

This discussion paper is/has been under review for the journal Hydrology and Earth System Sciences (HESS). Please refer to the corresponding final paper in HESS if available.

Engaging the students of today and preparing the catchment hydrologists of tomorrow: student-centered approaches in hydrology education

I. Ngambeki¹, S. E. Thompson², P. A. Troch³, M. Sivapalan⁴, and D. Evangelou¹

¹School of Engineering Education, Purdue University, West Lafayette, IN, USA

²Department of Civil and Environmental Engineering, University of California, Berkeley, CA, USA

³Department of Hydrology and Water Resources, University of Arizona, Tucson, AZ, USA

⁴Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign, IL, USA

Received: 15 December 2011 – Accepted: 19 December 2011 – Published: 13 January 2012

Correspondence to: S. E. Thompson (sally.thompson@duke.edu)

Published by Copernicus Publications on behalf of the European Geosciences Union.

HESSD

9, 707–740, 2012

**Student-centered
approaches in
hydrology education**

I. Ngambeki et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Abstract

As hydrologists confront the future of water resources on a globalized, resource-scarce and human-impacted planet, the educational preparation of future generations of water scientists becomes increasingly important. Although hydrology inherits a tradition of teacher-centered direct instruction – based on lecture, reading and assignment formats – a growing body of knowledge derived from engineering education research suggests that modifications to these methods could firstly improve the quality of instruction from a student perspective, and secondly contribute to better professional preparation of hydrologists, in terms of their abilities to transfer knowledge to new contexts, to frame and solve novel problems, and to work collaboratively in uncertain environments. Here we review the theoretical background and empirical literature relating to adopting student-centered and inductive models of teaching and learning. Models of student-centered learning and their applications in engineering education are introduced by outlining the approaches used by several of the authors to introduce student-centered and inductive educational strategies into their university classrooms. Finally, the relative novelty of research on engineering instruction in general and hydrology in particular creates opportunities for new partnerships between education researchers and hydrologists to explore the discipline-specific needs of hydrology students and develop new approaches for instruction and professional preparation of hydrologists.

1 Introduction

There is an increasing need to understand the dynamics of water resources as key determinants of development, human and environmental health, conflict and sustainability (Gleick and Palaniappan, 2010; Postel and Wolf, 2001; United Nations Development Program, 2011). The context of the global water crisis provides a strong motivation for universities to train cohorts of hydrologic professionals who can provide expertise in interpreting, predicting and managing the dynamics of water in the 21st century.

HESSD

9, 707–740, 2012

Student-centered approaches in hydrology education

I. Ngambeki et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Sustainable management of water resources is challenging for many reasons: the global nature of water scarcity, the complex interconnections between hydrologic dynamics and a myriad of physical, biological, social and economic processes that take place in catchments (Rockstrom et al., 2009; Vorosmarty et al., 2010; Crutzen and Stoemer, 2000), and the difficulties that global changes in climate and land use pose for prediction (Milly et al., 2008). In this context, the hydrologic community needs to critically appraise the teaching of hydrology, not only in terms of the content of hydrologic courses, but also in terms of the way that the subject is taught as it impacts the professional development of future hydrologists.

The science of education research expanded significantly during the latter half of the 20th century (Piaget, 1954; Smock, 1981; Zimmerman, 1981), with a specific focus on engineering education emerging in the past 10 yr (Shulman, 2005). This body of research into how students learn, and into the kinds of educational efforts that can promote desirable educational outcomes offers a valuable resource to hydrologists as they confront the challenge of evaluating and reforming hydrology education.

The aim of this paper is to provide a summary of some of the theoretical developments in educational research that are pertinent to the teaching of hydrology, to illustrate these concepts with hydrological examples, and to review our attempts to apply these developments in our own classrooms and within targeted hydrology summer schools. Despite the expansion of engineering education research there remains a dearth of research specifically targeting hydrology education, meaning that we have relied largely on anecdotal accounts when discussing hydrologic examples, and upon examples from the broader literature to provide empirical data. The only clear way to overcome these limitations is to engage upon a program of educational research within hydrology, and the paper concludes with a discussion of where the opportunities for such research might lie.

To avoid confusion between different disciplinary foci within hydrology, the paper primarily addresses educational issues associated with teaching catchment hydrology at an upper undergraduate – graduate level. The arguments may therefore reflect the

Student-centered approaches in hydrology education

I. Ngambeki et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



perspectives of catchment hydrologists, but we hope that they will prove relevant to teaching and learning across multiple hydrologic sub-disciplines.

2 Hydrology graduates: traditional requirements and modern challenges

Lying at the interfaces of many disciplines and perspectives, there are multiple dimensions to knowing and understanding catchment hydrology (Wagener et al., 2010; Vogel, 2011). The working definition of a catchment hydrologist for our purposes is someone who is engaged in the quantitative study of the terrestrial water cycle at the scale of individual catchments (Wagener et al., 2004). Two opposing approaches to conceiving catchment hydrology can be outlined: the first based on the application of fundamental physical laws – specifically the conservation of energy, mass and momentum – within boundary conditions set by the natural environment. Dooge (1981) referred to this reductionist, process-based approach as providing the “internal descriptions” of the catchment. Alternatively, hydrologists may study the dynamics of the overall catchment system without references to the detailed structure of its components. The nature of the functioning of the system is inferred from the input and output observations. Despite the process complexity at small scales, catchment responses at large scale are often rather simple (Sivapalan, 2003). Dooge (1981) calls this macroscopic approach the “external description” of the catchment. Both approaches have strengths and limitations: the internal description perspective is challenging to apply at large spatial scales, because natural systems are heterogeneous, contain complex forms of spatial and temporal organization, and are usually impossible to completely observe; while methods based on external descriptions are difficult to extrapolate to different places or different times.

There are many traditional tools that are used to make hydrologic predictions from both perspectives (e.g. flood frequency analysis, rational method, US-SCS curve numbers, unit hydrograph approaches, Green and Ampt infiltration equation). These tools have strengths and are often embedded in standard approaches for hydrological

Student-centered approaches in hydrology education

I. Ngambeki et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Student-centered approaches in hydrology education

I. Ngambeki et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



prediction, but are also subject to limitations (Wagener, 2007; Beven, 1993), which may be exaggerated under scenarios of land use and climate change (Sivapalan et al., 2003; Milly et al., 2008). As human activity increasingly drives hydrological dynamics, hydrologists are also forced to confront the interaction of natural and engineered systems, and of water resource management decisions on the dynamics of the hydrologic cycle, in effect expanding the domain of the discipline as a whole (Gupta et al., 2000). Numerous calls have been made to the hydrology community to alter its perspectives from a “business as usual” model to one which can respond to the challenges posed by global change (Gupta et al., 2000; Dooge, 1986, 1988; Torgersen, 2006; Hooper, 2009).

This emerging perspective in many ways requires a unification of the internal and external approaches. It challenges students to generate new knowledge, expertise and experiences that represent a synthesis of process knowledge and knowledge gained from interpreting data relating to hydrologic response directly at the catchment scale.

Hydrology education must provide students with the ability to approach the hydrologic prediction problem from both perspectives, and provide experiences to gain the depth of understanding to synthesize the knowledge and understanding derived from each one. Comprehending this level of complexity, and the duality of these ways to conceptualize hydrologic processes, requires higher-order, reflective, metacognitive and critical thinking skills.

Future hydrological scenarios are characterized by uncertainty, associated with non-stationarity, human influences, climate change and an increased appreciation of the non-local and complex interactions between hydrological processes and other environmental processes. Future hydrologists must undertake their work in the face of this uncertainty. In these contexts, scientists who make decisions based on didactic rules are unlikely to produce useful contributions. Interpreting data, formulating, developing and testing conceptual models, and critically testing ideas, however, will be essential, as will the ability to work across disciplines and across geographic areas (Gupta et al., 2000; Dooge, 1986, 1988; Torgersen, 2006; Hooper, 2009).

The challenge for the modern education of hydrologists, then, is to firstly provide graduates with a strong understanding of the fundamental theories, tools, methods and approaches of contemporary hydrology, and also, hopefully, with positive feelings about hydrology (educational outcomes in the affective or emotional domain) (Bloom, 1956).

Beyond knowledge, however, hydrology education is now challenged to prepare creative graduates with skills in critical thinking, collaboration, interdisciplinary communication, and with the intellectual confidence to proceed in an uncertain environment. Not only, therefore, do we need to teach hydrologists well, and to leave them with positive responses to hydrology as a discipline; but we need to adopt ways of teaching that can foster these intangible skills. The lecture and homework-problem based teaching that applies material covered in class and emphasizes getting the “right answer” (Mills and Treagust, 2003), typical of most hydrology courses (Aghakouchak and Habib, 2010; Elshorbagy, 2005; Mohtar and Engel, 2000), seems almost antithetical to the implicit skills hydrology graduates need. Education research suggests that it also leaves room for improvement from the perspective of developing understanding of content. To understand this point of view, it is necessary to review educational theory.

3 Framework, vocabulary, and an overview of educational theory

3.1 The four components of education

There are four essential elements in education – the learner; the curriculum, which comprises the skills and knowledge the learner is to master; the methods of teaching and learning activities used to bridge the two, known as the pedagogy; and the assessment used to measure outcomes of learning (Shuell, 1986; Smith et al., 2005; Pellegrino, 2006). To be effective, a pedagogical method must be appropriate to both the nature of the learner and the content being covered (Bransford et al., 2004; Svinicki, 2004; Catalano and Catalano, 1999). While we recognize the importance of the assessment of learning outcomes, this discussion focuses on the intersection of the learner, the content and the pedagogy.

Student-centered approaches in hydrology education

I. Ngambeki et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



3.2 Pedagogical content knowledge

What enables a good teacher to teach well? It is clearly not just an expert command of the subject matter – we have all known experts who teach poorly. Similarly, it must be more than mastering pedagogical skills: we would not expect an English professor to teach hydrology well, no matter how good an English teacher they were.

Good teachers, therefore, must have knowledge about how to teach particular kinds of subject matter. This understanding of how to link pedagogy with the subject matter is known as Pedagogical Content Knowledge, or PCK. PCK tends to be an idiosyncratic notion of what is appropriate to teach, at what point, through what method. As teachers develop their expertise, their PCK will also grow and develop. PCK can have many forms, but might be best defined as “the most powerful analogies, illustrations, examples, explanations, and demonstrations – in a word, the ways of representing and formulating the subject that makes it comprehensible for others” (Berry et al., 2008). To illustrate the concept of PCK, consider the use of the “leaky-bucket” or “flowerpot” analogy of a catchment, illustrated in Fig. 1.

The leaky-bucket or flowerpot analogy invites students to think about a catchment as a more elaborate form of a flowerpot. Water is introduced into the flowerpot system by irrigation or rainfall, is partitioned into infiltrated water and runoff at the surface, is transpired by the plants in the flower pot, and drains from the flower pot as it reaches its base (the “leaks” in the “leaky bucket”). Like real catchments, the flowerpot contains soil, water and vegetation, and represents a fluctuating, vertically inhomogeneous moisture store. Many of the simple process descriptions that can be applied at catchment scales are made intelligible by developing “leaky-bucket” models of the flowerpot.

Why is the flowerpot or leaky bucket effective PCK? It has several strong points: it draws on student familiarity with potted plants, it allows simple experiments to be performed, the processes in the flowerpot bear reasonably good correspondence to those in real catchments, and the mathematical and theoretical descriptions derived

Student-centered approaches in hydrology education

I. Ngambeki et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



from the model form a reasonable bridge to more complex process descriptions, or to forming scaled-up models that are suitable for representing catchment processes.

3.3 Varying teaching and PCK to reflect the way that people learn

Because PCK arises from an idiosyncratic relationship between instructor, content and the context of the students, there is never only a single “right” way to teach particular content. In fact, research on the development of disciplinary specific expertise has demonstrated that the suitability of instructional methods differs according to the nature of the discipline (Donald, 2002; Clough and Kauffman, 1999). However, higher quality teaching, and thus good PCK likely arises when the pedagogy and the content both work together to enhance student learning. To evaluate or design teaching approaches, it is therefore important to understand how students learn.

There are two broad kinds of learning that hydrology students will be engaged with – the learning of facts and principles, and the learning of skills and procedures (Svinicki, 2004). Both are important for catchment hydrologists, however there is less controversy over procedural learning. There is a general consensus that procedures are largely learned through the observation of others (Bandura, 1975, 1986).

As illustrated in cartoon form in Fig. 2, however, there are several theories regarding how facts and principles are learned. The oldest theory is known as information processing (Svinicki, 2004; Shuell, 1986). This theory proposes that a learner receives information through their senses (e.g. by reading, listening, touching, etc.), which is transmitted into their long-term memory. Information processing suggests that the quality of learning is primarily a function of the quality of the information presented by the instructor. Information processing has been widely criticized in recent years resulting in the development of constructivist theories of learning. These theories suggest that learners take a much more active role in determining what is learned from particular information sources. Constructivism posits that information is taken in from the environment through the senses and selectively stored in working memory. Learners then make connections between the new information and their prior knowledge, and

Student-centered approaches in hydrology education

I. Ngambeki et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



memories. This process results in the “construction” of new understanding or conceptualizations, which are stored in the long-term memory. Constructivism is arguably the dominant contemporary theory of learning. Constructivism implies that new knowledge is evaluated, manipulated, and connected using prior knowledge, preconceptions, values, and beliefs in order to make sense of experiences (Piaget, 1954; Smock, 1981; Zimmerman, 1981). A more recent theory argues that perception and long term memory are socially constructed by a group of learners through a process of discussion and collaboration, a theory known as socio-constructivism (Greeno et al., 1996). The constructivist and socio-constructivist theories have several implications for teachers and for successful teaching:

1. Constructivism suggests that the way students learn from new information and facts is context dependent. Teaching approaches that build on familiarity and intuition will help support students in understanding new topics. Conversely, it may be important to highlight areas where previous experiences or intuition might lead students astray, in order to make difficult subjects easier to understand, or to avoid generating misconceptions.

For example, the flowerpot analogy described above “works” because it draws on processes and objects that are familiar and intuitively understood by students, while allowing them to extend that familiarity to a new setting. However, the analogy has limitations – for instance its simplistic 1-D form may lead students to draw erroneous conclusions about the physics of subsurface flow and its links to runoff generation.

2. Constructivist ideas suggest that learning is not a passive process, but one in which learners are actively engaged. Creating opportunities for two-way communication between instructor and student can therefore assist instructors in adapting their teaching to student needs.

For instance, following the introduction of the flowerpot analogy, instructors might pose homework problems that ask students to critique the model in terms of its

Student-centered approaches in hydrology education

I. Ngambeki et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Student-centered approaches in hydrology education

I. Ngambeki et al.

Title Page	
Abstract	Introduction
Conclusions	References
Tables	Figures
◀	▶
◀	▶
Back	Close
Full Screen / Esc	
Printer-friendly Version	
Interactive Discussion	



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

applicability to real catchments, and to comment on (i) what was easy to understand about the model, and why, and (ii) what was difficult to understand about the model, and why. This homework problem firstly attempts to assess conceptual understanding, but also asks students to reflect on their learning, their comprehension, and areas of concern, giving instructors an opportunity to adapt their teaching.

- Two-way communication between a single instructor and tens or hundreds of students in a class is logistically challenging. However, students can learn from each other and engage in learning as a collaborative exercise – establishing 2-way communication with their peers, and constructing understanding together.

For instance, student groups could be given an in-task assignment to compare the predictions of a leaky-bucket model with observed in-stream hydrographs, to explore the differences between the data and the model, and to hypothesize about ways to extend the analogy to improve the match between theory and observation. Instructors could prompt groups to: “think about what happens if one leaky bucket drains into another leaky bucket” – thus prompting groups to think about the fundamental premise of the Nash Cascade model of the instantaneous unit hydrograph. Thus, small group settings can be used to reinforce teaching, to develop a collaborative approach to inquiry, and to advance conceptual and theoretical understanding.

Regardless of specific theories of learning, two further important principles must be emphasized. The first is that learning is not purely a cognitive undertaking; motivational and affective processes contribute significantly to the enterprise. Students must be active participants in their learning (Greeno et al., 1996; Smith et al., 2005). Empirical studies broadly confirm that student engagement is one of the determining factors in undergraduate students’ academic success (Astin, 1993; Light, 2001; Pascarella and Terenzini, 1991).

The second principle is that learning more information is not sufficient for the development of expertise. Mastering a subject also requires that students can rank information in terms of its importance, and organize it around conceptual hierarchies that enable knowledge to be used (Alexander, 1997; Shuell, 1986). Students therefore need opportunities to apply information in new contexts, to deconstruct concepts to reveal their underlying structure, and to integrate new and prior knowledge (Fink, 2003; Anderson et al., 2001). For example it is not sufficient to present hydrology students with interpretations from a hydrograph recession analysis: for students to really learn the concepts they would also need opportunities to fit recession curves to measured data, to derive the theory that links the hydrograph recession to catchment function (e.g. Brutsaert and Neiber, 1977), to integrate the recession analysis with their existing understanding of runoff generation, stream stage and flow variation, flow measurement techniques and other watershed-scale processes, and to question traditional theoretical interpretation of recession dynamics in light of new findings (Harman et al., 2009).

3.4 From instructor-centered to learner-centered teaching models

The shift from information processing to constructivist models of student learning implies an accompanying focus on the role of student engagement and cognitive effort. This necessitates a change in pedagogy that can support these important student roles: specifically from instructor-centered to more student-centered forms of instruction.

The typical techniques of hydrologic teaching such as lecturing, reading, and structured problem sets are instructor-centered. Instructors actively deliver material, while students take notes, read, and apply that material via problem sets. In contrast, learner-centered approaches offer students a degree of autonomy in directing their learning, and require students to share responsibility for building knowledge with the instructor (Bransford et al., 2004). Learner-centered methods generally begin with a specific realistic problem, e.g. experimental data, or a real world problem, enabling the student to see the relevance of the problem, and providing a clearer context for the student

Student-centered approaches in hydrology education

I. Ngambeki et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



to connect to their own prior knowledge (Prince and Felder, 2006; Lombardi, 2007; Herrington and Oliver, 2000). Many instructional strategies can be categorized as learner-centered, including problem-based learning, project-based learning, inquiry-based learning, case-based learning, and discovery learning, as illustrated in Table 2 and elaborated on in Sect. 4 (Herrington and Oliver, 2000; Thomas, 2000).

Both methods have benefits: instructor-centered methods can be highly effective in the acquisition of factual knowledge and the application of that knowledge to a defined range of contexts (Robinson, 1996; Costin, 1972), while student-centered approaches improve student engagement, motivation and transferability of knowledge from classroom settings to new problems (Chickering and Gamson, 1987; Astin, 1993; Light, 1992, 2001). The methods also have drawbacks, with instructor-centered approaches generally failing to provide opportunities for deconstruction, integration, and transfer of knowledge to novel contexts (Clough and Kauffman, 1999; Prince and Felder, 2006). Conversely, learner-centered approaches may be inefficient for teaching factual knowledge and conceptual understanding, are time and resource intensive, and, depending on the degree of autonomy offered the students, may result in the development of misconceptions (Yadav et al., 2011). Thus to a large degree, the two different approaches are complementary, and if employed together, offer a way to broaden students' learning experiences and develop expertise, without sacrificing the core components of a traditional education (Smith et al., 2005; Prince and Felder, 2006).

For hydrology instructors, who inherit a strongly instructor-centered educational tradition, this provides a motive to explore the forms of learner-centered methods that could be melded into a traditional "chalk-and-talk" based course. Studies in civil engineering students found that student learning was greater when a combination of both learner- and instructor-centered methods, including homework problems, group projects, experimentation, model building, conversing with experts, and real world projects, were combined (Bernold et al., 2000). A closer analysis matching specific pedagogical activities with student learning styles found that the learner-centered methods were particularly effective for students who characterized their learning styles

Student-centered approaches in hydrology education

I. Ngambeki et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



as “abstract and concrete experimenters” – over 50 % of the engineering student population (Bernold et al., 2000). Not only do empirical studies support improvements in content-related educational outcomes, but many studies support the value of learner-centered pedagogies for improving critical thinking skills (Litzinger et al., 2005), self-directed learning, research skills, and expression (Jiusto and DiBiasio, 2006), and confidence (Mahendran, 1995). These kinds of outcomes strongly reflect the need for creative, confident, independent and flexible hydrology graduates outlined in Sect. 2.

A common critique of student-centered approaches to engineering education is that these approaches require considerable investment of time and resources, which can prove to be a significant barrier to teachers adopting them (Jiusto and DiBiasio, 2006; Mahendran, 1995; Prince and Felder, 2006). Given the lack of literature regarding learner-centered teaching approaches in catchment hydrology, resource related concerns might be particularly challenging in this field. To offer a potential way forward, the following section presents two examples from the authors’ experiences. We note immediately that these examples have not been formally evaluated through an engineering education study, and therefore remain anecdotal. However, we can use the frameworks presented above to analyze the different kinds of student-centered pedagogy in each of the examples, highlight aspects of PCK in the examples, and compare them to published studies addressing similar teaching strategies in other engineering disciplines.

4 Student-centered catchment hydrology education in action

Two different examples are presented in this section. The first example relates to the teaching methods employed by two of the authors of the article (MS and PT) in their graduate and upper-undergraduate catchment hydrology courses. The courses contain many standard elements of lecture, reading and problem sets, but are supplemented by case studies, and elements of problem and discovery based learning. The second example relates to the Hydrological Synthesis Summer Schools, held in Vancouver,

Student-centered approaches in hydrology education

I. Ngambeki et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



British Columbia in the summers of 2009 and 2010. These Summer Schools had a research focus and a strong basis in discovery learning.

4.1 A curriculum based approach

4.1.1 Outline of the approach

MS and PT have taught catchment hydrology at undergraduate and graduate levels in Australia, Belgium, the Netherlands and USA (Illinois and Arizona), adapting their teaching methods over the years. At present, both instructors use a mix of student- and instructor-based teaching strategies. The curriculum for their contemporary catchment hydrology courses is shown in Table 2, and consists of three major components: catchment morphology, the link between morphology and hydrological dynamics in the catchment, and a comparative and synthesis component that considers spatially and temporally lumped dynamics of the water balance at catchment scales.

Fundamental material in the course (for example, the observational basis for catchment morphology, soils/geology and vegetation, and the process basis for linking catchment form with catchment dynamics) is introduced to students through typical lecture formats. This lecture course ensures that the core aspects of a traditional hydrological education are covered, and also provides the “scaffolding” that students draw on in the student-centered components of the course. The student-centered components of the course primarily address the synthesis of process (“internal descriptors” of Sect. 2) and catchment response (“external descriptors” of Sect. 2) across multiple locations.

The hydrologic theory used in the student-centered course component draws on the idea of “catchment function” (Black, 1997; Wagener, 2007; McDonnell et al., 2007). Wagener et al. (2007) presented the idea of hydrologic signatures as holistic representations of catchment function that can be observed in the variables of dynamic catchment behavior (e.g. streamflow or soil moisture). Signatures are outward manifestations of the internal catchment dynamics. The nature of the signatures changes with temporal and spatial scales at which they are observed or analyzed (Atkinson

Student-centered approaches in hydrology education

I. Ngambeki et al.

Title Page	
Abstract	Introduction
Conclusions	References
Tables	Figures
◀	▶
◀	▶
Back	Close
Full Screen / Esc	
Printer-friendly Version	
Interactive Discussion	



et al., 2003; Biggs et al., 2005; Farmer et al., 2003; Kirchner et al., 2004; Thoms and Parsons, 2003). Examples of signatures include, but are not limited to, those characterizing inter-annual variability (e.g. runoff coefficient, baseflow index), mean within-year variability (regime curve), random variability of daily flows within the year (i.e. the flow duration curve), the recession curve and the flood frequency curve.

These signatures provide an elegant, holistic representation of catchment responses, and provide vehicles to explore the underlying process controls. Exploring the nature of a given signature creates a “real world problem” for students to engage with. Starting with data from one to several catchments in different climatic or landscape settings, students can extract one or more signatures from the data. They draw on their knowledge of the underlying process controls and deconstruct these to interpret the signatures. Students then compare and contrast the properties of the signatures of several catchments, requiring synthetic, analytical and evaluative/interpretive thinking skills.

The problem-based task was introduced into the course as a term project. Support for its implementation was provided by a graduate teaching assistant, who acted as a resource for the students at the detailed level of code development and data analysis. In practice the mathematics needed to generate these signatures is not onerous, and the students readily understood the value of signatures for interpreting catchment behavior. The support of the teaching assistant was critical to the success of the term project: the students felt supported in their ability to complete the project tasks, while the professors’ time was freed to focus on the higher-level science questions that were explored in the comparative analysis.

In more advanced classes, students were encouraged to do class projects involving group efforts that focused on a single signature, where students would approach these signatures from several perspectives, and gain both holistic and in-depth process knowledge, or on applying process-based models to link climate and landscape properties to hydrologic response. For example, as part of the advanced Hydrologic and Hydroclimatic Variability class at Illinois a group of four students focused on the

Student-centered approaches in hydrology education

I. Ngambeki et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



flow duration curve (FDC) as a signature. One group of students worked on statistical analysis of over 200 catchments and extracting regional patterns. Another group of students approached the flow duration curve from a process modeling perspective. Starting with simple models, they systematically analyzed the process controls on the FDC, and increased model complexity until the model predictions matched the observations in a majority of catchments. This offered them deep insights on the functioning of the catchments. In another example, as part of the Advanced Catchment Hydrology class at Arizona, a group of six students studied similarities and differences between catchments along a climate gradient using a process-based model developed by Carrillo et al. (2011).

Through these projects, the students gained insight into the relative controls of climate, geomorphology, soils, and vegetation on hydrologic response. The analysis gave students the opportunity to explore the effects of heterogeneity of climate and landscape on catchment function, and illustrates that there are forms of understanding in catchment hydrology that can only be derived from insightful exploration of data and patterns extracted from data. Qualitatively, the problem-based approach appeared to increase student motivation (as inferred from the relative quality of the term-project presentations when compared to standard problem sets during the course), to enhance team-work skills and create opportunities for students to learn from each other, and seemed to improve student recall and understanding of the topics covered in the course.

4.1.2 Student-centered teaching strategies employed

Several components of the course outlined by MS and PT rely on student-centered teaching strategies: specifically the use of case studies to motivate the topic, and problem-based learning approaches to address comparative and synthesis aspects of the curriculum. These approaches have unique characteristics, challenges and benefits for engineering education.

Student-centered approaches in hydrology education

I. Ngambeki et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Case studies

Case studies are a flexible teaching method, that can be implemented in both instructor- and learner-centered ways (Prince and Felder, 2006). When the case is well defined and solutions are presented, case studies are usually instructor-centered; when no or limited solutions are presented, providing opportunity for critical thinking; information seeking; analysis; transfer; and creativity, case studies offer an opportunity for student-centered learning.

Case-based learning draws on realistic situations to motivate analysis and problem solving. In the courses taught by MS and PT, case studies include analysis of historical dam-break and flood scenarios, analysis of paired catchment experiments, or historical or contemporary water resources management problems. By studying the cases, students familiarize themselves with real-world problems and the skills needed to address them.

Case-based learning is fairly common in engineering education (Yadav et al., 2010). Several studies of case-based learning have found that it increases student engagement with the material (Hoag et al., 2005), their critical thinking, and their problem solving skills (Dochy et al., 2003; Yadav and Beckerman, 2009; Henderson et al., 1983). However, students have indicated that case studies do not necessarily improve their conceptual understanding (Yadav et al., 2011).

Problem-based learning

The exploration of signatures of catchment function using analysis of real-world data in PT and MS's classes is an excellent example of how problem-based learning (PBL) can be adapted to the hydrology classroom. In PBL, student effort is focused on an open-ended real world problem. Suitable problems should have moderate complexity and limited structure, with a few plausible solution paths and alternative solutions (Jonassen and Hung, 2008). Teams of students work on the problem, identifying areas of learning that they need in order to achieve a solution. They then pursue various

HESSD

9, 707–740, 2012

Student-centered approaches in hydrology education

I. Ngambeki et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



means to acquire the necessary knowledge (Albanese and Mitchell, 1993). PBL classroom activities can be structured around groups creating and executing work plans, within and between group discussions, and brief lectures (Duch, 2001; Mills and Treaugust, 2003). The instructor acts as a guide and a resource rather than the primary source of information.

PBL is uncommon in engineering, and there is no consensus on the benefit of PBL for engineering teaching and learning. From a theoretical standpoint, PBL provides extensive opportunities for students to develop questioning and critical thinking skills (Hmelo-Silver, 2004), and encourages engagement through the use of real world problems. PBL promotes knowledge transfer by allowing students to learn skills in a fluid situation, which is transferable to novel contexts (Lombardi, 2007). However, the results of the few studies that have been undertaken are contradictory. PBL was shown to increase motivation and critical thinking in industrial engineers in the Netherlands (Litzinger et al., 2005), but another study in the Netherlands concluded that PBL was not suited to engineering instruction (Perrenet et al., 2000). One example of the successful implementation of PBL is in the biomedical engineering program at the Georgia Institute of Technology (Newstetter, 2005). This program implements elements of the PBL approach from the beginning to the end of the curriculum asking students to undertake such tasks as: designing a device to rapidly identify types of mold present in a room or using biomechanics to determine the probability that a deceased infant died from a brain injury received from shaking (see Newstetter, 2005 for a detailed description of this program).

4.2 A discovery based approach

In 2009 and 2010, several of the authors of this paper were involved in the Vancouver Hydrological Synthesis Summer Institutes: novel educational and research enterprises in which students took the lead in outlining, planning and implementing research around four consecutive topics over a 6 week period (Thompson et al., 2011; Wilson et al., 2010). A group of 8–12 students was confronted with four general research

Student-centered approaches in hydrology education

I. Ngambeki et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



topics and provided with supporting datasets. The students were challenged to (i) develop research questions and hypotheses that were relevant to the research topic and which could be addressed using the available data; (ii) to develop a research strategy by which the team could answer these research questions and investigate the hypotheses; (iii) implement that research strategy, adapting it as necessary; and (iv) to present their results at a “capstone” symposium consisting of other young earth scientists. For instance, in one project students developed hypotheses and research plans to explore the determinants of catchment water balance partitioning using data from 430 US Watersheds, and a combination of data analysis, analytical modeling and GIS based methods. The details of the Summer Institutes are reported in several papers regarding hydrological synthesis (Thompson et al., 2011; Wilson et al., 2010), the research outcomes of the 2009 Institute are published in a Special Issue of Water Resources Research, and the 2010 Institute outcomes are currently being submitted to a Special Issue of the Journal of Geophysical Research. There are several aspects of the Summer Institutes that are worth emphasizing in terms of their implications for student-centered learning.

For example, the role of mentors as resources and guides was critical, given that students’ followed a research and discovery path that was set by their curiosity and their questions, rather than their existing skill base. Because of this, students required considerable support. The ratio of faculty mentors to students was approximately 1:4. Thus, the teacher to student ratios required to successfully implement this kind of model in the engineering classroom may prove unrealistically high for many classes. The student group, however, also relied strongly on peer-to-peer support, allowing more experienced students to supplement the role of faculty in mentoring and guiding their peers. Students regular shared knowledge and skills with each other, and collaborated as a group to determine hypotheses and the overall research direction. The Summer Institutes thus seem to have been quite successful in building a community of learners (Brown and Campione, 1990, 1994; Shuell, 1986; Shulman and Sherin, 2004), and fostering a social environment in which students could learn.

Student-centered approaches in hydrology educationI. Ngambeki et al.

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[◀](#)[▶](#)[◀](#)[▶](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

2001). Discovery learning is also used in innovative computer interfaces, service learning projects, and museums. The limited use of this method in engineering coursework, particularly at undergraduate level, reflects its time-consuming nature, the requirement for high levels of student engagement and motivation, and the real risk that with such limited guidance, misconceptions would be developed (Mayer, 2004). Its successful deployment at the Summer Institutes relied on a high level of faculty and mentor support, on the fact that students could dedicate 6 solid weeks to the discovery-learning program, and to the high levels of student engagement and motivation, which were secured by the competitive application process to the Summer Institute.

As was the case for problem-based learning, students not only pursued the solutions to problems but also learned the tools they needed to solve those problems as they went. This was exemplified by one student learning wavelet and Fourier analysis techniques during the 2009 institute in order to explore the coupling between flow and chemical concentration timeseries from an agricultural watershed (Guan et al., 2011). Despite the logistical challenges and demanding nature of discovery learning, the Summer Institutes indicate that with motivated students, a focus on learning from data, and sufficient faculty support, discovery learning can be highly enriching, particularly for advanced students.

4.3 Other student-centered learning techniques

The other major form of student-centered learning available to hydrology instructors include project or design based learning. Being product oriented (Thomas, 2000), project based learning familiarizes students with professional practices, while its relatively constrained scope minimizes the possibilities of incorporating incorrect information and forming misconceptions (Mills and Treagust, 2003).

Project-based learning is relatively widely implemented in engineering education. Studies indicate that it increases engagement, critical thinking, self-direction and research skills, again at the expense of a significant time and resource commitment (1995) (Jiusto and DiBiasio, 2006), while the emphasis on creating a product rather

Student-centered approaches in hydrology education

I. Ngambeki et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



than on the learning process itself can be a disadvantage (Mills and Treagust, 2003). Because hydrology is often more concerned with process understanding and representation than with a specific product, the value of project- versus problem-based learning might be more limited in this field.

5 Conclusions

The expansion of research into education in the latter half of the 20th century has led to a revolution in thinking about pedagogy. This revolution can be characterized by shifts: from information processing towards constructivist models of learning, from instructor-centered to more student-centered models of teaching, and towards a broad recognition of the significance of specialized knowledge about how to teach particular content in determining teacher expertise and student success. Engineering has been a relative latecomer to this research domain, and hydrology remains almost entirely unexplored from the perspective of education research. As hydrologists critically reflect on teaching, learning and student outcomes, however, there is scope both to draw on the experience in other branches of science and engineering, and to initiate hydrology education research programs to develop discipline-specific knowledge.

As outlined here, engineering education research suggests that students are more likely to acquire the higher order analytical, evaluative, and synthesis skills needed to handle the uncertainties of hydrologic prediction and interpretation when student-centered approaches to teaching and learning are adopted as a complement to traditional direct instruction. We have argued that hydrology education therefore needs to incorporate learning experiences that will foster such higher-order skills. We have provided examples from our own experience, including upper-level university instruction to focused hydrological institutes, and shown how student-centered approaches that focus on learning from data can be incorporated into these educational settings. However, significant questions remain. What content in hydrology are student-centered methods best suited to – and is our thesis that they apply best when synthesizing

Student-centered approaches in hydrology education

I. Ngambeki et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Dooge's internal and external approaches valid? Can student-centered approaches be applied to lower-level hydrology teaching, for example in first-year engineering survey courses? Which student-centered strategies are most suitable for which subject matter? And how can teaching programs and student outcomes be evaluated to measure the success of different educational approaches?

While we can draw on broader engineering education research to inform our approach in hydrology, there is a need to initiate education research initiatives that are specific to hydrology education. These initiatives should include the development of a taxonomy of pedagogical content knowledge for hydrology that includes a set of the most important topics in the various sub-specialties and the various ways in which these can be represented, explained and demonstrated. This includes an understanding of which of these topics are easy or difficult for students, where misconceptions commonly occur and what makes topics difficult. Research in teaching and learning hydrology should evaluate the effectiveness of both learner- and instructor-centered approaches as applied to specific content knowledge, and how these vary with students' learning styles and prior experiences. These research initiatives could contribute to the broader endeavor of teaching and learning research by providing examples of PCK and learning strategies in hydrology, allowing comparisons with other fields (Abell, 2008; Viiri, 2007).

By supporting and evaluating the use of student-centered teaching and learning in hydrology, such a program would benefit educators and hydrologists alike. Given the many open questions about teaching and learning in hydrology, the challenges facing the next generation of hydrologists, and the expanding effort in engineering education, initiating collaborative research efforts between engineering education specialists and hydrology teachers is opportune, vital to endeavors to reform hydrology teaching, and likely to add value to student and learning outcomes in both disciplines.

Student-centered approaches in hydrology education

I. Ngambeki et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Acknowledgements. Work on this paper was inspired by the Summer Institute organized at the University of British Columbia (UBC) during June–July 2009 and 2010 as part of the NSF-funded project: Water Cycle Dynamics in a Changing Environment: Advancing Hydrologic Science through Synthesis (NSF Grant EAR-0636043, M. Sivapalan, PI).

5 ST acknowledges support from NSF-EAR-10-13339.

References

- Aghakouchak, A. and Habib, E.: Application of a conceptual hydrologic model in teaching hydrologic processes, *Int. J. Eng. Educ.*, 26, 1–11, 2010.
- Albanese, M. A. and Mitchell, S.: Problem-based learning: A review of literature on its outcomes and implementation issues, *Acad. Med.*, 68, 52–81, 1993.
- Alexander, P.: Mapping the multidimensional nature of domain learning: The interplay of cognitive, motivational, and strategic forces, *Advances in Motivation and Achievement*, 10, 1997.
- Anderson, L., Krathwohl, D., Airasian, P., Cruikshak, K., Mayer, R., Pintrich, P., Raths, J., and Wittrock, J.: A taxonomy for learning, teaching, and assessing: A revision of bloom's taxonomy of educational objectives, Longman, New York, 2001.
- 15 Astin, A.: What matters in college? Four critical years revisited, Jossey-Bass, San Francisco, CA, 1993.
- Atkinson, S., Sivapalan, M., Viney, N. R., and Woods, R. A.: Predicting space-time variability of hourly streamflows and the role of climate seasonality: Mahurangi catchment, *Hydrol. Process.*, 17, 2171–2193, 2003.
- 20 Bandura, A.: Analysis of modeling processes, *Sch. Psychol. Digest*, 4, 4–10, 1975.
- Bandura, A.: Social foundations of thought and action, Prentice-Hall, Englewood Cliffs, NJ, 1986.
- Bernold, L. E., Bingham, W. L., McDonald, P. H., and Attia, T. M.: Impact of holistic and learning-oriented teaching on academic success, *J. Eng. Educ.*, 89, 191–199, 2000.
- 25 Berry, A., Loughran, J., and van Driel, J. H.: Revisiting the roots of pedagogical content knowledge, *Int. J. Sci. Educ.*, 30, 1271–1279, 2008.
- Beven, K.: Prophecy, reality and uncertainty in distributed hydrological modeling, *Adv. Water Resour.*, 16, 41–51, 1993.

Student-centered approaches in hydrology education

I. Ngambeki et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



- Biggs, B. J. F., Nikora, V. I., and Snelder, T. H.: Linking scales of flow variability in rivers to lotic ecosystem structure and function, *River Res. Appl.*, 21, 283–298, 2005.
- Black, P. E.: Watershed functions, *J. Am. Water Resour. As.*, 33, 1–11, 1997.
- Bloom, B. S.: Taxonomy of educational objectives, handbook i: The cognitive domain, David McKay Co Inc., New York, 1956.
- Bransford, J. D., Brown, A. L., and Cocking, R. R.: How people learn: Brain, mind, experience and school, National Academy Press, Washington DC, 2004.
- Brown, A. L. and Campione, J. C.: Communities of learning and thinking, or a context by any other name, in: Contributions to human development, edited by: Kuhn, D., Karger, The University of California, 108–125, 1990.
- Brown, A. L. and Campione, J. C.: Guided discovery in a community of learners, *Classroom lessons: Integrating cognitive theory and classroom practice*, edited by: McGilly, K., MIT Press/Bradford Books, Cambridge, MA, 1994.
- Brutsaert, W. and Neiber, J.: Regionalized drought flow hydrographs from a mature glaciated plateau, *Water Resour. Res.*, 13, 637–643, doi:10.1029/WR013i003p00637, 1977.
- Budyko, M. I.: *Climate and life*, Elsevier, New York, 1974.
- Carrillo, G., Troch, P. A., Sivapalan, M., Wagener, T., Harman, C., and Sawicz, K.: Catchment classification: hydrological analysis of catchment behavior through process-based modeling along a climate gradient, *Hydrol. Earth Syst. Sci.*, 15, 3411–3430, doi:10.5194/hess-15-3411-2011, 2011.
- Chickering, A. W. and Gamson, Z. F.: Seven principles for good practice in higher education, *AAHE Bulletin*, 39, 3–7, 1987.
- Clough, M. P. and Kauffman, K. J.: Improving engineering education: A research based framework for teaching, *J. Eng. Educ.*, 88, 527–534, 1999.
- Costin, F.: Lecturing versus other methods of teaching: A review of research, *Brit. J. Educ. Technol.*, 3, 4–31, 1972.
- Crutzen, P. J. and Stoemer, E. F.: The anthropocene, *Global Change Newsletter*, 41, 17–18, 2000.
- Dochy, F., Segers, M., VandenBossche, P., and Gijbels, D.: Effects of problem-based learning: A meta-analysis, *Learn. Instr.*, 13, 533–568, 2003.
- Donald, J.: *Learning to think: Disciplinary perspectives*, Jossey-Bass Publisher, San Francisco, 2002.
- Dooge, J. C. I.: Model structure and classification, in: *Logistics and benefits of using mathe-*

Student-centered approaches in hydrology education

I. Ngambeki et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Student-centered approaches in hydrology education

I. Ngambeki et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



ments, ETR&D-Educ. Tech. Res., 48, 23–48, 2000.

Hmelo-Silver, C. E.: Problem-based learning: What and how do students learn?, *Educ. Psychol. Rev.*, 16, 235–266, 2004.

Hoag, K., Lillie, J., and Hoppe, R.: Piloting case-based instruction in a didactic clinical immunology course, *Clinical Laboratory Science*, 18, 213–220, 2005.

Hooper, R.: Towards an intellectual structure for hydrologic science, *Hydrol. Process.*, 23, 353–355, 2009.

Justo, S. and DiBiasio, D.: Experiential learning environments: Do they prepare our students to be self-directed, life-long learners?, *J. Eng. Educ.*, 95, 195–204, 2006.

Jonassen, D. H. and Hung, W.: All problems are not equal: Implications for problem based learning, *The Interdisciplinary Journal of Problem Based Learning*, 2, 6–28, 2008.

Kirchner, J., Feng, X., Neal, C., and Robson, A. J.: The fine structure of water quality dynamics: The (high-frequency) wave of the future, *Hydrol. Process.*, 18, 1353–1359, 2004.

Light, R. J.: *The harvard assessment seminars: Second report*, Harvard University Press, Cambridge, MA, 1992.

Light, R. J.: *Making the most of college*, Harvard University Press, Cambridge, MA, 2001.

Litzinger, T. A., Wise, J. C., and Lee, S. H.: Self-directed learning readiness among engineering undergraduate students, *J. Eng. Educ.*, 94, 215–221, 2005.

Lombardi, M. M.: Authentic learning for the 21st century: An overview, *Educause Learning Initiative*, 1–12, 2007.

Lyons, J. and Young, E. F.: Developing a systems approach to engineering problem solving and design of experiments in a racecar based laboratory course, *J. Eng. Educ.*, 90, 109–112, 2001.

Mahendran, M.: Projec-based civil engineering courses, *J. Eng. Educ.*, 84, 1–5, 1995.

Mayer, R.: Should there be a three strikes rule against pure discovery learning?, *Am. Psychol.*, 59, 14–19, 2004.

McDonnell, J. J., Sivapalan, M., Vache, K., Dunn, S., Grant, G., Haggerty, R., Hinz, C., Hooper, R., Kirchner, J., Roderick, M. L., Selker, J., and Weiler, M.: Moving beyond heterogeneity and process complexity: A new vision for watershed hydrology, *Water Resour. Res.*, 43, W07301, doi:10.1029/2006wr005467, 2007.

Mills, J. E. and Treagust, D. F.: Engineering education – is problem based or project based learning the answer?, *Australasian Journal of Engineering Education*, Online Publication, 1–16, available at: <http://www.aee.com.au/journal/2003/mills.treagust03.pdf>, 2003.

Student-centered approaches in hydrology education

I. Ngambeki et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



- Milly, P. C. D., Betancourt, J., Falkenmark, M., Hirsch, R. M., Kundzewicz, Z., Lettenmaier, D. P., and Stouffer, R. J.: Stationarity is dead: Whither water management?, *Science*, 319, 573–574, 2008.
- Mohtar, R. H. and Engel, B. E.: Www-based water quality modeling systems to enhance student learning, *J. Eng. Educ.*, 89, 89–94, 2000.
- Newstetter, W. C.: Designing cognitive apprenticeships for biomedical engineering, *J. Eng. Educ.*, 94, 207–213, 2005.
- Pascarella, E. T. and Terenzini, P. T.: How college affects students: Finding and insights from twenty years of research, Jossey-Bass, San Francisco, CA, 1991.
- Pellegrino, J. W.: Rethinking and redesigning curriculum, instruction and assessment: What contemporary research and theory suggests, Commission on the Skills of the American Workforce, Chicago, 1–15, 2006.
- Perrenet, J. C., Bouhuijs, P. A. J., and Smits, J. G. M. M.: The suitability of problem-based learning for engineering education: Theory and practice, *Teach. High. Educ.*, 5, 345–358, 2000.
- Piaget, J.: The construction of reality in the child, Basic Books, New York, NY, 1954.
- Postel, S. L. and Wolf, A. T.: Dehydrating conflict, *Foreign Policy*, 60–67, 2001.
- Prince, M. J. and Felder, R. M.: Inductive teaching and learning methods: Definitions, comparisons and research bases, *J. Eng. Educ.*, 95, 123–138, 2006.
- Robinson, P.: Learning simple and complex rules under implicit, incidental rule-search conditions, and instructed conditions, *Stud. Second Lang. Acq.*, 18, 27–67, 1996.
- Rockstrom, J., Steffen, W., Noone, K., Persson, A., Chapin, F. S., Lambin, E., Lenton, T. M., Scheffer, M., Folke, C., Schellnhuber, H. J., Nykvist, B., de Wit, C. A., Hughes, T., van der Leeuw, S., Rodhe, H., Sornlin, S., Snyder, P. K., Costanza, R., Svedin, U., Falkenmark, M., Karlberg, L., Corell, R. W., Fabry, V. J., Hansen, J., Walker, B., Liverman, D., Richardson, K., Crutzen, P., and Foley, J.: Planetary boundaries: Exploring the safe operating space for humanity, *Ecol. Soc.*, 14, available at: <http://www.ecologyandsociety.org/vol14/iss2/art32/>, 2009.
- Shuell, T. J.: Cognitive conceptions of learning, *Rev. Educ. Res.*, 56, 411–436, 1986.
- Shulman, L. S.: If not now, when? The timelines of scholarship of the education of engineers, *J. Eng. Educ.*, 94, 11–12, 2005.
- Shulman, L. S. and Sherin, M. G.: Fostering communities of teachers as learners: Disciplinary perspectives, *J. Curriculum Stud.*, 36, 135–140, doi:10.1080/0022027032000135049, 2004.

Student-centered approaches in hydrology education

I. Ngambeki et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



- Sivapalan, M.: Process complexity at hillslope scale, process simplicity at the watershed scale: Is there a connection?, *HP Today, Hydrol. Process.*, 17, 1037–1041, doi:10.1002/hyp.5109, 2003.
- Sivapalan, M., Blöschl, G., Zhang, L., and Vertessy, R.: Downward approach to hydrological prediction, *Hydrol. Process.*, 17, 2101–2111, doi:10.1002/hyp.1425, 2003.
- Smith, K. A., Sheppard, S. D., Johnson, D. W., and Johnson, R. T.: Pedagogies of engagement: Classroom-based practices, *J. Eng. Educ.*, 94, 87–101, 2005.
- Smock, C. D.: Constructivism and educational practices, in: *New directions in piagetan theory and practice*, edited by: Sigel, I. E., Brodzinski, D. M., and Golinkoff, R. M., Erlbaum, Hillsdale, NJ, 1981.
- Svinicki, M. D.: *Learning and motivation in the postsecondary classroom*, Jossey-Bass Publishers, San Francisco, 2004.
- Thomas, J. W.: *A review of research on project-based learning*, The Autodesk Foundation, San Rafael, 1–46, 2000.
- Thompson, S. E., Harman, C. J., Schumer, R., Wilson, J. S., Basu, N. B., Brooks, P. D., Donner, S. D., Hassan, M. A., Packman, A. I., Rao, P. S. C., Troch, P. A., and Sivapalan, M.: Patterns, puzzles and people: Implementing hydrologic synthesis, *Hydrol. Process.*, 25, 3256–3266, doi:10.1002/hyp.8234, 2011.
- Thoms, M. C. and Parsons, M.: Identifying spatial and temporal patterns in the hydrological character of the condamine-balonne river, australia, using multivariate statistics, *River Res. Appl.*, 19, 443–457, 2003.
- Torgersen, T.: Observatories, think tanks, and community models in the hydrologic and environmental sciences: How does it affect me?, *Water Resour. Res.*, 42, W06301, doi:10.1029/2005WR004466, 2006.
- United Nations Development Program: *Sustainability and equity: A better future for all*, United Nations Development Program, New York, USA, 2011.
- Vogel, R.: Hydromorphology, *J. Water Res. Pl.-ASCE*, 137, 147–149, 2011.
- Vorosmarty, C. J., McIntyre, P. B., Gessner, M. O., Dudgeon, D., Prusevich, A., Green, P., Glidden, S., Bunn, S. E., Sullivan, C. A., Liermann, C. R., and Davies, P. M.: Global threats to human water security and river biodiversity, *Nature*, 467, 555–561, doi:10.1038/nature09440, 2010.
- Wagener, T.: Can we model the hydrological impacts of environmental change?, *Hydrol. Process.*, 21, 3233–3236, 2007.

Wagener, T., Sivapalan, M., McDonnell, J. J., Hooper, R., Lakshmi, V., Liang, X., and Kumar, P.: Predictions in ungauged basins as a catalyst for multidisciplinary hydrology, *EOS Transactions*, 85, 451–457, 2004.

Wagener, T., Sivapalan, M., Troch, P., McGlynn, B., Harman, C., Gupta, H., Kumar, P., Rao, P. S., Basu, N., and Wilson, J.: The future of hydrology: An evolving science for a changing world, *Water Resour. Res.*, 46, W05301, doi:10.1029/2009WR008906, 2010.

Wilson, J. S., Hermans, C., Sivapalan, M., and Vörösmarty, C. J.: Blazing new paths for interdisciplinary hydrology, *EOS Transactions*, 91, 53, doi:10.1029/2010EO060001, 2010.

Yadav, A. and Beckerman, J. L.: Implementing case studies in a plant pathology course: Impact on student learning and engagement, *Journal of Natural Resources and Life Sciences Education*, 38, 50–55, 2009.

Yadav, A., Shaver, G. M., and Meckl, P.: Lessons learned: Implementing the case teaching method in a mechanical engineering course, *J. Eng. Educ.*, 99, 55–69, 2010.

Yadav, A., Subedi, D., Lundeberg, M. A., and Bunting, C. F.: Problem-based learning: Influence on students' learning in an electrical engineering course, *J. Eng. Educ.*, 100, 253–280, 2011.

Zimmerman, B. J.: Social learning theory and cognitive constructivism, in: *New directions in piagetian theory and practice*, edited by: Sigel, I. E., Brodzinski, D. M., and Golinkoff, R. M., Erlbaum, Hillsdale, NJ, 1981.

HESSD

9, 707–740, 2012

Student-centered approaches in hydrology education

I. Ngambeki et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Table 1. Examples of inductive teaching and learning approaches for hydrology teachers.

Technique	Example hydrology problems/projects	Classroom Activities
Problem-based Learning/ Inquiry-based Learning	How will predicted changes in rainfall and population growth affect urban water security? What are the implications (safety, social, economic, ecological) of dam removal? Why has continental runoff declined globally?	Group work plans Group discussion Task execution Targeted lectures (brief)
Project-based Learning	Design a flow-measurement system to be implemented in a deep, flash flood prone canyon. Develop design criteria for stormwater management at a proposed mine site in an environmentally sensitive area. Design a water-harvesting system and water management plan for a remote, unpowered, desert community.	Group work plans Group discussion Task execution Targeted lectures (brief) Prototype construction/ design drafting Class presentations
Case-based Learning	What were the hydrological implications of water diversion from Owens Lake to San Francisco? How predictable were these? What commonalities arise when comparing the water use and water policy trajectories of different cities (e.g. Los Angeles versus Atlanta)?	Case review Targeted lectures Group work and discussion
Discovery Learning	Multiple problems are suitable	Self-directed by students

Student-centered approaches in hydrology education

I. Ngambeki et al.

Title Page

[Abstract](#) [Introduction](#)
[Conclusions](#) [References](#)
[Tables](#) [Figures](#)

◀ ▶
◀ ▶
[Back](#) [Close](#)

[Full Screen / Esc](#)

[Printer-friendly Version](#)

[Interactive Discussion](#)



Table 2. Summary curriculum adopted by Troch and Sivapalan uniting deductive and inductive teaching methods for graduate catchment hydrology education.

Desired Outcomes	Modes of teaching
<p>Empirical basis for catchment form:</p> <ul style="list-style-type: none"> – Morphology (drainage area, shape, network structure, slope, aspect) – Climate and vegetation (aridity index, land use, eco-region, LAI, phenology) – Soils and geology (soil texture distribution, soil hydraulic properties) <p>Link between form and dynamics:</p> <ul style="list-style-type: none"> – Point scale water and energy balance – Plant hydraulics (stomatal regulation, xylem, root structure, cavitation) – Runoff generation (fill and spill, connectivity, infiltration excess, saturation excess, variable source areas, macropores, preferential flow paths) – Runoff routing and baseflow (rill and gully flow, sheet flow, kinematic wave, dynamic wave, Muskingum, de St.-Venant, Dupuit-Forcheimer, Boussinesq, riparian aquifer, baseflow recession, master recession curve) – Spatial variability and heterogeneity (remote sensing, representative volumes, effective parameters) – Process Interactions (hillslope-stream connectivity, vegetation organization) <p>Water balance at catchment scales:</p> <ul style="list-style-type: none"> – Patterns of behavior across multiple catchments (Budyko, L'vovich, regime curve, dominant process concept) – Vegetation dynamics (phenology, drought, climate change, disturbance) – Effects of human intervention (urbanization, drainage, reservoirs) – Top-down and bottom-up modeling (data based v. process based) 	<p>Instructor-centered:</p> <ul style="list-style-type: none"> – Lecture format (concepts, links to hydraulics, physics, chemistry, mathematics etc.) – Homework (give students opportunity to apply knowledge to well-posed problems) – Tests and quizzes (assessment) – Discussion of landmark papers (peer-to-peer learning, critical thinking, communication) <p>Student-centered:</p> <ul style="list-style-type: none"> – Analysis of real-world data (confront students with complexity, guide analysis and reporting, patterns of behavior, develop and test hypotheses) – Comparative hydrology (move from individual sites to many places, hypothesize about patterns of similarity and difference) – Case studies (discussion, interest, context for fundamentals) <p>Synthesis and applications:</p> <ul style="list-style-type: none"> – Top-down / bottom-up modeling (synthesize knowledge, study process interactions, learn from patterns of behavior) – Design and management (apply knowledge to generate products)

Student-centered approaches in hydrology education

I. Ngambeki et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



“Flowerpot” Runoff Model:

$$Q = -k S$$

$$dS/dt = P - ET - Q$$

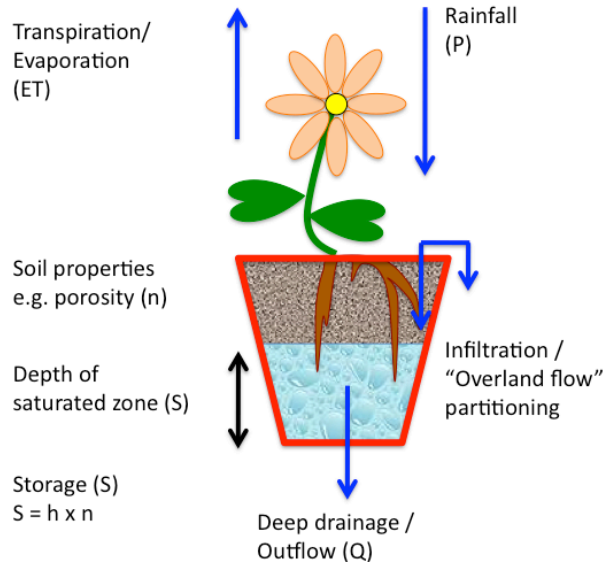


Fig. 1. Cartoon illustration of the flowerpot analogy for a catchment used in teaching catchment hydrologists. Containing vegetation, a root zone, a vadose zone, a saturated zone and soil; and modeling processes of rainfall, infiltration, surface flow partitioning, drainage, outflow, evapotranspiration and water storage in the soil, the flowerpot is an effective example of PCK commonly employed by catchment hydrologists. By employing simple parameterizations of the fluxes and a water balance over the flowerpot, a simple runoff model can be made and explored.

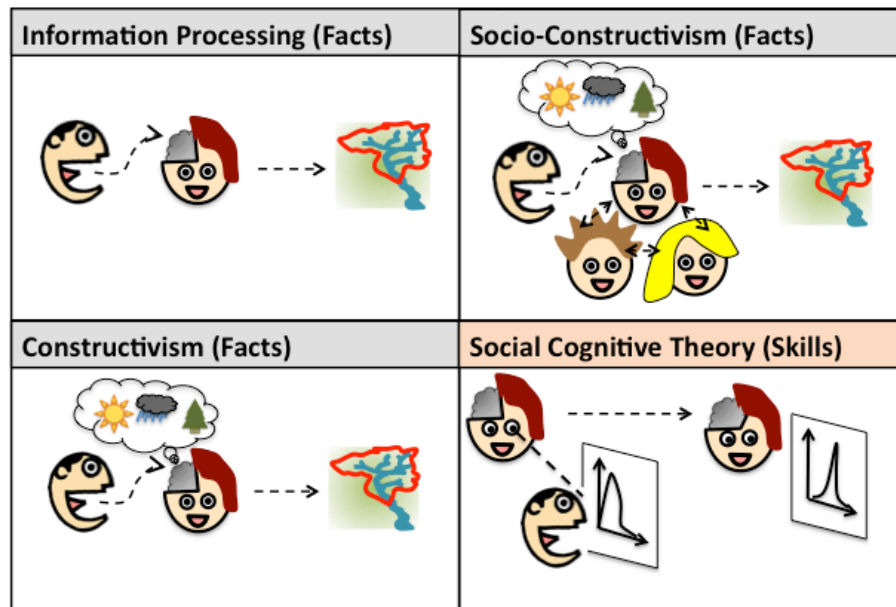


Fig. 2. Cartoon illustration of the major categories of learning theory. Information processing holds that knowledge is formed from received information: in this example, a teacher explains a conceptual model of a catchment, which the student adopts directly. Constructivism posits that learners integrate received information with their existing knowledge to construct understanding of new principles: students would link the teacher's explanation with their own understanding and experience of energy balance, rainfall, vegetation water use etc. to develop a mental model of a catchment. Socio-constructivism emphasizes the role of social interactions between learners in facilitating the construction of knowledge. Learning of skills and procedures is thought to occur by learners observing, mimicking and practicing skills as modeled by a teacher, and then successfully applying the skill in a new context, as described by social cognitive theory.

Student-centered approaches in hydrology education

I. Ngambeki et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

