as opposed to "students will solve problems". (d) **R**elevant – This indicates that the objectives are relevant to the content being addressed. Avoid writing objectives about material that is not being addressed in the specific unit. (e) **T**imely – This is not always needed, but is used to indicate any time frame attached to achieving the objective.
(7) Activate student attention and establish instructional purpose – If you grab student interest in the beginning, they are likely to pay more sustained attention through the lesson. For example, use a current problem or novel and paradoxical events related to the topic; make a clear link between the content and students' prior knowledge – tell them why it matters to them; make it clear how the present learning relates to other learning tasks.

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Table 1. Continued.

(8) Provide a structure or an advance organizer for the information you want to present – Use an outline or a chart or graphic to demonstrate what information you plan to present and in what sequence – this should help students identify what's coming next.
(9) Trigger students' previous knowledge about the topic – Try to make connections between what students already know and the content you are trying to present. Students are likely to remember information better when they can link it to knowledge that they already have.
C. During the lesson
(10) Arouse interest and motivation throughout the lesson – Relate the lesson objective to future job requirements and make instructional goals relevant to students' personal lives.
(11) Use different strategies to deliver information – Useful strategies include using graphics or videos to enhance slides, using examples and metaphors to clarify concepts, presenting smaller and more simple chunks of information before presenting bigger and more complicated chunks of information, talking through the steps and reasoning involved in different procedures, and engaging students in small exercises and group work to solve problems and case studies.
(12) Focus attention – Focus your attention on the students' reactions, and use teacher effect such as gestures, eye contact, animation, vocal inflection, enthusiasm, etc to give students your feedback.
(13) Practice – Give students the chance to practice what they have learned. Every 10–20 min or after every ~5 slides, insert some questions based on the material just presented. This gives students a chance to show what they have learned and also breaks up the monotony of a long lecture.
D. Ending the lesson
(14) Summarize and review – Summarize and review what you have taught in order to reinforce the students' knowledge.
(15) Transfer knowledge to new settings – Explicitly state how the newly learning information can be applied in different settings.
(16) Assess student knowledge – Use a quick quiz or ask a series of questions of the students to assess student learning. Also, from students' feedback, you can evaluate your teaching and remediate your lesson plan for next time.

* Doran, G. T.: There's a S.M.A.R.T. way to write management's goals and objectives. Management Review, 70(11), p. 35, 1981.

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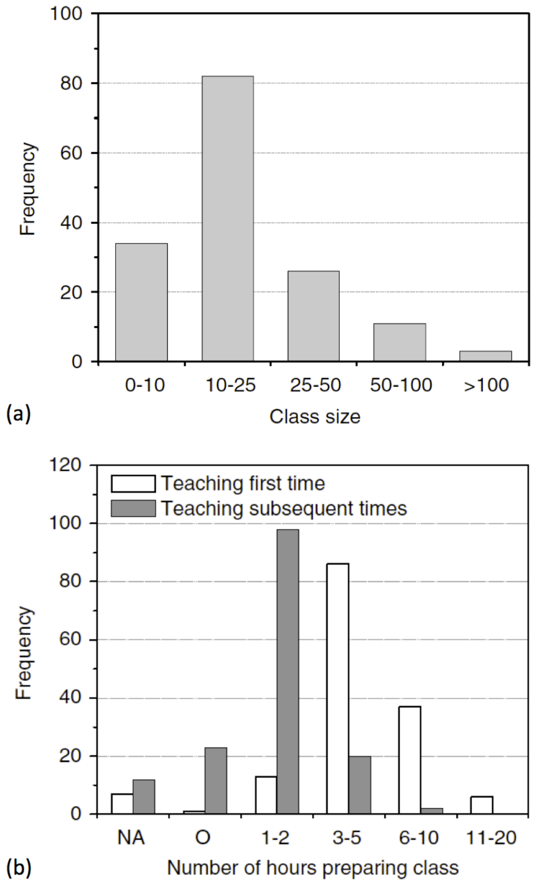

Fig. 1. Survey results showing class sizes and preparation times of hydrology educators (from Wagener et al., 2007).

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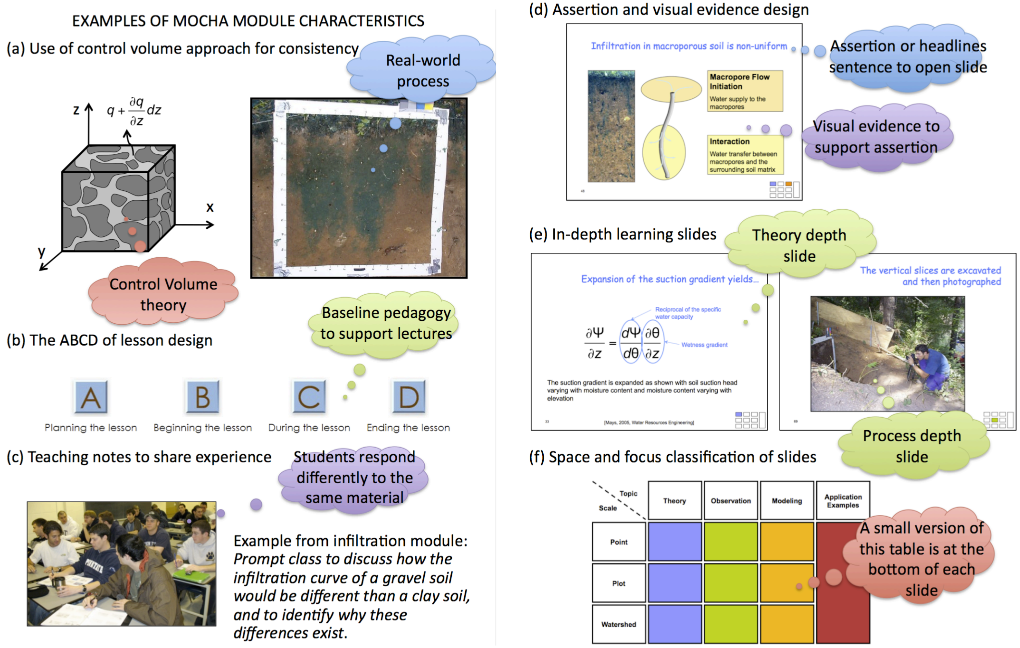

Fig. 2. Main characteristics of the MOCHA PPT modules.

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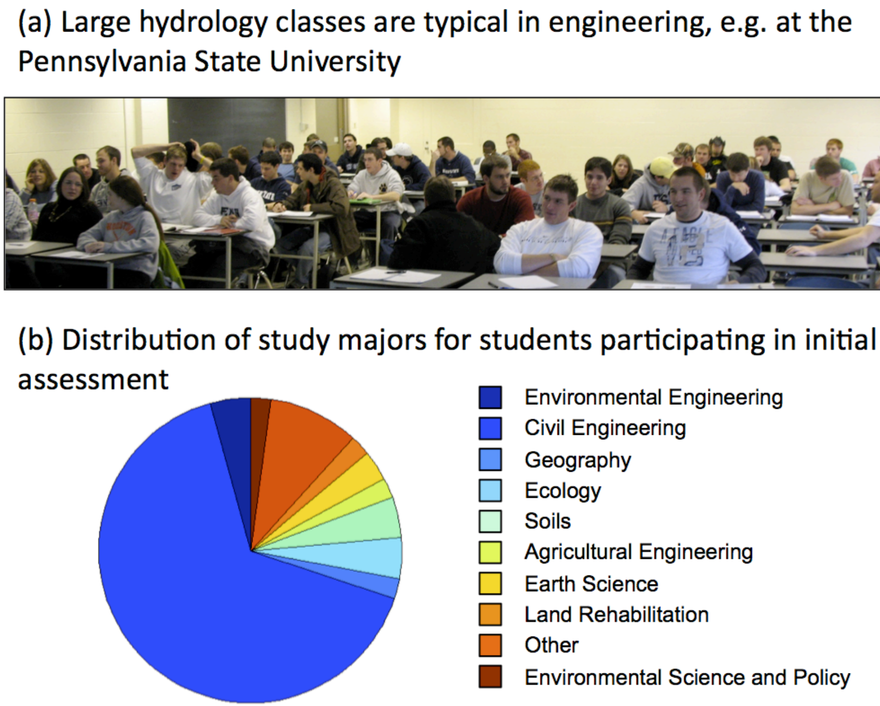

Fig. 3. Major disciplines for the 110 students included in the initial module assessment.

Discussion Paper | Discussion Paper | Discussion Paper | Discussion Paper |

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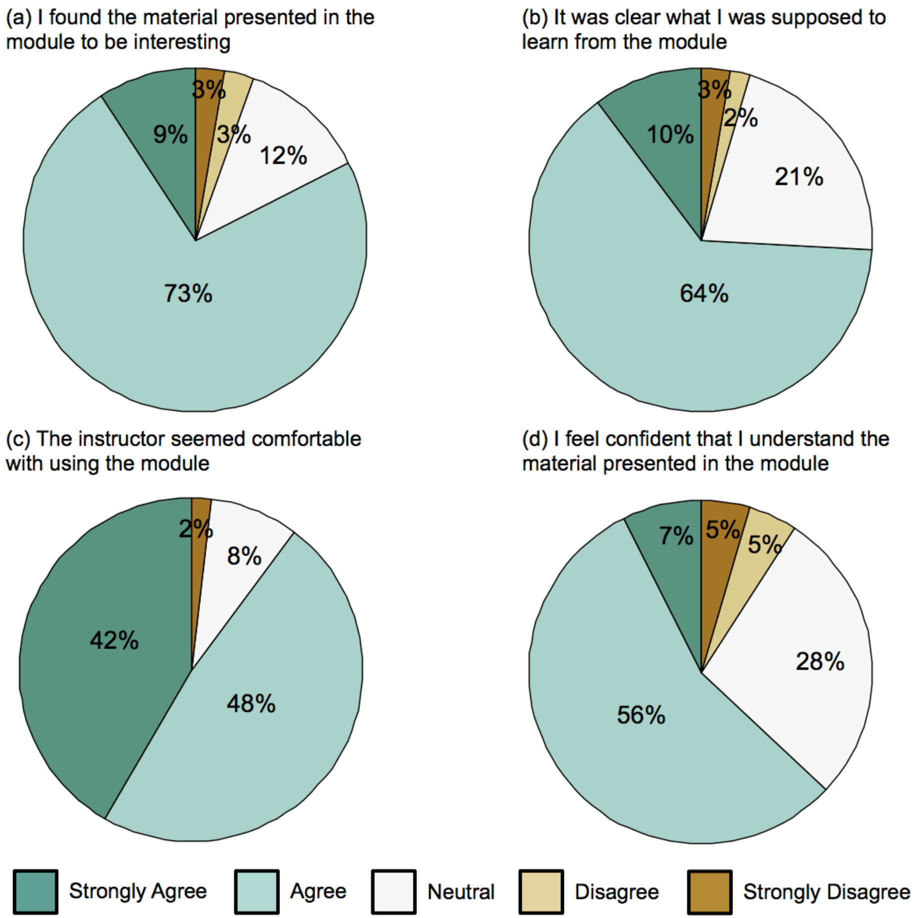

Fig. 4. Student responses from the initial module assessment at Plymouth State (5 students), Montana State (27 students), and Penn State (78 students).

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It takes a community to raise a hydrologist

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