Response to comments from the Open Discussion Period

The authors wish to thank Drs Bardsley, Bucat, Pathirana, and Treagust for their positive feedback and constructive suggestions regarding this manuscript. Our overall impression of the review comments is that the majority addressed points requiring only minor revisions to the text. The nature of these minor revisions and the manner in which we propose to respond to them are outlined below.

Item 1: *Dr. Bardsley raised concerns about the fit between the paper contents and its title, and recommended that an alternative title be adopted, such as: "Student centered approaches in hydrology education."*

Response: The comments raised by Dr. Bardsley regarding the title were a little unclear to us. On the one hand, it was suggested that in addressing the title towards hydrologists, but orienting the paper towards engineering hydrologists, the title was too broad. On the other hand, it was also suggested that in addressing the title towards catchment hydrologists, the title was too specific given that educational issues raised in the paper have applicability beyond catchment hydrology specifically. We note also that Dr. Pathirana suggested that we explicitly acknowledge that the paper is largely a review and synthesis of existing knowledge, recontextualized for hydrologists to apply.

In an attempt to address both perspectives, we have retitled the paper as follows: "Incorporating student centered approaches into catchment hydrology teaching: a review and synthesis."

Item 2: *Dr. Bucat pointed out that there is some confusion in the text between two different educational concepts: the "Information Processing" theory of learning, and the "Information Transmission" model of teaching. The former relates primarily to theory that states that learners obtain information through their senses, and must then do mental work to make sense of it. The latter relates to a didactic model of teaching that is predicated on an expert instructor transmitting information to essentially passive learners. As a part of this confusion, Dr. Bucat also suggested amending Figure 2.*

Response: We are grateful to Dr. Bucat for pointing out this confusion. Both information processing models of learning and information transmission models of teaching merit discussion in the text, and some aspects of the text require alteration. For instance, we incorrectly criticized information processing models of learning in Section 3.3 – this criticism would more appropriately have been levied at information transmission models of teaching.

To address this issue we have revised Section 3.3 and Section 3.4, ensuring that information processing is described appropriately. We have not specifically used the term "information transmission," but refer to didactic and "chalk-and-talk"

models, since we do not want to contribute to any further confusion about terminology.

We have revised the description of information processing as follows:

Information processing theories focus upon how information is communicated to learners and is transformed into knowledge (Shuell, 1986; Svinicki, 2004). 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. These theories are helpful in explaining common observations of students, for instance "information overload", unconscious selection of input stimuli, and reduction of knowledge to rote memory (Johnstone, 1997). While information-processing theories explain how learners deal with sensory stimuli in the classroom, the dominant theory regarding the transformation of these stimuli into knowledge is now constructivism.

In response to Dr. Bucat's detailed comments, we also substantially revised Figure 2. The new figure is reproduced here, with its caption:

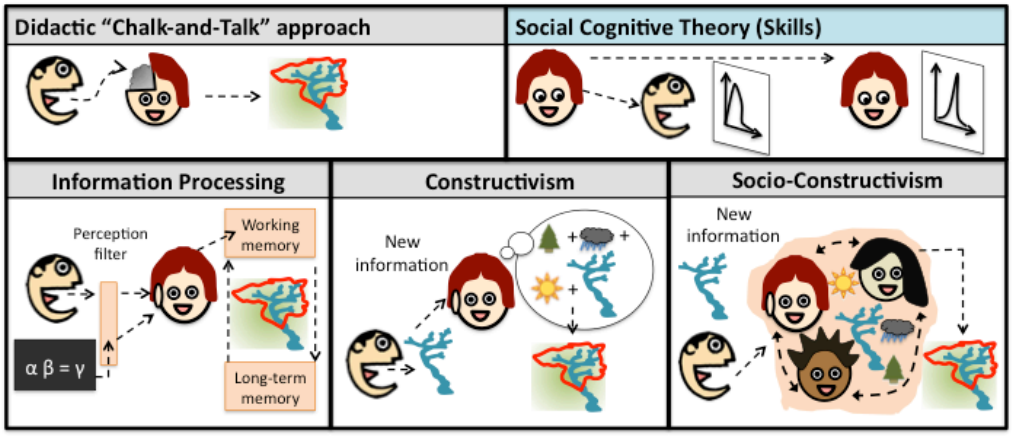

Figure 2: Cartoon illustration of the major categories of learning theory in contrast with the assumptions implicit in a didactic or "chalk-and-talk" approach to teaching. Information processing accounts for the challenges associated with communication in a learning context. Students unconsciously filter the sensory inputs from ears and eyes, so that what the students "hear" is not necessarily what the instructor said. Once received, students must do mental work on information held in their short-term, working memory, in order to generate long-term knowledge. There are physiological and mental limits to memory capacity and to the rate of mental work. Information overload, selective retention and a resorting to rote memorization can be understood in terms of the cost of this mental effort. Constructivism posits that learners integrate new 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. as they refined their 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. In contrast to the implicit assumption that students will learn the information transmitted by the instructor, these learning theories highlight the active role that students must play as learners.

This figure is now more explicit in its representation of information processing. Several of Dr. Bucat's major concerns are addressed: the "open brain" is retained only in respect to the didactic mode of instruction; the role of filtering and working/long term memory are schematized with respect to the information processing model; the "new" information (about the nature of a river network) is shown as the object of the instructor's discussion and as an item to be integrated with existing knowledge in both individual and social settings. The contrast between the simplistic assumptions "if you teach it they will learn" behind a didactic approach and the complex ways that students process information and learn from it is outlined explicitly.

Item 3: *Dr. Bucat suggested that a description of Process Oriented Guided Inquiry Learning (POGIL) was merited in the text, particularly in regard to the significance of education as a process of 2-way communication between learners and teachers.*

Response: We agree that this is an appropriate addition to the paper and have included it in Section 3.3 in the discussion of developing PCK that is relevant to the issue of 2- way communication, as follows:

> *New educational technologies are now available to assist instructors with obtaining rapid feedback from students in large classes, including electronic "clickers" and web or mobile-phone based polling tools. Increased use of these technologies to facilitate constructivist teaching and learning has been championed in other disciplines, for instance via the Process-Oriented Guided Inquiry Learning (POGIL) movement in Chemistry (Moog & Spencer, 2008).*
>
> *For instance, student groups could be given an in-class task to predict the behavior of a leaky-bucket model. A web-based poll could be used to give immediate feedback to the instructor in terms of the response the students expect to see. Small group discussions can then be used to allow students to explain their thinking to each other. The students could then be polled again, in order to evaluate the outcome of this group activity. Thus, small group settings can be used to reinforce teaching, to develop a collaborative approach to inquiry, and to advance conceptual and theoretical understanding. Collaborative learning does raise obvious challenges in terms of assessment, but several models, including group homework assignments complemented by individual tests (Felder, 1995), self-assessment, assigned team roles, and even collaborative components on tests or examinations have also been suggested (Yezierski, et al., 2008).*

Item 4: *Dr. Bucat also suggested that the paper mention the need to change student attitudes in order to successfully implement learner-centered educational strategies.*

Response: We agree that this is a relevant point and have included it in a revised Section 3.4, as follows:

Student-centered approaches place a large onus of responsibility for learning on students, and thus often require a change in student attitude, and may meet strong resistance from students (Felder, 1995).

Item 5: *Dr. Bucat was supportive of the need to undertake further research in hydrology education.*

Response: We greatly valued the points raised by Dr. Bucat re. the importance of valuing the teaching of the hydrology as much as the study of the hydrology itself and of the importance of documenting PCK to avoid "professional amnesia". We have reflected these points in a revised conclusion:

… can we find ways to document the outcomes of this research and use it to educate the next generation of hydrology teachers, avoiding the problem of recurrent professional amnesia that otherwise assails engineering educators at the college level, who are rarely taught how to teach (Stice, Felder, Woods, & Rugarcia, 2000)?

Item 6: *Dr. Pathirana mentioned the desirability of collecting data on the outcomes of the educational approaches discussed in the case studies, and reflected that the paper is much like a review paper in nature.*

Response: We acknowledge both of these points. Unfortunately there has been so limited a culture of undertaking educational research in hydrology that even when implementing the rather novel curricula or educational initiatives we describe, efforts were not made to formally document the outcomes. Consequently, although student evaluations were collected and student responses solicited in all cases, we are not ethically able to utilize this data. Consequently we are limited to anecdotal studies at present.
We agree that the paper has strong elements of review and synthesis. The aim of the paper has largely been to bring educational theory and developments from other aspects of the sciences and technical professions to bear on hydrology. These are reflected in the revised title:

Incorporating student centered approaches into catchment hydrology teaching: review and synthesis

Item 7: *Dr. Pathirana questioned the completeness of our flowerpot analogy as an example of PCK.*

The reviewer's point is well taken: namely that the utilization of the flowerpot analogy as a component of PCK is "good PCK" only if care is taken during instruction to avoid the generation of misconceptions. We picked up on this point in Section 3.3, dot point (1), where we note the limitations of the analogy. To avoid making overly strong statements about the value of the flowerpot analogy, we have altered the wording in the paragraph in Section 2.2 as follows:

Why is the flowerpot or leaky bucket an effective element of 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 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. As with all conceptual models of real world processes, it may result in the generation of misconceptions (for instance it is a poor representation of heterogeneity and of the relative scale of vegetation to catchment size). Effective PCK in this case would also involve highlighting the ways in which a flowerpot's water balance behavior differs from reality, and the limitations of the usefulness of thinking about catchments in this way.

Item 8: *Dr. Pathirana also raised a concern related to our observation that teaching assistants played a critical role in successfully implementing a student-centered learning approach. The concern raised related to general misgivings about the pedagogical value of teaching assistants, given the potential for such a system to limit student engagement with their main instructors.*

Response: The statements related to teaching assistants are motivated by the demands of working with large hydrological datasets. These datasets pose challenges for students which are not hydrological in nature, but which are largely associated with the use of software for data manipulation. Technical support, provided by teaching assistants, is therefore a necessary catalyst for the success of data-driven learning, by giving students access to assistance that helps them overcome technical roadblocks; while leaving the main instructor free to discuss the substantive hydrological content of analyses with students. Ultimately this is one reflection on the importance of instructors as resources for students in a student-centered learning situation, and the potential value of technical support to help students overcome issues associated with the use of a tool and allow them to have more time and ability to focus on the processes revealed when the tool is used correctly.

While this paper is not the appropriate venue to debate the general value or otherwise of teaching assistants, we stand by the point that this model of student-centered learning is greatly facilitated if there is a resource students can turn to for technical assistance. We would also dispute that there is a net loss of pedagogical quality associated with a student assisting with the implementation of a software tool than if the professor were to offer the same assistance. We agree, of course that

the presence of a TA is not a substitute for face-time between students and their main instructors. To clarify these points and to emphasize the importance of maintaining engagement between professor and students, we have rephrased the sentence in the paper as follows:

The support of the teaching assistant was critical to the success of the term project: the teaching assistant provided technical support (in terms of making available the needed data and the data analysis tools) to students that helped the students complete their analyses efficiently, and allowed the professor to focus their interactions with students on the hydrological questions that emerged as they engaged with their data.

***Item 9**: Following the publication of some of the papers from the HESS Special Issue on Hydrology Education is is obvious that there is a need to cross reference this study with these publications. Accordingly we have now made reference to Shaw and Walter, whose paper on comparative approaches in hydrology is utterly complementary to the approaches described in our paper.*