Dear Dr. Stumpp

Thank you for your efforts in handling this manuscript. Please find our detailed responses (given in italics) to reviewer comments following in this letter with the revised manuscript provided at the end of the letter. Individual review responses have also been uploaded via the HESS website. In general, the reviews were positive of the study and its inclusion in the special issue on "Hydrology education in a changing world".

There was an overarching call for a more critical assessment of active learning techniques and the methodology considered in this study. We have addressed this in our revisions by providing expanded discussion on active learning requirements and by highlighting the potential shortcomings of the methodology considered in this study. This is useful for readers interested in improving their own course evaluations. Further, the reviewers questioned the connections to ecohydrology in the course considered. We take a thorough consideration of this in the revision and suggest some avenues forward to strengthen this connection in a new subsection of the discussion. In addition, we have better placed the course in context.

In all, we have been well served by the reviewers. We feel we have been able to address all the concerns in this revision and that the overall manuscript has improved. With that, we thank the reviewers for their efforts and resubmit the manuscript for consideration.

Please contact us straight away with any additional questions or concerns.

Yours truly,
SW Lyon (corresponding author)
MT Walter
EJ Jantze
JA Archibald

Reviewer #1 (M. McClain)
The manuscript of Lyon et al. offers an unexpected, and welcomed, opportunity to continue the discussion begun by McClain et al. in this same special issue. I appreciate the authors' efforts to add detail to the discussion and provide, as they say, a "how-you-can-do-it" example addressing both content and instructional approaches. The example they present is of a new (June 2012) three-week summer course offered to MSc-level students in a Hydrology, Hydrogeology and Water Resources program at Stockholm University. The course is entitled Ecohydrology: A Mediterranean Perspective and is divided into three main teaching and learning activities that consider the central concepts of ecohydrology and delve deeper into the process of evapotranspiration via classroom exercises and fieldwork. The course also utilizes an active learning approach, which stimulates the students to play more active roles in the learning process. The effectiveness of the approach is assessed through student evaluations of the course and the personal reflections of students and teachers. The assessment does not appear to have been designed as a formal investigation of the effectiveness of active teaching approaches but rather a basic evaluation typical of quality assurance in many educational programs.

We start by thanking Michael McClain for the appreciation of this study and for providing a valuable review of the work. In general, we agree with the reviewer's assessment and have attempted to present this study in a clearer light throughout. We feel that addressing these comments (taken in turn in the following) in our revisions have allowed us to better tune the message of this study by highlighting its strengths and more thoroughly considering potential weaknesses.

Evaluating the merits of this course and the lessons learned in the context of the framework presented by McClain et al. is not straight forward because the framework considers ecohydrology in a broader educational context and at the MSc level focuses on full programs rather than a single course on the subject. If the manuscript continues to feature this link, it would be helpful to describe the position and purpose of the course in the larger Hydrology, Hydrogeology and Water Resources MSc program at Stockholm University. How does this course fit into the learning objectives and design of the MSc program? Is it the only explicit consideration of ecohydrology in the program? I presume the course is elective given it is the first time it has been offered and it is taught in collaboration with another university. Are there plans for the future of the course in the program or for the future incorporation of more content in ecohydrology?

It is agreed that there is some misalignment between the breadth of full MSc level ecohydrology program outlined in McClain et al. and the course offered up in this current study. We do feel that there is connection between the two studies such that a link between the two is valid. To help adjust for this, we have taken the reviewer's comment to provide a better context surrounding the course relative to the larger Hydrology, Hydrogeology and Water Resources MSc program at Stockholm University in the revised text.

As correctly pointed out by the reviewer, the course considered in this study is currently an elective that provides the main consideration of ecohydrology in that Hydrology MSc program. The course matches well with the central learning objectives of the MSc program. The Hydrology, Hydrogeology, and Water Resources Master's Program seeks to provide broad knowledge in the field of hydrology and water resources with substantially deeper knowledge and *insight into current research and development activities. Further, and in a more general sense, the program encourages students to critically, independently and creatively identify and formulate water issues and to plan and carry out advanced tasks within specified time limits, so to contribute to the development of knowledge around these issues.*

Further, there are plans to increase the level of ecohydrology content directly considered in this course through course development (as addressed in response to other reviewer comments) and through cross-listing the course in the newly started Landscape Ecology MSc program at Stockholm University. We have attempted to highlight this throughout the revised manuscript as we outline how this course presents a structure that is likely relevant for ecohydrology education.

Considering the content of the course, I was struck by the absence of any real consideration of ecology - plant ecology in particular. Students will have encountered references to ecological processes in TLA #1 "What is Ecohydrology", but there were no recommended readings on plant water use, variations among species, variations among crops and 'wild' plants, etc. Moreover, the exercises in TLA#2 and research questions in TLA#3 (Table 3) deal only with physical factors influencing evapotranspiration (i.e. temperature, humidity, vapor pressure, soil moisture, and albedo). Did students learn anything about the ecological processes that influence and sometimes control these critical physical variables? The Mediterranean focus of the course is perfect for learning about unique plant adaptations to limited water availability, and the differences in water use between native plants and irrigated crops is fundamental to understanding differences in evapotranspiration. Landscape ecology and changing land use/land cover (i.e. species composition) would seem to offer another opportunity for learning about the interaction of ecology and hydrology in the Mediterranean region. In my opinion it is this explicit incorporation of ecological as well as hydrological concepts and approaches that distinguishes ecohydrology. From a content perspective (and excluding the literature review in TLA#1), how is this course different from the standard teaching of evapotranspiration in any hydrology program?

We appreciate this comment and take the message to heart as it echoes across other reviewer comments. Clearly, this course is in its infancy and needs further development to achieve the status of what would be considered a fully-vetted ecohydrology course. The reviewer highlights several key factors that could be considered in this future development. Further, the reviewer hones in on exactly what we feel is a central message of this study: How do we get to an effective ecohydrology course?

We have, thus, restructured the manuscript to highlight this aspect of the study and softened claims that our course offering was a full-blown ecohydrology course. Namely, we have more explicitly stated that this course is an example of a potentially effective structure that can evolve towards a more rich and focused ecohydrology content course (even if it is not 100% there yet). This evolution towards an elusive, optimal ecohydrology course (i.e., one that encompasses all the aspects highlighted across all the reviewers) is then taken up in a more explicit discussion around our recommendations regarding the 'road forward'. This involves, for example, cross listing the course a landscape ecology MSc program (see above) to better mix student perspectives. It also involves bringing in local and site specific expertise from the region more familiar with local vegetation and ecology to address potential recent shifts regional and their connection with hydrology. In future offerings of the course, the plan is to include more *“physiological” ecohydrology aspects into the course such as consideration of rooting depth into model development or stomata response on controlling transpiration.*

Lastly, the level of “ecohydrology” realized in this course is partly linked to the active learning environment itself. Allowing, for example, students to design their own experiments precludes instructors from pushing a clear agenda throughout. Students, thus, selected to design an experiment that centered on the more physical side of ecohydrology (of course, the course design of TLA#1 and TLA#2 helped guide them). During the course, instructors also identified that the course was getting away from ecohydrology. To offset this to some extent and help distinguish this course from standard teaching of evapotranspiration offered in any hydrology program, the instructors put together a demonstration aimed at drawing students' attention to the impact of biological adaptation to evaporation while at the Navarino Environmental Observatory. This activity (a description of which has now been included in the discussion text) consisted of a small experiment carried out by the teachers to demonstrate the impact of plant type (broadleaf vs. needle leaf) on evaporation. We highlight this as a potential shortcoming or limitation of an active learning environment in the revised text whereby some control on what the students actually do may be sacrificed. As such, there might not be the opportunity to explore in detail all the aspects of a given subject (particularly one as broad as ecohydrology).

Turning to the assessment of instructional approaches used and the effectiveness of active learning approaches, the reviewers of the McClain et al manuscript emphasized that novel instructional techniques and attention to personal competencies are not unique to training in ecohydrology. I agree and am confident that Lyon et al acknowledge this as well. That said I found the results of the authors’ assessment to be quite interesting. One must be cautious, however, to not over interpret or draw too-firm of conclusions from the feedback of such a small number of students in one course. I think Lyons et al present a fairly balanced analysis and discussion in this respect, although the statement in the Concluding Remarks that learning "can never be active enough" may cross the line.

We thank the reviewer for confirming our intentions to present a balanced interpretation of the results of this study. And we agree that the statement that learning “can never be active enough” is an overstatement and it has been removed.

The authors note that 5 of the 6 students were female which warrants a bit more attention given possible (or perceived) gender-based differences in learning styles. Another factor which was not mentioned in sufficient detail is the background of the students. On page 9347 it says the students have a "homogeneous prior educational background that likely typifies non-engineering hydrology Master’s students most teachers would come across in an ecohydrology course." Academic culture varies considerably between countries and continents and the response of students to active learning approaches may be influenced by this background. Were the students all Swedish (with undergraduate degrees from Swedish universities) or did they come from a diversity of cultural and educational backgrounds? If there is a lack of cultural diversity I recommend toning down the use of "typifies" and "most teachers" because the results may only apply to a narrow portion of the cultural academic spectrum. Time will tell.

Yes, the academic cultures do vary around the World and we appreciate the intent of this comment. To clarify, the mix of backgrounds (cultural and educational) was fairly spread from *our perspective (students came from and had been previously educated in Sweden, Denmark, France, Germany, and Iran while the instructors came from Sweden and the US). We have explicitly mentioned this in the revision to justify our assumption that this mix could be considered to typify classrooms at many universities.*

Minor point: There are minor grammatical and typographical errors throughout the manuscript. The language is also at times too informal and imprecise (e.g "can never be active enough" comment). A careful revision and tightening up is needed.

Agreed and we have attempted to tighten up language and correct all minor grammatical errors in our revision.

Reviewer #2 (S. Shaw)

The manuscript is well written and reads easily.

We thank Dr. Shaw for this review and his general support of the study. We feel that, by addressing the concerns in this review, the manuscript has improved. This is true in particular with regards to a more critical assessment of active learning.

Given the very small sample size and lack of direct testing of learning outcomes relative to a control group, most of the conclusions are simply anecdotal. It isn't realistic for the authors to more rigorously test the learning outcomes, but it might be useful to consider with some additional criticality whether more "active" learning (TLA 3) is always the best teaching approach.

For instance:

i. How does "active" learning influence long term retention and application of knowledge? Do students build a sufficient mental framework that allows them to connect an experiment they did over a day or two to other concepts in the same or different discipline?

ii. Are there certain topics that are less suitable to "active" learning? Certainly, learning about experimental design, learning how to make measurements, and learning how to interpret experimental data is probably best taught by trying to carry out an experiment. But, are more theoretical aspects of the science suitable for active learning?

It is correctly identified that it is not (in the context of this current study) necessarily realistic to provide a rigorous test of the learning outcomes or the student abilities to achieve them over the length of the course. This is often an issue when comparing different teaching and assessment strategies within cross-disciplinary courses (see Lyon and Teutschbein, 2011). That being said, we agree that a more critical view of situations or environments where active learning may not be the best alternative could be provided in this study to help round out the presentation.

With that, we have added more text highlighting potential limitations of this study and of active learning environments in the discussion section (specifically in the section 4.2 How active is active enough?) as follows:

"It is often problematic to measure what 'works' in the classroom (Prince, 2004) and it should be noted that active learning environments and/or techniques may not always be optimal. For example, it is rather straightforward to see the benefits of a hands-on environment with regards to learning how to design and conduct experiments (e.g., Spronken-Smith, 2005; Levia and Quiring, 2008) and research has shown how active environments can increase course effectiveness (e.g., Hake, 1998) with some evidence suggesting that even the simplest active techniques can improve student retention (e.g., student-student collaboration during lecture pauses as in Berry, 1991). Still, Mayer (2004) suggests that the 'activity' in and of itself does not necessarily support learning indicating that active learning must involve well designed activities that promote thoughtful engagement around learning outcomes in order to be effective. For example, some purely active techniques like discovery learning (where students engage with

materials without any instructor support) have been shown to be inferior to guided learning with regards to gaining knowledge (Kirschner et al., 2006; Mayer, 2004). Also, as highlighted by Drake (2012), in many cases where active learning shows improved student retention of class materials, instructors still provided a lecture and guided (to some extent) the activities. The take-home message here is that an active learning environment needs to be thought out and planned for to be valuable. This is echoed in the following sections where student and teacher reflections on the course are presented."

Additionally, I have a few minor suggestions:

1. Page 9339, Line 7: Could an additional line or two further summarizing McClain be added? While McClain is cited, most readers don't really want to immediately go read the McClain paper. What do McClain et al. see as the "pitfalls and complex challenges" of teaching ecohydrology?

The following has been added:

"McClain et al. (2012) propose an "educational vision focused on the development of professional and personal competencies to impart a depth of scientific knowledge in the theory and practice of ecohydrology and a breadth of cross-cutting knowledge and skills to enable ecohydrologists to effectively collaborate with associated scientists and communicate results to resource managers, policy-makers, and other stakeholders" necessitated by the trans-disciplinary nature of ecohydrology."

2. p 9342: Could TLA be written out in full on the subheading on this page and on subheadings on subsequent pages? I realize the convention is to establish an abbreviation once and then only continue to use the abbreviation. However, since most readers are unfamiliar with the TLA abbreviation, it would help clarify the organization of the paper to write it in full for the headings.

This has been done.

3. p 9346, 1st paragraph: I didn't quite understand how "active" is being used in this sense. If the student is directing their own learning, aren't they always actively involved (relative to a lecture)? It seems like the distinction is more along the lines of "goal-oriented" (TLA 3) versus "exploratory" (TLA 1) activities. I would consider both to require near equal amounts of student action.

We have clarified this in our revision by restating the general definition of active (with regards to active learning) adopted in this study and removing the confusing terminology. As such, active learning is defined in a general sense as any instructional method that engages students in the learning process (Prince 2004). This clarifies the confusion with regards to the level of activity required in the various activities.

Reviewer #3 (Anonymous)

Thank you for the chance to review this reflection on a recent ecohydrological summer school learning experience.

There is much in this paper to enjoy and draw on usefully. I do think that any models of innovative ways to deliver course content are valuable for the community to share, and I am fully supportive of the authors sharing these experiences in the HESS Special Issue.

I have a several concerns with the manuscript in its current form, however. Please treat these criticisms as a basis for improvement, rather than an attack on the motivation or the course and paper. I am focusing on these issues because they provide opportunities to improve the manuscript and focus the message. However, having just scanned my fellow reviewer's comments, it seems that they are shared concerns.

We are glad that the reviewer enjoyed this study and supports its inclusion in this HESS special issue on education. Also, we appreciate the criticisms offered up (which echo comment made by the other reviewers) as they have helped us focus our presentation and message.

In brief:
1. My most significant concern is that I am not convinced that the authors can robustly support their conclusions about the student orientation to active learning tasks based on the data they have collected.
2. I question just how ecohydrological this course really was – I see almost zero ecology/plant physiology in the course material.
3. The authors may be significantly under-estimating some of the challenges associated in scaling their approach to more typical classroom environments.
4. In terms of editorial issues – there are numerous spelling errors, typos, grammatical errors etc that need to be addressed. I’ve identified a few of them, but the manuscript is in need of a hard edit.

These concerns are elaborated on below.

We address these central concerns in response to the elaborations that follow.

1. Do the data support the conclusions?

There is a need to provide a more critical analysis of the student feedback and responses to inform future course planning. For future consideration, I would suggest that when working with such a small group of students, a different method of evaluation based on semi-structured qualitative interview techniques will be much more appropriate and useful than written evaluations. This approach is widely used in the educational literature to "go deeper" when sample sizes are small, so that even when there is limited statistical power, there is still scope to identify interesting educational outcomes based on student reflection. In this methodology, a neutral party (ideally an education researchers) offers a set of predefined interview questions, but has the opportunity to follow up on interesting points students make in depth. The interviews are recorded, and are analyzed through group-based scoring methods to reduce selection bias etc by the main researchers.

The comment is an excellent suggestion on how to improve our (or any study's) ability to evaluate teaching methods as we target educational research. We have highlighted in the revision (in the Methodology) that such evaluation design would be useful and pointed out that we have not used it in the current study as a potential shortcoming. While this is a potential weakness of the current study, there is, as highlighted by this and other reviewers, much content that reminas valuable from the evaluation considered. By including this criticism of the methodolgy, we feel that we provide useful insight to readers of this HESS special issue.

In the absence of the more detailed information about the students' experiences that such a technique might have yielded, I just cannot agree with the authors that the increase in the evaluations along the trajectory of the 3 tasks can be attributed to the % of active learning. We can posit an almost infinitely large number of alternative hypotheses for the observed increase, and have no basis to dismiss them.

Alternative interpretation 1: Time.
Summer schools take time to "ramp up". Relationships need to be built. Instructors need to work out how to work with their student cohort. My experience in this (from the NSF Hydrological Synthesis Summer Institutes) is that the student teams become much more confident, comfortable and efficient as the summer schools progress. This leads to a more satisfying experience, and presumably more successful educational outcomes, later in the programs.

Alternative interpretation 2: Goals
Could it just be that the goals of the exercises were progressively more interesting to the students? The goal of the first task is pretty abstract. I do not think the authors have the data to discriminate between the effects of the teaching method and the teaching goals when looking at student responses. Even if we could be convinced that the teaching method was not optimal, how can we be sure that this is because of the degree of how "active" it was, versus e.g. students' familiarity with the scientific literature? Could a course of lectures ("passive") have actually achieved the results in a better way?

Alternative interpretation 3: Quality of task design
Given that several students seemed to find Task 1 poorly defined… could it just be that more thought and planning had gone into Tasks 2 and 3?

I could go on. My point is that the evaluations can't be taken as evidence that student learning scaled with how active the tasks were. There is no control, and the student feedback itself points to alternative explanations. I think this discussion must be revised in much more cautious terms.

We take this point to heart and have, thus, highlighted the potential for confounding influences on this study due to the limitations of the evaluation design and small sample size. Further, we have taken up more catious terms in the discussion through edits and inclusion of more critical assessment (as also suggested by other reviewers) of both our own methodology and the utility of active learning envirnonments.

2. How ecohydrological was this course really?

I refer primarily to Table 3 in the manuscript – the questions that are posed have nary a mention of a plant, a root depth, a stomata, or a crop type in there! While I agree that the models put together for predicting soil moisture balance & ET (a la Laio et al 2001, Feddes models, Porporato and co.) really relate 2 physical entities (soil moisture & evaporation flux), the thing that makes them ecohydrological is that they (i) account for stomatal closure, (ii) account for root depth. I just don't see much beyond micrometeorology & maybe specifically agricultural micrometeorology in Table 3. Could the tasks not be rephrased to at least try to look for evidence of plant water stress…or something that puts the plants in the picture? Ok, this is a criticism of the course rather than the paper, but given all the nice discussion about trans and cross-disciplinarity, it was a bit disappointing to see such a very traditional micromet approach to this task. Maybe the authors could reflect on ways to get the vegetation into the research questions (e.g. via porometry measurements, or comparing 2 diff. plants under the same irrigation regime, or something!) for future courses?

This comment reflects other review concerns and, in part, some of the teachers' concerns with the first offering of this course. We have addressed this in the revised manuscript through the explicit introduction of a section on getting this course to be more 'ecohydrological' in nature. In addition, with respect the the student-generated questions in Table 3, this specifically highlights some of the difficulties that are faced when incorporating purely active learning techniques into ecohydrology teaching. We have expanded the discussion around these aspect.

Further, we greatly appreciate this reviewer's detailed suggestions and will consider including them in future course offerings! We have, as such, also included these (and other considerations) in our revision.

3. Scaling up to the classroom

One thing I was confused about was the student:teacher ratio during this course. At worst it must have been 1:6, and I suspect that it was at times higher than that. If a teacher is a good teacher, then the personalized attention these students must have received surely partly drives the very positive response the students had to the course? Could you achieve these sorts of outcomes with 30 students and 1 instructor?

How dependent was the success of this course on having the students focus singly on the course topic for 4 weeks? Would it have survived intact in a "normal" curriculum situation where students time and attention would have been otherwise divided? What was the total time commitment students put in? Again looking at previous experiences at summer institutes, many students put in over 60 hours a week – which would come to 16 a week in a 15 week semester – a high course load, at least in the context I'm familiar with (undergrad and grad education in the USA).

On page 9344 the authors describe the importance of giving students raw data. My experience with undergraduates (a different context, I acknowledge), has been that raw data were a big problem. If students are not adept at working with large datasets then performing QA/QC on a dataset is a major task for them, and consumes energy that would be better spent on the hydrological problem. I’m personally in 2 minds about it – I think it is important for students to have an appreciation of the effort and techniques involved in data preparation – but it was also a bummer to find students who had spent days of effort on it with limited success. Since this is a potential “trap” for folks looking to emulate your approach, perhaps some caution is needed?

We address these comments in our revision by adding the clear corollary that the teachers’ confidence in scaling up the course is only valid for a summer course or a full-time course where students dedicate to the course full time. Different consideration would be needed with regard to recreating this course, for example, within the context of a standard schedule of courses. Regardless, while the high student:teacher ratio may have helped in giving a successful course, we feel that the impact of including active learning into our teaching would carry over to larger courses (with a potential trade-off of increased difficulty due to logistics).

In addition, with respect to having students work with raw data, we stand by our initial statement with regards to its importance but acknowledge the reviewer’s concern here and have, thus, softened our initial statement. For this specific course, the potential dangers of having the students work with the raw data were out weighted by the teachers’ a priori knowledge of student skill sets. This knowledge came about from previous interaction with the students and the prerequisites for the course. We have explicitly highlighted this in the revised text.

4. Editorial issues

Page 9341 – typo in sentence 2 (line 2-3).
Corrected

Page 9342 – typo in line 23 (reads synthesis, should read synthesize) and 24 (reads “Greek” should, I think, read “Greece”)
Corrected

Page 9343 – lines 6-9 – took me several reads to understand the intention of the sentence. Maybe consider rewording?
Corrected

Page 9344 lines 1-3 – did you compile a list of these “teachable moments”? It might have been instructive…?
We have added several examples of the teachable moments that came up in this TLA. These teaching moments included, for example, comparison of potential versus actual evapotranspiration conceptualizations, discussion of plant transpiration/water uptake responses under drought conditions, and basic review of the differences between empirical and physics-based modeling approaches.

Page 9344 line 4 – what data were in this dataset!
We have listed that this dataset included temperature, precipitation and streamflow data

Page 9344 – did the students also have an opportunity to compare the estimates to observed data? It seems to me that in the absence of some empirical measure of ET (e.g. from a flux tower, from water balance closure, from sap flux, from soil moisture balances…) that this might have been a

slightly unsatisfying experience – 400mm worth of variation in estimates, but no sense of what the actual errors were??
We did not have access to ET flux tower data to help confirm estimates. It was possible to roughly confirm estimates using the experimental data collected on site in TLA #3.

Page 9345 – if you're going to discuss the "location's unique features" … perhaps you could share those unique features with your readers?
We have listed the uniqueness of the site which include its location and the proximity of agriculture, native, and recreational vegetation (landscaping and turf grass) under various management strategies.

Section 3 – perhaps title this as "Assessment of educational effectiveness: Methods" or something that makes it clear that the methods you're discussing here relate to the way that you assessed the effectiveness of the techniques, and not the methods used to implement the techniques (which you just described!).
We have renamed this section.

Page 9348 – line 3 – I think you mean cognizant rather than cognitive? Excuse the US spelling, my spell checker doesn't think cogniscent (which I think is the UK version, but wouldn't bet on) is a word!
Sentence changed in response to a previous comment.

Figures

Fig 1 – caption doesn't read well – poor grammar. Can you rephrase?
Corrected

Fig 2 – should read "effective" not "affective" (affective would mean "relating to the emotions", and I hope is not what was being asked!)
Corrected

References

Berry, L.: Collaborative Learning: A Program for Improving the Retention of Minority Students, U.S.: Virginia, 1991-00-00, ED384323, 1991.

Drake, J. R.: A critical analysis of active learning and an alternative pedagogical framework for introductory information systems courses, Journal of Information Technology Education: Innovations in Practice, 11, 2012.

Hake, R.: Interactive-engagement vs. traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. American Journal of Physics, 66(1), 64, 1998

Kirschner, P. A., Sweller, J., and Clark, R. E.: Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. Educational Psychologist, 41(2), 75-86, 2006.

Levia, D. F. and Quiring, S. M.: Assessment of Student Learning in a Hybrid PBL Capstone Seminar, Journal of Geography in Higher Education, 32, 2, 217-231, 2008.

Lyon, S. W. and Teutschbein, C.: Problem-based learning and assessment in hydrology courses: Can non-traditional assessment better reflect intended learning outcomes?, Journal of Natural Resources and Life Sciences Education, 40, 199-205, doi:10.4195/jnrlse.2011.0016g, 2011.

McClain, M. E., Chicharo, L., Fohrer, N., Gavino Novillo, M., Windhorst, W., and Zalewski, M.: Training hydrologists to be ecohydrologists and play a leading role in environmental problem solving, Hydrology and Earth Systems Sciences, 16, 1685-1696, doi:10.5194/hess-16-1685-2012, 2012.

Mayer, R. E.: Should there be a three-strikes rule against pure discovery learning? American Psychologist, 59(1), 14-19, 2004

Prince, M.: Does Active Learning Work? A Review of the Research, Journal of Engineering Education, 9, 3, 223-231, 2004.

Spronken-Smith, R.: Implementing a problem-based learning approach to teaching research methods in geography, Journal of Geography in Higher Education, 29, 2, 203-221, 2005.

Training hydrologists to be ecohydrologists: A ‘how-you-can-do-it’ example leveraging an active learning environment for studying plant-water interaction

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Abstract

Structuring an education strategy capable of addressing the various spheres of ecohydrology is difficult due to the inter-disciplinary and cross-disciplinary nature and general breadth of this emergent field. Clearly, there is a need for such strategies to accommodate more progressive educational concepts while highlighting a skills-based education. To demonstrate a possible way to develop courses that include such concepts, we offer a case-study or a potential ‘how-you-can-do-it’ example from a recent course set in an ecohydrological context co-taught by teachers from Stockholm University and Cornell University at Stockholm University’s Navarino Environmental Observatory (NEO) in Costa Navarino, Greece. This course focused on introducing hydrology Master’s students to some of the central concepts of ecohydrology while at the same time supplying process-based understanding relevant for characterizing evapotranspiration. As such, the main goal of the course was to explore some of the central theories in ecohydrology and their connection to plant-water interactions and the water cycle in a semiarid environment. While this course is still in its infancy with regards to addressing some of the more in-depth aspects of ecohydrology, it does provide a relevant basis with an initial emphasis on the more physical concepts of ecohydrology from which to build towards the more physiological concepts (e.g., unique plant adaptations to water availability or differences in water use between native plants and irrigated vegetation). In addition to presenting this roadmap for ecohydrology course development, we explore the utility and effectiveness of adopting active teaching and learning strategies drawing from the suite of learn-by-doing, hands-on, and inquiry-based techniques in such a course. We test a potential gradient of 'activeness' across a sequence of three teaching and learning activities. Our results indicate that there was a clear advantage for utilizing active learning with a preference among the students towards the more 'active' techniques. This demonstrates the added value of incorporating even the simplest active learning approaches in our ecohydrology (or general) teaching.

1. Introduction

Ecohydrology is an evolving discipline that deals with the interaction between ecosystems and hydrology. The field of ecohydrology has been rapidly growing since early work on vegetation and hydrology interactions (e.g. Hack and Goodlett, 1960; Penman, 1963; Eagleson, 1978). Today, ecohydrology still maintains an active and healthy discussion about what forms the core of this emergent field (e.g., Hannah et al., 2007; Wilcox, 2010) and where the future will be found (e.g., King and Caylor, 2010). This rapid growth and discussion on the research side has been mirrored more recently in the associated education. Take, for example, the work by McClain et al. (2012) outlining a potential structure for ecohydrology education. They clearly identify the potential pitfalls and complex challenges associated with teaching and education within ecohydrology stemming from the various disciplines involved. With that, McClain et al. (2012) propose an "educational vision focused on the development of professional and personal competencies to impart a depth of scientific knowledge in the theory and practice of ecohydrology and a breadth of cross-cutting knowledge and skills to enable ecohydrologists to effectively collaborate with associated scientists and communicate results to resource managers, policy-makers, and other stakeholders" necessitated by the trans-disciplinary nature of ecohydrology.

According to McClain et al. (2012), this creates various ‘spheres’ of ecohydrology that should be addressed in order to train the future generation of ecohydrologist such that they can play a leading role in environmental problem solving. As outlined in McClain et al. (2012) in this special issue on ‘Hydrology education in a changing world’, these principle spheres consider (i) climate-soil-vegetation-groundwater interactions at the land surface; (ii) riparian runoff, flooding, and flow regime dynamics in river corridors; and (iii) fluvial and groundwater inputs to lakes/reservoirs, estuaries, and coastal zones. Each conceptual sphere (and their interface – see McClain et al. (2012)) can bring about its own unique set of challenges that reflect the broad range of topics under the umbrella of ecohydrology. For example, the required flow regime and subsequent dynamics necessary to protect desired ecological functions represent a key focal area of active ecohydrological research (Arthington et al., 2010). Further, much work currently centers on how the composition and configuration of vegetation alter the hydrological cycle across scales in connection with process-level changes due to land use alteration (e.g., van Griensven et al., 2006; Wilcox, 2010). While the research field of ecohydrology abounds with challenges and numerous avenues for potential advancements, the issue still remains how to best address these different ‘spheres’ in practice and, more specifically, in our courses.

This issue is compounded by the inter-disciplinary and cross-disciplinary nature of ecohydrology, which can become a challenge in the classroom. Such challenges are longstanding in standard hydrology education due to its inherent interdisciplinary nature (Wagener et al., 2007) and can lead to combinations of intended learning outcomes (ILOs) in courses that may not be easily or completely achieved using traditional lecture-based learning environments or using basic problem-solving techniques (Lyon and Teutschbein, 2011). As such, ecohydrology education may be better achieved through inclusion of more learner-centered approaches and strategies (e.g. experiential learning, inquiry-based learning, and collaborative learning) (Huba and Freed, 2000). These approaches are traditionally considered to fall under the broad umbrella of active learning approaches (Bonwell and Eison, 1991).

Active learning is defined in a general sense as any instructional method that engages students in the learning process (Prince 2004). As such, active learning requires students to carry out meaningful learning activities and think about what they are doing (and why they are doing it) (Bonwell and Eison, 1991). Such approaches lend themselves organically to natural science disciplines. For example, geography education has seen benefits from more active learning approaches since it has traditionally contained collaborative, hands-on, and experiential learning through lab and field-based learn-by-doing courses (Spronken-Smith, 2005; Levia and Quiring, 2008). In hydrology education, Lyon and Teutschbein (2011) demonstrated how students both preferred and performed better in a problem-based learning environment, which is, by definition, an active learning environment in nature. Shaw and Walter (2012) point to the potential for inquiry-based comparative analysis approaches centered on resolving similarities and differences between hydroclimatic regions to help in linking across disciplines and developing critical thinking within hydrology courses. Given the history of success adopting active-learning approaches in natural sciences and hydrology, it stands to reason that ecohydrology education could also benefit from adopting such approaches. What is yet to be seen is to what extent ecohydrology courses (and all our courses in general) need to be ‘active’ in nature to achieve their goals.

Taken all together, there is clear need for ways forward in ecohydrology education that can include/promote active learning environments. McClain et al. (2012) highlight an educational framework for training hydrologists to be ecohydrologists. Here, we seek to begin adding details to such a framework in the form of suggesting potential course structures. Specifically, we present a potential ‘how-you-can-do-it’ example from a recently conducted course set within the context of ecohydrology. From this starting point, we consider a potential roadmap forward on how to design courses that promote an active learning environment while being targeted at ecohydrology. Further, we test the utility of such an active learning environment (from both the students’ and teachers’ perspectives) for achieving the course goals (which are likely representative of what would be expected from many ecohydrology courses). We also seek to answer the question ‘How active is active enough?’ when considering how to design and structure teaching and learning activities (TLAs) in such a course.

2. Ecohydrology: A Mediterranean perspective

Recently, an international Master’s course was developed by Dr. Steve W. Lyon, Department of Physical Geography and Quaternary Geology, Stockholm University (Sweden) and Dr. M. Todd Walter, Department of Biological and Environmental Engineering, Cornell University (USA) for the Navarino Environmental Observatory (NEO). The goal of this course was to supplement general hydrological education available to students by exploring some of the central concepts of ecohydrology. This course, entitled *Ecohydrology: A Mediterranean perspective* brought together students from both universities to investigate processes driving plant-water interactions in the Mediterranean environment surrounding Costa Navarino where the NEO is located. Students designed and carried out a field experiment highlighting both the location's uniqueness and potential sensitivity to climatic changes that emphasized the more physical side of ecohydrology. This provided an excellent opportunity for both the students and teachers to bridge the gap between theory and practice (McClain et al., 2012) by beginning to place the NEO in an ecohydrologic-relevant framework.

In this initial offering, the course was designed primarily to supplement the existing Hydrology, Hydrogeology, and Water Resources Master's Program within the Department of Physical Geography and Quaternary Geology at Stockholm University by offering a topic-specific elective. With that, the explicit design of this course may differ from those conceptualized or envisioned in McClain et al. (2012) as it seeks to fit the intended learning outcomes of a more hydrology-focused Master's program. The Hydrology, Hydrogeology, and Water Resources Master's Program seeks to provide broad knowledge in the field of hydrology and water resources with substantially deeper knowledge and insight into current research and development activities. Further, and in a more general sense, the program encourages students to critically, independently and creatively identify and formulate water issues and to plan and carry out advanced tasks within specified time limits, so to contribute to the development of knowledge around these issues.

The main goal and intended learning outcomes (ILOs) of the course (Table 1) were, thus, designed to explicitly target some of the central concepts of ecohydrology while building on the hydrological education background of the students. Due to the broad and varied concepts in ecohydrology (d’Odorico et al., 2010; Wilcox, 2010), the relative “newness” of the course in its first-time offering, and natural settings of the NEO, the course attempted to narrow in on plant-water interactions and coupled land-water management impacts on evapotranspiration. We have uploaded the course syllabus as supplementary information to provide a complete overview of the course (including assessment methods and grading criterion). The course was structured to correspond to about 3-to-4 weeks of teaching time and to be carried out during a summer term following the first sequence of Master’s level hydrology education. In the following, we provide a general overview of the course’s three main teaching and learning activities (TLAs) (Biggs and Tang, 2007) and the motivation behind them.

2.1. Teaching and Learning Activity (TLA) #1: What is ecohydrology?

In this first TLA of the course, students reviewed central concepts of ecohydrology through a combination of state-of-the-science literature review and discussion (see reading list in syllabus as supplementary information). The goal here was to build the students’ knowledge base around the question ‘What is ecohydrology?’. This first step was necessary in this specific case study example as the general composition of students in the course (i.e., upper level Master’s students following a program in Hydrology, Hydrogeology and Water Resources) were unfamiliar with the main tenants of ecohydrology.

Learning in this TLA was designed to be exploratory and self-regulated in nature. Students were presented with a subset of the state-of-the-science literature relevant for ecohydrology and asked to summarize and synthesize across the seemingly divergent topics. These topics focused on ecohydrology in a general sense, evapotranspiration mechanisms and processes, and hydroclimatic assessments in Greece and the Mediterranean region to provide a site-specific background relevant for this course. Students were encouraged (and required) to explore the current literature on these topics and include their own references (i.e., those not specified by the instructors) as they attempted to answer the central question of this TLA. After approximately one week, students lead discussions on the breadth and interconnections across the literature provided and the literature they gathered. In addition to leading discussion sessions, students were required to complete a short, written summary that could be assessed by the teachers (Table 2). Based on these summaries and the in-class discussion, students were able to identify several central concepts with regards to climate-soil-vegetation-groundwater interactions at the land surface. Student perspectives were clearly guided by the initial assigned literature list and course structure (see supplemental information). The assigned literature could, of course, be shifted in future course offerings to highlight or encompass different aspects of the field (i.e., plant water use, variations among species, variations among crops and "wild" plants, etc.). Ultimately, the free-form discussions in this TLA allowed for identification of knowledge gaps to be better addressed in next two TLAs in the course.

2.2. Teaching and Learning Activity (TLA) #2: Calculations of evapotranspiration

This second main TLA specifically targeted providing relevant 'tools' for the students' toolboxes such that they could tackle designing and carrying out an ecohydrological-relevant experiment. Here, we specifically refer to the appropriate theories and methodologies to characterize evaporative fluxes from the landscape. This is in line with the skills-based style of education called for by McClain et al. (2012). In this TLA, students developed relevant hydrologic models (with teacher guidance) to estimate evaporative fluxes using a myriad of approaches. Specifically, we targeted using a water balance (closure) approach, several empirical temperature-based approaches, and traditional energy balance relationships for estimation of potential and actual evapotranspiration relevant for the hydroclimatic setting of NEO. The modeling allowed for investigation of the interaction between plants and water from a mechanistic perspective to exemplify the terrestrial fluxes of water from the landscape. Modeling was carried out in an open computer lab setting with the students encouraged to interact and help each other. The attempt here was to motivate cooperative learning. In addition, the in-class discussions also provided ample, often spontaneous, teaching moments to address knowledge gaps that were inevitable given the short timeframe the students had to synthesize the concept(s) of ecohydrology and experiment with different modeling approaches. These teaching moments included, for example, comparison of potential versus actual evapotranspiration conceptualizations, discussion of plant transpiration/water uptake responses under drought conditions, and basic review of the differences between empirical and physics-based modeling approaches. As such, these "teaching moments" were used somewhat to help guide the learning process in general.

This TLA leveraged off existing hydroclimatic monitoring collected in connection with ongoing NEO field activities. Students were given about 3-years of 15-minute raw data covering temperature, precipitation, and streamflow. They needed to perform quality controls on these raw data and reduce them to daily information. It should be noted that while working with raw data is often a good first step for students, it can be a time sink in many situations depending on student abilities. For this course, teachers were comfortable with the students' existing skills at working with raw data through previous experiences and design of the prerequisites of the course. After compiling the data, students were asked to develop a simple water balance (which scaffolds on their previous hydrology courses) and implement temperature-based empirical estimates of potential and actual evapotranspiration (e.g., Langbein, 1949; Turc 1954; Hargraves and Samani, 1985). Lastly, students developed a full

Penman-Monteith (Penman, 1984; Monteith, 1981) estimate of potential evaporation for the NEO site. Rather than teaching this explicitly, students were directed to existing publically available and standard techniques (e.g., Allen et al., 1998) to explore the range of approaches and carry out the calculations. This allowed students the opportunity to trouble shoot and make the necessary approximations and assumptions required when faced with data limitations.

By adopting several different approaches, students were able to appreciate the full spectrum of possible estimates for potential evapotranspiration. Student estimated potential evapotranspiration values spanned the range from about 900 mm per year using the Thornthwaite approach (Thornthwaite and Holzman, 1939) to about 1300 mm per year using the Penman-Monteith approach. These various estimates allowed teachers to highlight the implications and potential limitations associated with the various parameterizations in each approach, the assumptions made when synthesizing across various hydroclimatic datasets, and the potential added value of site-specific estimation. It also allowed for students to explore the potential variability within one given approach (e.g., the full Penman-Monteith method) depending on the values taken for the numerous physical and parameterized relationships in the equation.

2.3. Teaching and Learning Activity (TLA) #3: Designing and conducting an ecohydrological experiment

This third TLA was carried out in the field at the NEO in southwestern Messina region of Greece. Students were tasked with designing a field experiment to test key assumptions and simplifications relevant to the calculations carried-out in TLA #2 and connect these estimates back to ecohydrological concepts outlined in TLA #1. These include, for example, the selection of a representative value for relative humidity when estimating evapotranspiration given the inherent heterogeneity faced at the landscape scale and the potential impact of diurnal variations on net radiation considered in energy balance estimates. Setting the structure and nature of this experiment was fully in the hands of the students. As such, students were required to self-organize and divide tasks accordingly to design and complete their experiment. This fostered a collaborative learning environment. Teachers provided some general overview and detailed knowledge when necessary (e.g., detailed lectures on Penman-Monteith calculations or demonstrations of how to use field equipment).

During the visit to the NEO (about 5 days in total), students took time to brainstorm ideas for relevant experiments that took advantage of the location’s unique features, the available equipment, and their own knowledge base. As background, NEO’s uniqueness can be seen by its geographic location in a warm Mediterranean landscape offering an abundance of energy to drive processes while at the same time experiencing seasonal water limitations. Further, the region’s long-standing development of agriculture (mainly olives and some citrus) and more recent development of tourism offer strong gradients of land-water management for studying various aspects of ecohydrology. After an initial break-out style discussion to facilitate the brainstorming, teachers and student convened to synthesize and generate an overarching testable hypothesis with several supporting questions to be answered (Table 3). For the course offering considered in this case study, students centered their experiment around the more physical aspects of ecohydrology and put forward the hypothesis that evapotranspiration would be higher from more-managed locations (i.e., more extensively irrigated) and open water bodies than from less-managed locations (i.e., drip-irrigated and non-irrigated landscapes). To test this hypothesis and answer the supporting research questions, students conducted field measurements to gather data and performed the necessary calculations (Figure 1). This TLA concluded with student presentations and discussion of the answers to their research questions, the validity of their hypothesis, and potential implications for regional development. This allowed students to collaborate and begin to place the NEO in an ecohydrology-relevant framework.

3. Assessment of educational effectiveness: Methods

With regards to the aforementioned course structure and TLAs, the intention was to explicitly involve a gradient of active learning strategies. Again, active learning is defined in a general sense as any instructional method that engages students in the learning process (Prince 2004). As such, these TLAs can be relatively ranked in the following broad sense according to their level of ‘activeness’. TLA #1 offers a low-level of active learning as students self-guide their reading of state-of-the-science literature and self-regulate their intake of knowledge. TLA #2 can be conceived as a mid-level of active learning environment as students work with processing raw data and applying/adapting relevant evapotranspiration equations. Further by having open computer lab sessions where students are encouraged to assist each other, TLA #2 brings in some aspects cooperative learning. Lastly, TLA #3 clearly has a high-level of active learning as students design and carry out a field-based experiment. As the students self-organized into a functioning research team to complete the experiment, there was also high level of collaborative learning.

This potential gradient of active learning across the TLAs allowed us to gauge the effectiveness of a more versus less active learning environment in an ecohydrology course. Here this was done by assessing students’ views of the usefulness of the individual TLAs for achieving the overall goal of the course (Table 1). We also asked the students if the course achieved its overall goal and if they felt the general active learning environment was affective for achieving this goal. This assessment was conducted using anonymous course evaluations at the end of the most recent course offering (June 2012). During this initial offering, we had an enrollment of 6 Master's level students all of which had completed the first year of the Hydrology, Hydrogeology and Water Resources Master's Program offered through the Department of Physical Geography and Quaternary Geology at Stockholm University. This background education was a prerequisite and created a more-or-less homogeneous prior Master's level educational background that could be considered to typify non-engineering hydrology students most teachers could experience in an ecohydrology course. The demographic distribution of the students was skewed towards female (5 of 6) in this cohort. Further, the mix of backgrounds (with regards to culture and undergraduate education) was fairly diverse with students coming from (and having been previously educated in) Sweden, Denmark, France, Germany, and Iran. The instructors came from Sweden and the U.S. such that this cohort of students might represent the demographic distribution of classrooms at many universities.

Within the context of the written voluntary course evaluations completed at the completion of the course, students were asked to quantify the utility of each TLA and the utility of the over-all active learning environment on an integer scale from 1 (not very useful) to 5 (very useful). We avoided asking specifically about the ILOs as these were more custom tailored and aligned in relation to the TLAs (i.e., we would not expect TLA #3 to help in achieving ILO #1). In addition to quantifying student opinions on the utility of each TLA, we also collected student reflections via open-form comments on the usefulness of the TLAs and the overall active learning environment. Since the small course size and use of student reflections may tend to skew results, we have also elected to include some teacher reflections on the effectiveness of employing an active learning environment relative to more traditional forms of education. Also, we reflect on several alternative considerations that would help develop this course towards a more ecohydrology-relevant context. As these were gained through this initial offering, we hope this serves as a potential road map forward for incorporating active learning environments in ecohydrology education.

It should be noted that, in this methodology, we have not explicitly involved semi-structured qualitative interview techniques (or similar) that can be used to create a dialogue between students and teachers and may be useful when dealing with small sample sizes (such as those presented in this course). This limits to some extent our ability to isolate the effect of increasing active learning techniques across the three TLAs relative to other potentially confounding influences. While this is a shortcoming of our methodology, it serves as an opportunity for us to highlight the value of designing course evaluations in concert with educational researchers or pedagogical experts (when possible). Such consideration could, for example, better inform teachers about specific aspects of their courses such as the general utility of various techniques considered in the classroom.

4. Results and Discussion

4.1. On the general use of an active learning environment to achieve the course goal

When asked if the course had achieved its main goal, 100% (6 out of 6) students responded that it had. We considered this as an indication of a successful course. In addition, this (from our perspective) lends credence to the following results and discussions in light of the small sample size considered and methodology used. When explicitly asked about the effectiveness of an active learning environment relative to their experiences with traditional lecture-based environments for achieving course goals, students by-and-large agreed that this active learning environment was useful (to very useful) in achieving course goals (Figure 2). Considering the 1 to 5 integer scale as a scoring system, the average score was 4.67 across all students with regards to the effectiveness of the active learning environment. From this simple survey, the students were clearly aware of the attempt to involve an active learning environment and also that this approach differed from what they had previously experienced in some of the more traditional lecture-based environments offered across their hydrology Master's program of study. Again, this result helps lend support to the following comparisons with regards to the individual TLAs and their utility in such a course.

4.2. How active is active enough?

Clearly, there was agreement among the students that the more 'active' the TLA; the more useful it was in achieving the course goal (Figure 2). Again, considering the 1 to 5 integer scale as a scoring system, the average score for TLA #1 for achieving the course goal was 3.33 while it was 4.17 for TLA #2 and 4.50 for TLA #3. To some extent, this result would be anticipated based on previous active-learning research in the sciences (e.g., Knight 2004; Neilsen et al., 2012) and in hydrology (e.g., Lyon and Teutschbein, 2011). As such, it is not that surprising here that TLA #3 where students designed and carried out an experiment would be considered the most useful to achieve the course goal.

What might be interesting here, however, is that we see clear preference across what could be considered as a gradient of active learning strategies towards the more active approaches. This preference potentially demonstrates the added value we can assign in part to the effort of including additional active learning in teaching. Further, it highlights that even partial inclusion of active learning techniques have clear benefits. For example, moving from student exploration of literature (TLA #1) to active participation in data analysis and calculations (TLA #2) increased (significant at $p < 0.05$) the utility of the TLAs (and thus efficiency of our teaching) in this course. We feel this is an important results since it demonstrates that while it might not always be an option to immerse students in a full-on active learning environment, such as that fostered by TLA #3 in this case study, there are alternative or incremental degrees of ‘activeness’ that can add value to our courses. The potential for confounding influences do exist, however, as students could be simply responding to better TLA design across the three TLAs or to the classic time effect whereby cohorts of students become more comfortable with material and each other over time within a course. Still, the general trend seen across a clear gradient of TLA archetypes is encouraging for those faced with developing new course in emergent research fields (such as ecohydrology) where the funding or field sites may not yet be well established.

It is often problematic to measure what ‘works’ in the classroom (Prince, 2004) and it should be noted that active learning environments and/or techniques may not always be optimal. For example, it is rather straightforward to see the benefits of a hands-on environment with regards to learning how to design and conduct experiments (e.g., Spronken-Smith, 2005; Levia and Quiring, 2008) and research has shown how active environments can increase course effectiveness (e.g., Hake, 1998) with some evidence suggesting that even the simplest active techniques can improve student retention (e.g., student-student collaboration during lecture pauses as in Berry, 1991). Still, Mayer (2004) suggests that the ‘activity’ in and of itself does not necessarily support learning indicating that active learning must involve well designed activities that promote thoughtful engagement around learning outcomes in order to be effective. For example, some purely active techniques like discovery learning (where students engage with materials without any instructor support) have been shown to be inferior to guided learning with regards to gaining knowledge (Kirschner et al., 2006; Mayer, 2004). Also, as highlighted by Drake (2012), in many cases where active learning shows improved student retention of class materials, instructors still provided a lecture and guided (to some extent) the activities. The take-home message here is that an active learning environment needs to be thought out and planned for to be valuable. This is echoed in the following sections where student and teacher reflections on the course are presented.

4.3. Student reflections

Students clearly appreciate the feeling of being involved and engaged with their education, which was fostered in the active learning environment across this course. According to one student, it was “great to be involved from the start and get acquainted to a ‘scientific approach’ of experimentation”. Such engagement tends to promote deeper learning approaches (Biggs and Tang, 2007). The students were aware of and confirmed that deeper learning was taking place in this ecohydrology course. One student explicitly commented on TLA #2 and TLA #3 saying that together these TLAs helped put things in a practical context and “that made it much easier to understand”. This contextual understanding is precisely the focal point called for by McClain et al. (2012) and can be seen as necessary for generating the next generation of functioning ecohydrologists.

Of course, as expected, there were criticisms with regard to the level of active learning involved in the course since this deviates from the tradition-styles normally encountered by students. According to one student, “The structure felt somewhat unclear [during TLA #1] and there was a bit too much confusion.” This comment is likely motivated by the exploratory nature of the literature review used in TLA #1. Another student agreed and felt that more lecture-based teaching would be useful in the early stages (during TLA #1 and TLA #2). This highlights the potential influence of poor TLA design on the results of this study with regards to assessing the impact of an increased active learning gradient across the three TLAs. These comments, further, touch on what can be a major roadblock for adopting more active learning approaches in our classrooms. Namely, this is the perceived difficulty by many teachers associated with incorporating active learning into courses. Such approaches can be perceived by students as, for example, unstructured relative to their lecture-based counterparts and may lead to low scores on course evaluations. This makes many teachers question if including active learning approaches are really worth the effort. Pathirana et al. (2012) note that “Innovative [active] teaching is not synonymous with providing the students a comfort-zone in education. Indeed, students may feel somewhat uncomfortable, at least in the beginning, of the novel and unfamiliar approaches to education.”

In our case study course, a student summed up this unstructured perception quite nicely by stating that in “[TLA #1] we need more planned working [since] I prefer more planned working to know what I should do next”. It is likely that the student identified the safety associated with planned lectures and uncertainty associated with open-ended questions (Lyon and Teutschbein, 2011) and experimentation. Still, it can be argued that it is exactly the creative thinking needed to solve such problems that we would like our students to obtain in an ecolohydrology course (McClain et al., 2012) or in a science-based Master’s program in general. This seems to justify the potential added effort associated with developing and incorporating active learning methods in our teaching.

Although these student reflections are good indications that active teaching styles like those developed for this course are effective, we recognize that student feedback is not always the best indicator of this. Pathirana et al. (2012) caution that although “student evaluations provide useful signals about such situations and can be invaluable mechanisms of feedback on how students feel […] they do not necessarily provide good indications on how effective the education is.” Recognizing this potential shortcoming, we would recommend utilizing additional techniques to gather and assess student feedback. This could involve, for example, inviting a neutral party (such as an educational researcher) to conduct more detailed student interviews. Without this level of detail, we concede that it is difficult to isolate the active learning impact on student experiences as there are many potential confounding aspects (e.g., improved TLA design across the three activities). Still, we feel there is value in this exercise to the hydrology community at large such that we conclude here with teacher reflections on the inclusion of active learning and the overall course itself.

4.4. Teacher reflections

4.4.1. On the active learning environment

The size of the course (6 students) was intentionally kept low to help with logistical planning during this initial offering of the course *Ecohydrology: A Mediterranean perspective*. As such, managing the high-level of active learning (particularity in TLA #3) was rather efficient and effective. We do feel that this course structure, however, can be easily scaled up to the about 20 or so students one would expect in a second-year Master's level course dealing with ecohydrology. For example, considering ILO #3, students could easily be divided into several small groups to design and conduct different and/or complimentary experiments. The results of these different experiments could then be synthesized (either by the teachers or the students as an additional exercise) to build a broader sense of ecohydrology. To scale the course beyond about 20 students will most likely lead to logistic problems that can be common with any larger course. Such a large course size would also start to push the upper limit of what we would expect to see with regards to a cohort of students in a second-year Master's level course. Of course, this confidence in scaling up the course is only valid for a summer course or a course where students are dedicated full time. Different consideration would be needed with regard to recreating this course, for example, within the context of a standard schedule of courses like those on offer at many universities around the world.

The number of students considered here may also make the student feedback less reliable due to a small population size. While this is a potential shortcoming to this current study, the small course size, in our opinion, helped create a fair amount of candor between students and teachers. As such, we tend to lend credibility to the students' reflections while being aware of the potential for bias (e.g., Pathirana et al. (2012)) with regards to evaluating education. Still, this would be improved with a more structured interview methodology to assess student opinions. Further, we have not assessed student learning in the course using any examination-based assessment (see supplemental information) due to the problems associate with such traditional assessment methods in problem-based learning environments (Lyon and Teutschbein, 2011). As such, we present our own self-reflection here with regards to student performance in this course relative to our collective experiences in other courses offering more traditional forms of learning.

With regards to student involvement in the course, the level of active learning used in the course considered in this case study created more enthusiasm in the classroom than we typically associate with traditional learning environments. This potentially reflects the feeling of ownership of the education expressed by the students and, in our opinion, likely facilitates self-regulation of learning. From the teacher perspective, this generally higher level of enthusiasm also makes teaching more enjoyable in a general sense creating a feedback effect whereby the teachers can become more involved in the learning process. Further, by having students develop and design experiments it allowed the level of teacher-student discourse in the classroom to be elevated over more traditional learning environments thus placing teachers and students on a consistent level (i.e., everyone was a researcher in the class). This consistent level aided communication which we feel helped facilitate knowledge transfer since it fostered an environment where students were not afraid to ask questions and/or offer opinions. This self-reflection is consistent with the results from the study by Lyon and Teutschbein (2011) on the utility of problem-based learning in the classroom.

Counter to potential benefits, such an open environment might be scary or uncomfortable for some students. Still, such an atmosphere from the teachers' perspective is rather stimulating and appropriate in a second-year Master's level course. To help alleviate some student apprehension, one could consider more hybrid approaches that couple both active learning and lecture-based approaches. As such, teachers could start with more traditional forms of teaching and slowly transfer and incorporate an active learning environment across the span of a course. With respect to this current case study course, we fully anticipate such hybridization will occur in future offerings. This should help lessen students' reflections regarding a 'lack of structure' over time as we further develop and improve upon this course.

4.4.2 On getting more 'ecohydrological'

Clearly, this course is in its infancy and will need further development to achieve the status of a fully-vetted ecohydrology course. Being aware of this, we reflect here on some of the potential limitations of the current course with regards to ecohydrology education and identify possible pathways forward to achieve a more ecohydrological-centric course. In the first offering of this course, it tended to focus on the more physical aspects of ecohydrology both by design due to the backgrounds of the students and by being coupled with a hydrology Master's program. There was a limited amount of consideration given to other aspects (i.e., unique plant adaptations to limited water availability or differences in water use between native plants and irrigated crops) across the field, in part due to student direction, i.e., the students may have tended to choose activities with which they were somewhat familiar. Thus, the instructors need to consistently assess student progress to ensure that the intended material is covered in the course. In future offerings of the course, the instructors plan to include activities that intentionally incorporate more physiological ecohydrology aspects into the course such as consideration of rooting depth into model development or exploring stomata response controls on transpiration. It is envisioned that this will allow us to better leverage the uniqueness of the Navarino Environmental Observatory (NEO) by having students make detailed measurements on, for example, old-growth olive orchards in proximity to actively-managed and landscaped coverages.

We highlight this realized shift of focus away from the “eco” in ecohydrology as a potential limitation of a pure active learning environment where instructor control may be sacrificed. As such, there might not be the opportunity to explore all the aspects of a given subject (particularly one as broad as ecohydrology) in detail. During the course, we became aware of this focus on the more physical aspects of ecohydrology. So, to help distinguish from the standard teaching of evapotranspiration offered in any general hydrology course, we broke script during TLA #3 to put together a demonstration aimed at drawing students' attention to the impact of biological adaptation to evaporation at the Navarino Environmental Observatory. This (admittedly *ad hoc*) activity consisted of a small experiment to demonstrate the impact of plant type (broad leaf vs. needle leaf) on evaporation. The Mediterranean setting and focus of the course aided in demonstrating plant adaptations to limited water availability as there are clear differences in water use across plant type and water management. As such, by improvising on the course script, we were able to bring in more physiological aspects of ecohydrology. This eye to flexibility and adaptation is an important aspect to be aware of when designing trying to bring together active learning and ecohydrology education.

Another clear step forward to raise the level of ecohydrology considered in this type of course would be the involvement of local experts from the region. This would offer up more familiarity with local vegetation and ecology, thereby making it possible to address, for example, potential regional changes seen to date in the landscape and their connection with hydrology. For this specific course, we are planning to involve instructors and students from the nearby University of Peloponnese and the Messenia region in the next offering. Further, there are additional plans to cross-list the course in the Landscape Ecology Master's program at Stockholm University. This will likely accomplish two goals. First, it will allow us to involve instructors with specific knowledge in landscape ecology, which opens up new areas of expertise to this course. Second, it will create a more mixed class setting such that exchange and paired learning can take place between students from hydrology and ecology perspectives.

5. Concluding Remarks

We have intended this case study to help serve as a potential road map for designing and implementing ecohydrology courses with respect to existing hydrology programs. In our case study example, we target plant-water interactions within the realm of ecohydrology from a Mediterranean perspective. While this suited our needs, such focus is clearly not necessary as the general structure presented here could be adopted to any of the 'spheres' within ecohydrology (McClain et al., 2012) or be developed to leverage off of any established or startup field sites. Independent of the details, any ecohydrology course will by nature likely tend towards cross-disciplinary and inter-disciplinary work that warrants the consideration of active learning approaches. From our case study, students identified the utility of such approaches over their more traditional, lecture-based counterparts for achieving course goals. With respect to ‘how active is active enough’ we saw that there is potential for added value associated with additional ‘activeness’ in our teaching. This is a positive take home message for those of us faced with developing attractive and successful ecohydrology courses on potentially limited budgets and time.

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References

Allen, R. G., Pereira, L. S., Raes, D., and Smith, M.: Crop evapotranspiration: Guidelines for computing crop requirements.” Irrigation and Drainage Paper No. 56, FAO, Rome, Italy, 1998.

Arthington, A. H., Naiman, R. J., McClain, M. E., and Nilsson, C.: Preserving the biodiversity and ecological services of rivers: new challenges and research opportunities, Freshwater Biol., 55, 1-16, doi:10.1111/j.1365-2427.2009.02340.x, 2010.

Berry, L.: Collaborative Learning: A Program for Improving the Retention of Minority Students, U.S.: Virginia, 1991-00-00, ED384323, 1991.

Biggs J. and Tang C.: Teaching for quality learning at university. Open University Press/Mc Graw-Hill Education, pp. 335, 2007.

Bonwell, C. and Eison, J.: Active Learning: Creating Excitement in the Classroom, AEHE-ERIC Higher Education Report No. 1, Washington, D.C., Jossey-Bass, 1991.

d’Odorico, P., Laio, F., Porporato, A., Ridolfi, L., Rinaldo, A., and Rodriguez-Iturbe, I.,: Ecohydrology of terrestrial ecosystems, BioScience, 60, 898-907, doi:10.1525/bio.2010.60.11.6, 2010.

Drake, J. R.: A critical analysis of active learning and an alternative pedagogical framework for introductory information systems courses, Journal of Information Technology Education: Innovations in Practice, 11, 2012.

Eagleson, P. S.: Climate, soil and vegetation. 1. Introduction to water balance dynamics, Water Resources Research, 14, 705-712, 1978.

Hack J. T. and Goodlett J. C.: Geomorphology and forest ecology of a mountain region in the central Appalachians. United States Geological Survey, Professional Papers, 347, 1960.

Hake, R.: Interactive-engagement vs. traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. American Journal of Physics, 66(1), 64, 1998.

Hannah, D. M., Wood, P. J., and Sadler, J. P.: Ecohydrology and hydroecology: A ‘new paradigm’?, Hydrological Processes 18, 3439-3445, 2004.

Hargreaves, G. H. and Samani, Z. A.: Estimating potential evapotranspiration, Technical Note, Transactions of the American Society of Agricultural Engineering, 108, 3, 225-230, 1982.

Huba, M. E. and Freed, J. E.: Learner-centered Assessment on College Campuses: Shifting the Focus from Teaching to Learning, Allyn & Bacon, Boston, MA, 2000.

King, E. G. and Caylor, K.K.: Ecohydrology in practice: strengths, conveniences, and opportunities, Ecohydrology, 4(4), 608-612, doi 10.1002/eco.248, 2011.

Kirschner, P. A., Sweller, J., and Clark, R. E.: Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. Educational Psychologist, 41(2), 75-86, 2006.

Knight, R. D.: Five Easy Lessons: Strategies for Successful Physics Teaching, (Addison Wesley, San Francisco, CA, pp. 61, 2004.

Langbein,W. B.: Annual Runoff in the United States, US Geological Survey Circular, p. 52, 14, 1949.

Levia, D. F. and Quiring, S. M.: Assessment of Student Learning in a Hybrid PBL Capstone Seminar, Journal of Geography in Higher Education, 32, 2, 217-231, 2008.

Lyon, S. W. and Teutschbein, C.: Problem-based learning and assessment in hydrology courses: Can non-traditional assessment better reflect intended learning outcomes?, Journal of Natural Resources and Life Sciences Education, 40, 199-205, doi:10.4195/jnrlse.2011.0016g, 2011.

McClain, M. E., Chicharo, L., Fohrer, N., Gavino Novillo, M., Windhorst, W., and Zalewski, M.: Training hydrologists to be ecohydrologists and play a leading role in environmental problem solving, Hydrology and Earth Systems Sciences, 16, 1685-1696, doi:10.5194/hess-16-1685-2012, 2012.

Mayer, R. E.: Should there be a three-strikes rule against pure discovery learning? American Psychologist, 59(1), 14-19, 2004

Monteith, J. L.: Evaporation and surface temperature, Q. J. R. Meteorol. Soc., 107, 1-27, 1981.

Neilsen, T. B. Strong, W. J., Anderson, B. E., Gee, K. L., Sommerfeldt, S. D. and Leishman, T. W.: Creating an active-learning environment in an introductory acoustics course, J. Acoust. Soc. Am., 131, 3, 2500-2509, 2012

Pathirana, A., Koster, J. H., de Jong, E. and Uhlenbrook, S.: Interactive comment on “On teaching styles of water educators and the impact of didactic training”, Hydrol. Earth Syst. Sci. Discuss., 9, C2498-C2501. 2012.

Penman, H. L.: Natural evaporation from open water, bare soil and grass, Proc. R. Soc. London, A193,120-145, 1948.

Penman, H. L.: Vegetation and Hydrology, Commonwealth, Agricultural Bureaux: Farnham Royal, 1963.

Prince, M.: Does Active Learning Work? A Review of the Research, Journal of Engineering Education, 9, 3, 223-231, 2004.

Shaw, S. B. and Walter, M. T.: Using comparative analysis to teach about the nature of nonstationarity in future flood predictions, Hydrol. Earth Syst. Sci., 16, 1269-1279, doi:10.5194/hess-16-1269-2012, 2012.

Spronken-Smith, R.: Implementing a problem-based learning approach to teaching research methods in geography, Journal of Geography in Higher Education, 29, 2, 203-221, 2005.

Thornthwaite, C. W. and Holzman, B.: The determination of evaporation from land and water surfaces, Mon. Weath. Rev., 67, 1, 4-11, 1939.

Turc, L.: The water balance of soils', relation between precipitation evaporation and flow, Ann. Agronomiques, 5, 491-569, 1954.

van Griensven, A., Meixner, T., Grunwald, S., Bishop, T., Diluzio, A., and Srinivasan, R.: A global sensitivity analysis tool for the parameters of multi-variable catchment models, J. Hydrol., 324, 10-23, doi:10.1016/j.jhydrol.2005.09.008, 2006.

Wagener, T., Weiler, M., McGlynn, B., Gooseff, M., Meixner, T., Marshall, L., McGuire, K., and McHale, M.: Taking the pulse of hydrology education, Hydrological Processes, 21, 1789-1792, 2007.

Wilcox, B.P.: Transformative ecosystem change and ecohydrology: ushering in a new era for watershed management, Ecohydrology, 3(1), 126-130, doi:10.1002/eco.104, 2010.

Table 1: The main goal and intended learning outcomes (ILOs) for the recently taught course *Ecohydrology: A Mediterranean perspective*.

Main Goal	The main goal of the course was to explore central theories in ecohydrology and their connection to plant-water interactions and the water cycle in a semiarid environment.
ILO #1	Explain and differentiate the basic theories and current literature that forms the core of ecohydrology.
ILO #2	Synthesize relevant data and observations to provide an ecohydrological framework to characterize a region and set up a hydrologic model.
ILO #3	Define, develop, and conduct field-based research experiments to test fundamental assumptions behind our state-of-the-science understanding of the interactions between the water cycle and vegetation.
ILO #4	Communicate via a written scientific reports and presentations how the previous three outcomes intersect for Mediterranean perspective using the Navarino Environmental Observatory (NEO) as an example.

Table 2: Selected central concepts of ecohydrology identified by students with regards to ILO #1 in the course *Ecohydrology: A Mediterranean perspective*.

ILO #1: What is ecohydrology?
Ecohydrology studies how ecosystems and hydrology mutually affect and feedback on each other.
Ecohydrology investigates interrelationships between biota and water raising questions about potential human impacts on water resources.
Spatiotemporal climate-soil-vegetation dynamics appear central to much ecohydrology research and many key concepts.
In the field of ecohydrology, different approaches (i.e., from the viewpoint of an ecologist or a hydrologist) can lead to different end results and interpretations.
Ecohydrology can be considered as a way to look deeper into the importance of the boundaries and integration between hydrology and landscape perspectives.
Ecohydrology is a field that should operate in a cross-disciplinary mode in order to transcend both ecology and hydrology.

Table 3: The overarching hypothesis and several supporting questions developed and answered by students in the course *Ecohydrology: A Mediterranean perspective*.

Overarching Hypothesis
Evapotranspiration from the more-managed sites (and open water site) are higher than the evapotranspiration from the less-managed sites.
Supporting Questions
Is the surface/air temperature of the managed (irrigated) areas lower than the unmanaged areas?
Is the relative humidity over the managed areas higher than over the unmanaged areas?
Is the vapor pressure over the managed areas higher than over the unmanaged areas?
What varies more over the course of the day: relative humidity or vapor pressure?
Is the soil moisture higher in the managed areas than in the unmanaged areas?
Is out-going radiation (or albedo) higher from managed or unmanaged areas?
How are the characteristics of the drip-irrigated (intermediately managed) areas different from the sprinkler (highly managed) and non-irrigated (unmanaged) areas?
How will pan evaporation differ between the open water site (located in a fountain) and dry site (located in a parking lot)?

Figure 1: Students in the field conducting measurements as part of their self-designed experiment in the course *Ecohydrology: A Mediterranean perspective*. Dr. M. Todd Walter (center with hat) supervises.

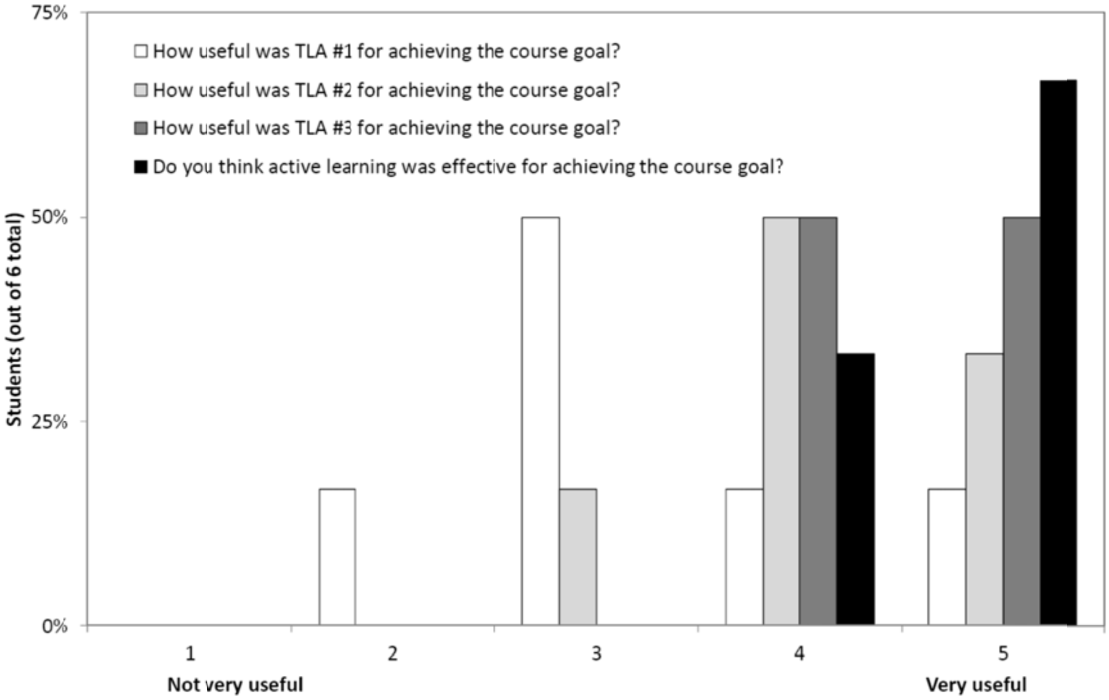

Figure 2: Students' views regarding the utility of the active learning and various teaching and learning activities (TLAs) included in the course *Ecohydrology: A Mediterranean perspective*.