

09/11/2015

Dear Dr. Uhlenbrook,

Thank you for the opportunity to revise our manuscript entitled: 'Enhancing the T-Shaped Learning Profile when Teaching Hydrology using Data, Modeling, and Visualization Activities.' to be further considered for publication in *HESS*. We have considered and responded to all reviewer concerns (please see our attached responses below), and have likewise made changes to the manuscript to address reviewer concerns (please see marked up manuscript below).

In sum, our changes were as follows:

1. Add a reference to Levene's test results to assuage concerns regarding different sample sizes (Reviewer 1)
2. Clarify how pretest results were used in the current analyses and control for levels of prior knowledge (Reviewers 1 and 2)
3. Add raw pretest scores to Table 3 (Reviewers 1 and 2)
4. Re-articulate the learning outcomes to make them more concrete and accessible, including revisions to all Figures/Tables (Reviewer 2)
5. Provide a visualization of the current pattern of results, now Figure 3 (Reviewer 2)
6. Add some discussion acknowledging the speculative nature of the explanation for an increase in learning outcomes relative to professional roles (Reviewer 2).

We thank you and the reviewers for the insightful comments on the manuscript, and we feel that the above changes have made the manuscript that much stronger. We hope that the manuscript is now acceptable for publication in *HESS*. If there are any further concerns or issues, please let us know immediately.

Sincerely,

Christopher Sanchez

(also on behalf of)

Benjamin Ruddell

Roy Schiesser

Venkatesh Merwade

**Please see our responses to each reviewer comment below in BOLD, below the corresponding comment from the reviewer.**

General comments:

Interesting article about enhancing the T-shaped learning profile of hydrology students. In the article a comparison of a DMDGC simulation module with a paper laboratory module. It is hypothesized that students who followed the DMDGC module would demonstrate a better understanding of theoretical and applied hydrology concepts related to flooding in a contextualized and realistic scenario and that the simulation condition would lead to a better understanding of the professional role of hydrologists. The DMDGC model produces a visualization of modeled and observed hydrograph results. In the paper module students had to perform hand calculations. In fact it is a comparison between a traditional paper pencil method with a computer simulation method, asking whether the latter method is more effective than the first one. It is good to read that the use of a simulation model can enhance student's knowledge and understanding of the hydrology field.

**We thank the reviewer for their positive comments regarding the manuscript.**

Specific comments:

About the methodology, it is not clear why the group sizes of the two groups differ. Why does the DMDGC group consist of 52 students and the control group of 36? What criteria have been used to create this difference? As far as I can read also no further analysis took place on students' backgrounds and preferred learning styles which might have influenced the outcomes of this study. Also no information is given on the results of the pretest. Were the 52 DMDGC students better than 36 control students. How did the allocation of students to each of the two methods take place? Has this allocation influenced the result of the investigation?

**As this investigation represented an implementation in an actual classroom section at a local community college, the difference in the number of participants across the groups was a natural reflection of course enrollment, by lab section. This factor was outside our control, however we would caution the interpretation that either condition contains, in any way, a small or inadequate sample size. Further, issues of unequal sample size are often founded on the concern that such small samples would in fact bias the sampling of critical variables by creating unequal variances between groups, and thus undermining the estimation of the experimental effect. However, statistically speaking, this was not the case in the current experiment, as Levene's tests for all included comparisons produced a non-significant result ( $p>.05$ ) across the group variable, confirming that the variance across groups was equivalent despite the difference in sample size. In other words, variances across the groups, and for all measures, were statistically equivalent as measured here. Coupled with the robustness of the ANOVA/ANCOVA procedure relative to violations of the assumption of equal variances, we are confident that this small disparity in group sizes did not affect the evaluation of the**

current manipulation. We do appreciate the concern however, and will add a reference to this fact in the revised manuscript.

Related to this issue, all students in the current study were also drawn from the same population of students (e.g., community college) that self-selected to enroll in this course (without the knowledge that this experiment would be part of the curriculum). As such, while numerous demographic differences were not explicitly evaluated, it is reasonable to expect that these students are more or less equivalent on educational background, SES, etc. We would also caution any consideration of learning styles as a relevant variable, as there has been much research in the field dismissing such assertions as incorrect (Pashler et al., 2008).

Finally, related to the above points, we would also like to emphasize that we are comparing differences in learning within participants, albeit across groups. If one were to concede that the participants were in fact different in each group (which again we would not), these differences are in fact controlled for in a gross sense as we are evaluating the participants progress against themselves. Perhaps the most critical variable that might affect the accurate assessment of these knowledge gains (e.g., prior knowledge assessed via the Pretest), was also in fact explicitly controlled for by the ANCOVA procedure, by utilizing Pretest performance as a covariate. Group means as presented in Table 3 represent adjusted means relative to this covariate, thus again controlling for any differences on the pretest. The reviewer is correct, in one sense, that it is always possible that other demographic variables might interact with this change, however we would suggest that this should be a topic for future research. We would also caution that the explicit control of such other variables (the reviewer does not explicitly identify specific characteristics) would also reduce the ecological validity of such investigations, which we see as a critical contribution of the current work.

T-shaped learning profile. Perhaps it is my lack of knowledge and understanding about the DMDGC module, but it is unclear to me how this module, has enhanced with the students the understanding of the role of hydrologists. It is said that the lectures, which were content wise the same for both groups, focused a.o. on the roles and responsibilities of agencies that provide flood prediction and management services in the USA. How has the simulation model helped to improve student's understanding the professional role of hydrologists?

The reviewer is correct that all participants received some consideration of the role of hydrologists in the lecture component of the course, however, it is our contention that the students in the DMDGC condition gained a better sense of this professional role by actively engaging in the DMDGC exercise. So in other words, rather than understanding the role of hydrologists in an abstract sense (likely conveyed via lecture), students who interacted with the DMDGC received a better sense of the day-to-day duties (meaning job skills) that hydrologists practice. Thus, it is our contention that the DMDGC exercise represents a realistic approximation of job duties of a hydrologist, whereas the paper and pencil lab sections still convey this understanding in a less explicit and more abstract way, as evidenced by the increase in appreciation of these duties by the DMDGC group.

Secondly, T-shape learning should not only focus only on widening one's own field of expertise; i.e. focusing on the professional role of hydrologists. In daily practice professionals should also be able to speak to people from other domains. Students should also be trained in this respect. So, this study is limited in its scope. About the learning outcomes. These are very poorly formulated as they do not say anything about the level of knowledge and skills students . Blooms taxonomy is fully lacking in this respect. The outcomes as they are described as such do not say anything about how well and at what level students have mastered these. Have the students been informed about these outcomes before the start of the course?

**We agree wholeheartedly that part of the job duties of any hydrologist (or even more broadly, scientist) is to interface with other individuals, both across fields and outside of the field (e.g., the public) effectively. However, such training is outside of the current scope of this experiment, as (to use the reviewer's own suggestion), the manipulation utilized here is designed primarily to address the cognitive aspects of Bloom's taxonomy. Not only are we evaluating the gain of knowledge in current areas (e.g., identified by learning outcomes), but we are also evaluating the application of these knowledge states (i.e., expert ratings of effectiveness). As such, we would argue that Bloom's taxonomy is alive and well within the current experiment, although we would simultaneously add that Blooms's taxonomy is only 1 of many potential means to defining learning outcomes. We would also finally add that the learning outcomes identified here are consistent with major learning outcomes across the field of hydrology, and thus it is important to evaluate learning interventions within the context of said outcomes, again to promote external validity.**

To the reviewer's final point, students were not made explicitly aware of the learning outcomes in their final form, as this could potentially bias student performance while learning. We wished to minimize such influence in an effort to provide a better estimation of the experimental effect. It would be of interest, however, to evaluate whether the presentation of such learning outcomes might magnify the current effect, as there is much classic research in the fields of cognition and education that suggests that presented organization affects how individuals encode information. However, we again stress that this might be a fruitful area for future research, extending the current findings presented here.

Technical comments The reading of the text could be improved to include table 3 and figure 2 in the text.

**We see the reviewers point, and would be happy to move these tables/figures should the editor deem it necessary. These materials currently appear at the end of the manuscript in an effort to remain consistent with APA style.**

Please see our response to each reviewer comment below in **BOLD**, below each reviewer comment.

I read this article with interest. The authors should be appreciated for attempting to shed light into an area that we academics often consider a secondary responsibility, namely creating an effective classroom learning experience.

The article is written in clear language that makes it easy to read and understandable by an international user of English language.

**We thank the reviewer for their kind words regarding the manuscript.**

I think educators are almost unanimous these days that it is of critical importance that clear definition of Intended Learning Outcomes (ILOs) or Learning Objectives is critical for ensuring good learning outcomes. (Whether we all practice it all the time is another matter!). Another almost common-sense guidelines is that the assessments (and learning activities) should be aligned to those ILOs (as proposed by constructive alignment [1]).

Reading this article, I failed to find a list of well-defined ILOs. Indeed authors list in Fig. 2 (Also in Table 2, which they do not refer to in the text – the ‘table 2 they refer in bottom of page 6337 should be table 3.’) they list what they refer to as ‘nine overall learning outcomes’, but these are not specific enough for me to know what were the specific, testable, verifiable goals behind the section in question.

This article would definitely benefit by stating a well defined set of learning objectives (see TeachOnline site of ASU [2] among many others for good practice).

This will shed light also to the appropriateness of the assessment instrument used. More on that later.

**We agree that more clear learning objectives would potentially aid in the understanding of the manuscript, and give a better sense of the specific content instructed here. We will thus not only adjust the incorrect table numbering and referencing, but will also better articulate the learning outcomes already included in the manuscript. We will also better direct the reader to Table 2 which gives concrete examples of the learning objectives.**

Recent literature has shown a large number of uses of the term ‘T-shape’. While at the conceptual level these uses agree, the precise meaning varies greatly among the different uses (especially on the ‘breadth’ aspect). The definition I found in the article is in the abstract, which requires ‘professional breadth combined with technical depth’. Upon reading the article, I wondered whether the important findings of this article are related to the T-shape idea.

While an interactive tool (DMDGC) will definitely provide a more absorbing learning experience, I fail to find how it provides ‘T-shaped’ learning. Overall it is my view that this article will be more effective if it does not discuss the notion of the ‘T-shape’ but focus on the learning quality differences of the two approaches – a worthwhile objective in itself.

We do agree that the notion of the 'T-shape' is used somewhat inconsistently in different contexts. However, we have tried to be as specific as possible regarding how our mapping of the different 'legs' of the 'T' are implemented here. It is our contention that the professional breadth is really an analogue for the understanding of the roles of a professional hydrologist, whereas the technical depth comes from understanding the concepts themselves. While certainly somewhat abstract, pragmatically speaking these legs seem to clearly represent different types of knowledge. Further, we would resist the urge to further specify the legs of the 'T' much more, as this was an introductory Earth Science course, and not a class specific to hydrology alone, and thus any such specification might be an overreach on our part related to the domain. We again agree that the relations of these legs of the 'T' to the learning outcomes may have not been as clear as possible (related to the Reviewer's earlier point), so we will attempt to make this connection more definite by rearticulating the learning outcomes. We do also agree that the learning quality differences should indeed be the primary focus here and will attempt to constrain our discussion of the results to focus more on the learning itself, as the reviewer suggests.

The authors do not provide the learning material used in the two cases. The article should provide supplements with or links for the learning material in order for the reader to understand the link between the learning experience and the outcomes discussed in the. I was able to find online [3,4] which I suspect are the material used for DMDGC case, but I failed to find the material used for PP case.

**While we would like to provide the PP materials, these materials are copyrighted and published by Kendall-Hunt, and thus we cannot freely release them without violating said copyrights. However, we have already included the correct reference to the materials in the Reference section should a reader seek to purchase the materials themselves. That said, we are attempting to find a way to potentially release these materials in a way that maintains compliance with Kendall-Hunt's copyrights, although we cannot guarantee anything at this point unfortunately.**

I have to admit that I did not read though the material in [3,4], but upon looking at them, I could not see how they will enable the students to better answer questions like Q3 and Q4 (table 1). They authors should attempt to explain what aspects in the interactive material that resulted in students answering such questions better.

The only information regarding PP material is in page 6335 (around line 25). This is a calculation to determine whether a channel will flood before and after urbanization occurs in a watershed. How does completion of such an exercise prepare students to answer questions like Q3 or Q4? If that does not prepare the students in anyway what so ever, then is it logical to test students for that and arrive at the conclusions listed?

The page 6336 (lines 9-10) lists essentially what was different between the two treatments. Then I fail to see how one can explain how that can explain the differences of marks for questions like Q3 and Q4 (or goals 7, 8 and 9).

**The factual material about the role of NOAA, USGS, and other agencies, is contained in the standard lecture material that accompanied the laboratory instruction. As such, it is important to note that this factual content was taught equally to both groups, and was not explicitly instructed in the laboratory exercises themselves. It is our contention, however, that the DMDGC exercise provides these learners a more tacit and explicit**

understanding of these job duties, such that when asked to answer such questions they were more easily able to recall and connect said job duties to specific agencies. In other words, their understanding of what these agencies do became less abstract and indirect, as they themselves became more familiar with the job duties themselves. While certainly speculative, the large group differences (and the fact that both groups were equally exposed to the factual information) seem to support this suggestion. We will make sure to emphasize the speculative nature of this interpretation in a revision, and would certainly be open to other interpretations.

I was a bit intrigued by the way analysis was presented. It would be nice to see the pre and after treatment scores for each question rather than presenting the analysis for each 'learning outcome'. This would provide a more straight forward way for the reader to evaluate the findings. Further the authors do not provide any indication about the pre-treatment results (other than the fact that it was used as covariate in the ANCOVA analysis).

**We would be happy to include the pre-treatment results (by learning outcome), and will do so in the revision. However, we must emphasize that comparisons between groups at the pre-treatment time point are not exactly warranted, and any initial group differences are indeed already accounted for by the current method of analysis. For example, given the quasi-experimental nature of the current study, such a comparison at pre-treatment would only demonstrate that the groups are potentially different based on enrolled lab section. If this were the only time point of measurement (it is not), or if these differences were not accounted for relative to later measurements (they are), this might be cause for concern. However, we would argue that these initial knowledge levels are only important relative to their final standing in the course (i.e., how much did they learn, controlling for their initial levels of knowledge). The current analysis does directly examine the amount learned, while also simultaneously controlling for initial knowledge levels. We feel that this is the most appropriate way to frame the current results as it directly evaluates the effectiveness of the instructional manipulation in the lab sections, and not pre-existing group differences. We would also add that this method of analysis is typical in most educational research.**

Further, we do feel it more straightforward to maintain the discussion of results relative to the learning outcomes. For example, if we were to discuss the results strictly relevant to each question, as each question taps multiple types of content knowledge (see Figure 2 for an example), we believe that this would make the pattern of results more confusing for readers.

Some sort of graphical representation of that results (e.g. box-plots) could have been useful.

**While technically redundant with the information presented in Table 3 (which already includes measures of central tendency and variance), we would be happy to include such a graphic to facilitate the demonstration of effect.**

Information about how the students were selected for the two types of treatments is also missing (randomly?).

**We would kindly direct the reviewer to section 2.1 where this information is already available; there were multiple laboratory sections of a single course, and each section was randomly assigned to either the control or treatment group.**

As indicated in the beginning I find this a useful and intersecting study. However, it needs considerable shaping up in order for it to become genuinely useful for the wide readership. I hope the authors would take up the challenge of revising it.

**We again thank the reviewer for their kind words and input, and hope that our revisions will effectively address the reviewer's concerns.**

1   **Enhancing the T-Shaped Learning Profile when Teaching Hydrology using**  
2   **Data, Modeling, and Visualization Activities.**

3

4   C.A. Sanchez<sup>1</sup>, B.L. Ruddell<sup>2</sup>, R. Schiesser<sup>3</sup> and V. Merwade<sup>4</sup>

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11

1    **Abstract**

2    Previous research has suggested that the use of more authentic learning activities can produce  
3    more robust and durable knowledge gains. This is consistent with calls within civil  
4    engineering education, specifically hydrology, that suggest that curricula should more often  
5    include professional perspective and data analysis skills to better develop the ‘T-shaped’  
6    knowledge profile of a professional hydrologist (i.e., professional breadth combined with  
7    technical depth). It was expected that the inclusion of a data driven simulation lab exercise  
8    that was contextualized within a real-world situation and more consistent with the job duties  
9    of a professional in the field, would provide enhanced learning and appreciation of job duties  
10   beyond more conventional paper-and-pencil exercises in a lower division undergraduate  
11   course. Results indicate that while students learned in both conditions, learning was enhanced  
12   for the data-driven simulation group in nearly every content area. This pattern of results  
13   suggests that the use of data-driven modeling and visualization activities can have a  
14   significant positive impact on instruction. This increase in learning likely facilitates the  
15   development of student perspective and conceptual mastery, enabling students to make better  
16   choices about their studies, while also better preparing them for work as a professional in the  
17   field.

18

1    **1    Introduction**

2    While there is a rising interest in and demand for civil engineering and hydrology education,  
3    some have suggested a widening gap between how students are instructed in hydrology, and  
4    the subsequent professional skill set required for a career as a hydrological engineer (Wagener  
5    et al., 2007). Recent research has shown a potential for great variability within the  
6    hydrological curriculum (Wagener et al., 2012). This variability includes differences in not  
7    only what conceptual material should be taught (Gleeson, Allen & Ferguson, 2012), but also  
8    how this material should be delivered pedagogically (Wagener, 2007). It has been suggested  
9    that an emerging requirement for new hydrological engineers is the ability to not only develop  
10   a well-defined knowledgebase of basic hydrological concepts, but also synthesize this  
11   conceptual learning with more authentic ‘real-world’ knowledge gained from the  
12   interpretation and application of this knowledge (Merwade and Ruddell, 2012).  
13   Unfortunately, field and modeling activities are often lacking in the hydrological curriculum,  
14   at least at the undergraduate and lower division level (ASCE, 1990; MacDonald, 1993; Nash  
15   et al., 1990; Ruddell & Wagener, 2013; Wagener et al., 2007, 2012). This is especially  
16   concerning as unlike laboratory sciences such as physics and chemistry, hydrology is  
17   fundamentally a place-based science. It can therefore be argued that hydrologists must  
18   engage in field and modeling activities in order to fully develop the critical ability to link  
19   hydrological concepts to applications in a specific place/instance (Eagleson et al., 1991).

20   This call to integrate experiential learning with traditional classroom instruction is not new,  
21   and has been advocated in other fields of engineering (Duderstadt, 2007; Lattuca, Terenzini,  
22   Volkwein & Peterson, 2006; National Academy of Science, 2007; Shulman, 2005), and has  
23   also been suggested more generally within the educational literature (e.g., Bransford, Brown  
24   & Cocking, 1999; Brown, Collins & Duguid, 1989). These suggestions are rooted in the  
25   simple tenet that when learners engage more deeply in the formation and development of  
26   relevant knowledge, the depth and quality of their understanding subsequently increases. This  
27   constructive process is integral to numerous pedagogical philosophies such as problem-based  
28   learning (PBL), guided discovery learning, and cognitive apprenticeship, to name a few  
29   (Alfieri et al., 2011; Brown et al., 1989; Collins, 1991; DeJong & Van Joolingen, 1998; Duch  
30   et al., 2001; Savery & Duffy, 1995; Wood, 2003).

31   While the various educational pedagogies mentioned above are different on several levels,  
32   they share at least two important unifying characteristics. Fundamentally, (1) they require the

1 learner to be actively engaged in the learning activity in order to realize any learning benefit,  
2 and (2) they are usually situated within an authentic or 'real' problem that the student must  
3 work to solve or address. Importantly, these characteristics imply that the problem is difficult  
4 enough that students must work towards a solution (i.e., they do not know the solution  
5 initially), and that each student has explicit engagement with the pursuit of this solution, as  
6 such activities are often implemented in group settings (Smith, Sheppard, Johnson & Johnson,  
7 2005). It has been argued that such authentic engagement fosters a more deep conceptual  
8 understanding of the material by 'anchoring' the more abstract learning material or concepts  
9 to the more accessible authentic learning scenario (CTGV, 1992; Hake, 1998). Thus, the  
10 contextualization of the material within an actual scenario increases not only retrieval cues  
11 that the learner can use to more efficiently access factual knowledge, but also likely increases  
12 the durability of the knowledgebase, thereby creating a more flexible state of information that  
13 could be applied appropriately in multiple instances (Hansen, 2008; Smith & Van Doren,  
14 2004).

15 Active engagement in the learning process has also been suggested as a means to increase  
16 interest in the topic to-be-learned (Paris & Turner, 1994; Scheifele, 1991), which might also  
17 address issues of motivation within students. Traditional lecture-based instruction that forces  
18 students to work towards normative educational goals in isolation is often cited as a major  
19 complaint of engineering students, and has measurable negative effects on motivation levels  
20 (Felder, Felder & Dietz, 1998). More authentic, problem-based activity has been shown to  
21 produce an increase in student attitudes towards the content area in general (Watters & Ginns,  
22 2000), offering an opportunity to offset such motivation issues. Importantly, this could not  
23 only increase motivation within the lesson itself, but also potentially affect the likelihood to  
24 continue with studies in a given domain. In other words, this motivation derived within a  
25 specific context could have a direct effect on overall interest in the major or field, as learners  
26 are better able to see how their own interests better align and apply to tangible problems.

27 However, efforts to adopt such authentic learning exercises within engineering education are  
28 often hampered by unclear learning objectives and assessment, logistical constraints, and the  
29 use of activities that do not necessarily optimize the learning experience (see Prince, 2004).  
30 For example, it is unclear about what degree of 'authenticity' is required, and how does one  
31 assess learning from 'field' activities relative to traditional instruction? For example, while  
32 PBL has been implemented successfully with electrical engineering students (Yadav, Subedi,

1 Lundeberg & Bunting, 2011), students who engaged with the PBL activity were compared to  
2 students who only had a lecture component, without the opportunity to engage in an  
3 equivalent control activity. As such, these studies cannot conclusively say that gains  
4 normally attributed to the instructional manipulation are due to the activity alone, and could  
5 reflect the influence of other factors (e.g., differences in time spent engaging with the  
6 material). Further, what is an appropriate ‘field activity’ in an engineering discipline, and  
7 how should these efforts be categorized and defined? As such, while this call for authentic  
8 activity is often advocated and supported theoretically, unfortunately it is not often  
9 consistently practiced, and thus leads to fragmented research on the issue (Prince, 2004).

10 There do also exist more specific pedagogical concerns regarding authentic learning within  
11 the area of hydrological engineering education (Gleeson et al., 2012). For example, there is  
12 little to no direct evidence that such activities are indeed effective at augmenting a  
13 hydrologist’s training, or even implemented with any kind of regularity for that matter  
14 (Ruddell and Wagener, 2013). What little evidence that does exist supporting the  
15 incorporation of student-centered activities into hydrology instruction is often anecdotal (e.g.,  
16 Thompson et al., 2012), without any kind of quantitative or measureable change in  
17 performance outcomes. Pragmatic and logistical issues (e.g., faculty time and expertise,  
18 student computer skills), and the use of curriculum materials that become rapidly outdated,  
19 also stand as barriers to the adoption of a more discovery-based or student- centered approach  
20 within hydrology (Merwade & Ruddell, 2012, Ruddell & Wagener, 2013). Finally,  
21 hydrological instruction is also traditionally implemented using a teacher-centered approach  
22 (e.g., lectures) that lacks the opportunity for applied experience (Wagener et al., 2007). Thus,  
23 it appears critical to find new ways to achieve instructional goals that might incorporate this  
24 real world experience, and are capable of side-stepping these methodological and logistical  
25 issues. Fortunately, the emergence of rich and dynamic computer simulation techniques,  
26 which allow students to interact with real data in ways that are consistent and appropriate with  
27 the profession, might offer an alternative to such traditional instruction, and thus provide an  
28 exciting opportunity for students to achieve this more authentic application of knowledge.

## 29 **1.1 Data modeling driven geoscience cybereducation**

30 Standardized data and modeling driven geoscience cybereducation (DMDGC) modules,  
31 developed and published by a dedicated community of educators, do potentially provide  
32 access to such dynamic and realistic learning experiences, while also avoiding some of the

1 logistical barriers mentioned above (Habib et al., 2012; Merwade and Ruddell, 2012). These  
2 modules utilize contextually specific, rich, and dynamic computer simulations that allow  
3 students to interact with current field data in a fashion equivalent to professional hydrologists.  
4 As students do not have to physically travel to a work site to collect data, nor do they require  
5 specialized tools to work with the data, these simulation activities can be easily integrated into  
6 normal laboratory sections via coursework. Most importantly, as the data is real, and also  
7 contextualized within a specific example, it presents an opportunity to apply hydrological  
8 concepts within a formally structured and valid situation, again consistent with professionals  
9 in the field.

10 An open question, however, is whether such activities do in fact realize the potential  
11 educational benefits that one might anticipate from authentic activities? Similarly, it is not  
12 known for which content areas/aspects of the curriculum are such benefits localized or  
13 strongest, if any? For example, do such activities help students better appreciate what it  
14 means to be a professional hydrological engineer? Or is this benefit localized to better  
15 understanding hydrological domain content alone? In other words, it must be evaluated  
16 whether DMDGC modules do in fact serve as an adequate opportunity to gain such authentic  
17 activity, while also permitting the learning and achievement of traditional class goals for  
18 knowledge attainment? It has therefore become important to pinpoint the learning benefits  
19 created by DMDGC activities, so that these activities can be optimized for content, structure,  
20 and integration with the traditional lecture format.

21 This study directly examines the efficacy of such data-driven simulations for hydrology  
22 education at the earliest point in a potential future hydrologist's university training: in a  
23 mandatory lower-division undergraduate earth science context that is part of general  
24 curriculum studies. At this level the student enters the classroom with very little (if any) prior  
25 knowledge about hydrologic theory, hydrology models/methods, or the broad applications and  
26 societal issues involved with hydrological engineering. Evaluating the effects of such an  
27 intervention at this very early point provides an opportunity to examine the full effect of  
28 DMDGC implementation, avoiding issues of self-selection bias and prior contextual  
29 knowledge about the hydrology profession that might exist in upper division or graduate  
30 students in the field. In other words, in this student population we can observe the effect of  
31 DMDGC activities on a breadth of knowledge related to the field and its application, beyond  
32 just core theoretical concepts and applied computer modeling skills.

1 Students in the DMDGC condition were given a data-driven hydrology activity that focused  
2 on urbanization and flooding, while a control group was given a paper-pencil based laboratory  
3 activity of equivalent general learning outcomes and effort, but lacked the specific applied  
4 context and data-driven components of the DMDGC. The inclusion of this paper-based  
5 activity is a critical methodological feature, as it permits a more appropriate evaluation of the  
6 simulation activity against an activity that is likely equally effortful and time consuming from  
7 the student perspective. Thus, any subsequent learning gains are less likely to be attributed to  
8 other confounding factors, and must instead be more localized to the nature of the  
9 manipulation itself. It was hypothesized that students who were presented with the DMDGC  
10 learning activities would demonstrate a better understanding of theoretical and applied  
11 hydrology concepts related to flooding, as their interaction with the material would be  
12 contextualized and likewise permit a dynamic exploration of the data not otherwise possible  
13 without such simulation. Further, it was also hoped that students in the simulation condition  
14 would develop a better appreciation for the roles of hydrological engineers and hydrology  
15 organizations in managing and preventing flooding problems, as they themselves are  
16 engaging in a contextualized problem within a realistic community scenario that required the  
17 intervention of hydrologists.

18 **2 Methods**

19 **2.1 Participants and experimental design**

20 One-hundred seven students ( $N=107$ ) enrolled in an Introductory Earth Science course (and  
21 corresponding laboratory sections) at a community college in the south-western United States  
22 were solicited for participation. Participants were evaluated both before and after a sub-unit  
23 within the course that focused on applying the Rational Method and a Synthetic Unit  
24 Hydrograph to estimate hydrographs and flooding for urban areas experiencing land use and  
25 climate change. Eighty-eight of these students successfully participated in both the pre and  
26 post assessments, an overall completion rate of 82%. These 88 participants were distributed  
27 among 2 different instructional conditions based on enrolled lab section: DMDGC modeling  
28 ( $n=52$ ; 79% participation rate), and paper-based activities ( $n=36$ ; 88% participation rate). All  
29 students shared the same single lecture instructor, and were thus given identical lecture  
30 content over a period of approximately two weeks of class.

1    **2.2 Materials**

2    **2.2.1 Curricular materials**

3    Both the DMDGC modules (Ruddell and Schiesser, 2012a;b) and the comparable paper  
4    laboratory (Lab 9 in Schiesser, 2008) were designed to be implemented in parallel with  
5    traditional lectures. In this unit, all students were given identical lectures (based on material  
6    covered in Schiesser, 2008) that covered the fundamentals of flood frequency, urbanization  
7    and land use change, flood risk, climate change effects on rainfall, and the roles and  
8    responsibilities of agencies that provide flood prediction and management services in the  
9    USA. In other words, the lecture component of the current design was identical for both  
10   laboratory groups, and the only instructional difference was whether the students received a  
11   DMDGC or paper laboratory module.

12   The experimental DMDGC module is written for Microsoft Excel™, a widely utilized and  
13   highly accessible spreadsheet application. It is a simple stormwater hydrograph modeling  
14   module that applies the widely utilized Rational Method and a Synthetic Unit Hydrograph to  
15   estimate hydrographs and flooding for urban watersheds. The model is based on assumptions  
16   optimized for a floodway in Maricopa County, Arizona; an urbanized desert area in the  
17   southwestern United States. The module has the ability to accept both observed rainfall and  
18   streamflow data so that a student may calibrate the parameters of the flood model to match  
19   any observed event. Importantly, the module is also broadly applicable to urbanizing  
20   watersheds anywhere in the world and can be adapted to other locations by simply adjusting a  
21   few model parameters and obtaining observed streamflow data for a flood event. As such, this  
22   DMDGC activity could be applied to nearly any urban area, an option that could be used to  
23   tailor context and content respective to each student population and their corresponding  
24   physical location.

25   The DMDGC module produces a visualization of modeled and observed hydrograph results  
26   (Figure 1). As is visible in Figure 1, the module emphasizes the determination of whether or  
27   not a given channel will flood during a 100-year design storm event as land use is  
28   progressively urbanized, and as the design storm changes due to climate change. These  
29   multiple interacting characteristics served as the foundation for the rubric described in the  
30   next section (and in Figure 2). The DMDGC module takes roughly two hours of preparation  
31   for a novice instructor, and roughly three hours of student effort to complete.

1 A paper lab activity (Lab 9 in Schiesser, 2008) requiring a similar effort was utilized as a  
2 control for comparison with the DMDGC module. The paper module requires students to  
3 perform hand calculations and determine whether a channel will flood before and after  
4 urbanization occurs in a watershed. Like the DMDGC module, a student considers the effect  
5 of issues such as rainfall infiltration, watershed area, and rainfall intensity, and channel  
6 capacity in determining a flood. Unlike the DMDGC module, the paper activity explicitly  
7 addresses issues of flood frequency using recurrence interval calculations using a brief table  
8 of historical peak flow events instead of a student's investigation of observed streamflow  
9 data. Also, no visualization or interaction is possible with the paper method. The paper lab's  
10 streamflow data is "stock" data that is hypothetical and not drawn from real-world or place-  
11 based sources. The paper module does not include customized data for the student's local  
12 watershed, nor an observed rainfall event in the local watershed, and is not able to provide  
13 visual feedback via the flow hydrograph when the student adjusts watershed parameters or the  
14 rainfall intensity. Finally, this paper-based activity is not contextualized within the local  
15 environment (e.g., Maricopa county). The estimated time to complete this paper activity is  
16 also approximately 3 hours. Thus, this exercise requires students to complete calculations of  
17 similar complexity and type as the DMDGC module, albeit in a paper and pencil form and  
18 minus the place-based contextualization and interactive visualization components. As such,  
19 effort and time with the material (across both lecture and laboratory components) are  
20 comparable across these instructional conditions, and not likely explanations for any  
21 subsequent effects.

## 22 **2.2.2 Learning Assessments**

23 The pre/post assessment instrument (Appendix A) features eight questions spanning a range  
24 of topics. Two of these 8 questions contained sub-questions, thus resulting in a total of eleven  
25 questions overall. To provide a more coherent evaluation of performance in the learning of  
26 hydrological concepts and the role of hydrologists, a rubric was developed resulting in nine  
27 overall learning outcomes representing important hydrology concepts related to flooding. The  
28 nine outcome areas presented in [Figure-Table 2](#) represent areas of conceptual mastery  
29 regarding climate, land cover, flood management, and hydrology. The first 6 areas  
30 specifically emphasize mastery of the physical concepts determining flooding (e.g., rainfall  
31 intensity and duration, hydrographs, infiltration, and stormwater management practices), [and](#)  
32 [thus are indicative of a good conceptual understanding of the material itself.](#) However, the

1 last 3 outcomes were designed to assess the understanding of the roles and responsibilities of  
2 flood-related professional agencies (e.g., agency roles & responsibilities, value of geoscience  
3 knowledge), or in other words, the potential job duties of a professional working in the field.  
4 To make this distinction more transparent, examples of conceptual mastery relative to the  
5 learning outcomes are also presented in Table 2. Together, these nine outcomes cover the  
6 basic physical details and a 'T-shaped profile' of professional and scientific competence  
7 (Cap-Net, 2008; McIntosh & Taylor, 2013; Pathirana et al., 2012, Pinter et al., 2013,  
8 Uhlenbrook & de Jong, 2012) needed for a basic appreciation of the profession and the social  
9 impacts of flood hydrology.

10 Each of the eleven questions was evaluated relative to the appropriate learning outcomes on a  
11 four-point scale (0-3) as to the level of conceptual mastery indicated by the response, where 0  
12 indicates no relevant response, 1 indicates a 'Novice' level, 2 indicates an 'Apprentice' level,  
13 and 3 indicates an 'Expert' level. A rating of 3 approximates the level of conceptual mastery  
14 expected by a practicing hydrological professional. Some subquestions did not assess some  
15 learning outcomes; these irrelevant combinations are indicated in the Figure 2 matrix in grey.  
16 Two hydrology educators independently coded the level of conceptual mastery indicated by  
17 student responses on the pretest assessment instrument, blind to condition, and indicated a  
18 high degree of inter-rater reliability across all nine learning outcomes (all ICCs>.91, p<.01).  
19 The post-assessments (which were again identical to the pre-assessments) were then coded by  
20 a single coder. Table 1 gives examples of conceptual mastery for each of the nine outcomes.

### 21 3 Results

22 To examine the effect of the DMDGC modules on the change in student knowledge in each of  
23 the nine outcomes, a simple 2-way ANCOVA was conducted between laboratory groups on  
24 the post-test scores for each outcome. Pretest scores for each measure were used as a  
25 covariate in every respective analysis to control for any differences in initial knowledge  
26 levels, and all results were evaluated for significance at the level of  $p < 0.05$ . Levene's tests  
27 for all analyses indicated a non-significant result ( $p > .05$ ), which affirms that variance was  
28 equivalent between comparison groups. Descriptive statistics for each measure by group, and  
29 all  $F$ -statistics, are available in Table 32. Results are also graphed in Figure 3.

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1    **3.1.1 Physical concepts of flooding**

2    As is visible in Table 23, the use of a DMDGC module significantly improved performance in  
3    all 6 areas (#1-6) save (#4) Effect of Decadal LULC Change on Flooding. Participants who  
4    were given the opportunity to learn with the DMDGC modules were better able to not only  
5    understand the effects of urbanization and other physical causes of flooding, but also  
6    demonstrated better knowledge of maximum discharge rates and impacts of flood  
7    management. The lack of result for outcome (#4) Effect of Decadal LULC Change on  
8    Flooding was not entirely unexpected, as although this content topic was originally intended  
9    to be emphasized in the lecture and lab settings, unfortunately it was not able to be covered in  
10   depth due to time constraints. Thus, it is not surprising that this outcome showed little  
11   divergence between groups as students were not explicitly instructed in this topic. As such,  
12   this likely reflects a shortcoming in the overall content covered, rather than demonstrating a  
13   lack of theoretical effect.

14   **3.1.2 Professional role of hydrologists**

15   Consistent with the content results above, users of DMDGC modules also appear to have  
16   gained a better appreciation for the professional role of hydrologists and the field. Across all  
17   3 sub-areas (#s 6-9), there was a significantly higher demonstration of expertise for the  
18   simulation group, above those simply using the paper-and-pencil activities. This suggests that  
19   not only does engaging in such authentic activity produce a measureable benefit in learning  
20   content, but this benefit also results in a better understanding of the professional duties within  
21   the field. This result is especially encouraging as it also could potentially indicate that such  
22   activities allow students to become better prepared for eventual careers in hydrological  
23   engineering, and thus provide a bridge between the content area and the application of  
24   knowledge.

25   In summary, when one considers the overall pattern of results it appears that the benefit for  
26   such dynamic simulation and visualization was not only limited to content knowledge areas  
27   such as rainfall intensity and flooding, but was also realized in regards to better understanding  
28   the professional and social impacts of hydrology. This suggests that ~~there was an increase in~~  
29   ~~performance across both legs of the 'T-shaped profile' (Ruddell & Wagener, 2013);~~ not only  
30   did learners better understand the material itself (~~e.g., depth~~), but also better understood the  
31   role of hydrologists (~~e.g., breadth~~) in a more general sense. Further, the medium to large  
32   effect sizes (Miles & Shevlin, 2001) realized by this manipulation further suggest that the

1 inclusion of the DMDGC module produced a practical and worthwhile change in  
2 performance, above and beyond reaching simple statistical reliability.

3 **4 Discussion**

4 While prior research in education has suggested that the use of applied examples could likely  
5 benefit learning, this suggestion was explicitly tested here in the context of hydrological  
6 education, using DMDGC modules. It was anticipated that the use of such dynamic and  
7 flexible simulation tools, which enable learners to contextualize and visualize the impact of  
8 minute changes in data over time, would lead to a marked increase in learning performance.

9 The results of this classroom study support exactly that. Learners who were permitted to  
10 interact with such simulations not only were better able to understand the content itself in the  
11 form of general knowledge, but these same learners were also better able to appreciate the  
12 role of professionals within the field. This increase was significantly larger than that  
13 experienced by the control group, which engaged with materials that required similar skills

14 but lacked the contextual and simulation components of the DMDGC module. It is our  
15 contention that the increase in both areas (breadth and depth) was a direct result of the  
16 experience with the DMDGC module. For example, in terms of conceptual learning, the  
17 DMDGC modules allowed learners to better understand the interaction of conceptual units  
18 and how to use tools like the hydrograph to anticipate flooding conditions. Similarly, this  
19 direct experience also allowed learners to better appreciate the job duties of practicing  
20 hydrologists, providing a tacit understanding of the role of agencies and geoscience education  
21 in society, which in turn led to better recall. While certainly speculative, given that both  
22 groups received identical discussion regarding agency duties in lecture (and thus in a  
23 decontextualized, abstract sense), the fact that the DMDGC group was able to better  
24 appreciate this kind of information seems to again suggest that the concrete experience helped  
25 make this understanding of professional duties more accessible to these learners.

26 As such, this overall pattern of results suggests that learners were gaining a more complete  
27 'T-shaped profile' of hydrological education (Ruddell & Wagener, 2013), balancing an  
28 increase in not only their specialized conceptual, quantitative, and modeling skills within the  
29 field, but also achieving a more broad understanding of the role of professionals in the field  
30 relative to real-world scenarios. This is a very encouraging result, as it suggests a dual benefit  
31 for such DMDGC training.

1 Further, another interesting point is that it is likely such multiple effects were observed  
2 because the participants in this study were just beginning their education in the field of  
3 hydrology, so issues of contextualized knowledge or self-selection were likely minimized in  
4 this sample. In other words, because learners were lacking a well-defined representation of  
5 not only the knowledge of the field, but also the role of working professionals in the field, this  
6 training experience permitted them to gain greater insight into both the field and requisite  
7 application. This fact is even more encouraging as it suggests that such interventions,  
8 introduced early in the educational trajectory, can provide a more robust and complete  
9 learning experience at all levels. It is possible that such increases in depth and breadth of  
10 knowledge early on could translate into more success with the material, thus likely increasing  
11 the likelihood of learners persisting in the pursuit of education in this domain. It appears that  
12 working with authentic data increases the appreciation of a novice student for the importance  
13 of the hydrology profession and for the physical problems this profession addresses.

## 14 **5 Conclusions**

15 For the fundamentally place-based geosciences such as hydrology, the integration of concepts  
16 will inevitably require exposure to real-world contexts and data. The results of this study  
17 demonstrate that computerized learning content can effectively bring the ‘real world’ into the  
18 classroom and make it accessible, especially in the case of students at lower levels and across  
19 the general curriculum. The findings of this paper also indicate that it is possible to deliver  
20 this type of content in a localized place-based context, and to realize learning gains on both  
21 physical and professional learning outcomes without introducing a great deal of complexity in  
22 the way of computer modeling and programming. A simple spreadsheet, combined with  
23 readily available online hydrological data, is sufficient in this case. In other words, these  
24 computerized techniques afford instructors the opportunity to have their students engage in  
25 realistic and authentic problem-based activities without the need to manage other logistical  
26 constraints often encountered with field research (i.e., transportation, materials, etc.). It is our  
27 hope that the positive findings of this study encourage investment in development of high-  
28 quality DMDGC learning materials, and the wider adoption of place-based DMDGC learning  
29 materials across the civil engineering curriculum. Implementing such learning experiences  
30 into the curriculum will ideally create more enriching experiences for student learners, and  
31 hopefully also develop more well-rounded and skilled practicing hydrologists.

1 While the current study focused on lower-division students, in future work it would also be of  
2 interest to expand this program longitudinally throughout the curriculum to identify how best  
3 to deliver DMDGC content at all levels of the hydrology curriculum to maximize its  
4 effectiveness. Efforts are currently ongoing to do exactly this, and also expand the  
5 application of DMDGC content to hydrological concepts beyond flooding and urbanization.

6

## 1    **References**

2    Alfieri, L., Brooks, P. J., Aldrich, N. J., & Tenenbaum, H. R. Does discovery-based  
3    instruction enhance learning?. *Journal of Educational Psychology*, 103, 1-18, 2011.

4    ASCE: Perspectives on water resources education and training, *J. Water Res. Pl. Manag.*, 116,  
5    99-133, 1990 , doi: 10.1061/(ASCE)0733-9496(1990)116:1(99)

6    Bransford, J. D., Brown, A. L., & Cocking, R. R. *How people learn: Brain, mind, experience,*  
7    and school. National Academy Press, Washington, D.C., 1999.

8    Brown, J. S., Collins, A., & Duguid, P. *Situated cognition and the culture of learning.*  
9    *Educational Researcher*, 18, 32-42, 1989.

10   Cap-Net. *Economics in sustainable water management training manual and facilitators' guide.*  
11   <<http://www.cap-net.org/training-material/economics-in-sustainable-water-management-english/>>(May 22, 2013), 2008.

13   Cognition and Technology Group at Vanderbilt. *Emerging technologies, ISD, and learning*  
14   environments: critical perspectives. *Educational Technology Research and Development*, 40,  
15   65-80, 1992.

16   Collins, A.: *Cognitive apprenticeship and instructional technology*, in: *Educational Values*  
17   and *Cognitive Instruction: Implications for Reform*, edited by: Idol, L. and Jones, B. F.,  
18   Hillsdale, NJ, Lawrence Erlbaum Associates, 121–138, 1991.

19   De Jong, T., & Van Joolingen, W. R. *Scientific discovery learning with computer simulations*  
20   of conceptual domains. *Review of Educational Research*, 68, 179-201, 1998.

21   Duch, B. J., Groh, S. E., & Allen, D. E. *Why problem-based learning. A case study of*  
22   institutional change in undergraduate education. In Duch, BJ, Groh, SE and Allen, DE,  
23   Sterling, Virginia (eds.), *The Power of Problem-Based Learning* (pp. 3-11), 2001.

24   Duderstadt, J. J. *Engineering for a changing world: A roadmap to the future engineering*  
25   practice, research, and education. Ann Arbor, MI: The University of Michigan, 2008.

26   Eagleson, P. S., Brutsaert, W. H., Colbeck, S. C., Cummins, K. W., Dozier, J., Dunne, T., ...  
27   & Zipser, E. J. *Opportunities in the hydrologic sciences*. Natl. Acad. Press, Washington, DC,  
28   1991.

1 Felder, R. M., Felder, G. N., & Dietz, E. J. A longitudinal study of engineering student  
2 performance and retention. V. comparisons with traditionally-taught students. *Journal of*  
3 *Engineering Education*, 87, 469-480, 1998.

4 Gleeson, T., Allen, D. M., & Ferguson, G. Teaching hydrogeology: a review of current  
5 practice. *Hydrology and Earth System Sciences*, 16, 2159-2168, 2012.

6 Habib, E., Ma, Y., Williams, D., Sharif, H. O., and Hossain, F. HydroViz: design and  
7 evaluation of a Web-based tool for improving hydrology education. *Hydrology and Earth*  
8 *System Sciences*, 16, 3767-3781, 2012. doi:10.5194/hess-16-3767-2012.

9 Hake, R. R. Interactive-engagement versus traditional methods: A six-thousand-student  
10 survey of mechanics test data for introductory physics courses. *American Journal of Physics*,  
11 66, 64-74, 1998.

12 Hansen, M. M.: Versatile, immersive, creative and dynamic virtual 3-D healthcare learning  
13 environments: a review of the literature, *J. Med. Internet Res.*, 10, e26,  
14 doi:10.2196/jmir.1051,2008.

15 Lattuca, L. R., P. T. Terenzini, J. F. Volkwein, and G. Peterson. The changing face of  
16 engineering education. *The Bridge: Linking Engineering and Society*, 36, 5-13, 2006.

17 MacDonald, L. H. Developing a field component in hydrologic education. *Water Resources*  
18 *Bulletin of the American Water Resources Association*, 29, 357-368, 1993.

19 McIntosh, B. S., & Taylor, A. Developing T-Shaped water professionals: Building capacity in  
20 collaboration, learning, and leadership to drive innovation. *Journal of Contemporary Water*  
21 *Research & Education*, 150, 6-17, 2013.

22 Merwade, V., & Ruddell, B. L. Moving university hydrology education forward with  
23 community-based geoinformatics, data and modeling resources. *Hydrology and Earth System*  
24 *Sciences*, 16, 2393-2404, 2012.

25 Miles, J. and Shevlin, M.: *Applying Regression and Correlation: a Guide for Students and Re-*  
26 *searchers*, Sage, London, UK, 2001.

27 Nash, J. E., Eagleson, P. S., Philip, J. R., Van der Molen, W. H., & Klemeš, V. The education  
28 of hydrologists (Report of an IAHS/UNESCO Panel on hydrological education). *Hydrological*  
29 *Sciences Journal*, 35, 597-607, 1990.

1 Paris, S. G., and Turner, J. C.: Situated Motivation, in: Student motivation, cognition, and  
2 learning: Essays in honor of Wilbert J. McKeachie, edited by: Pintrich, P., Brown, D., and  
3 Weinstein, C. E., Lawrence Erlbaum Associates, Hillsdale, NJ, 213–237, 1994.

4 Pathirana, A., Koster, J. H., Jong, E. D., & Uhlenbrook, S. On teaching styles of water  
5 educators and the impact of didactic training. *Hydrology and Earth System Sciences*, 16,  
6 3677-3688, 2012.

7 Pinter, N., Baer, S., Chevalier, L., Kowalchuk, R., Lant, C., & Whiles, M. An “IGERT”  
8 Model for Interdisciplinary Doctoral Education in Water-Related Science and Policy. *Journal*  
9 of Contemporary Water Research & Education

10 Prince, M. Does active learning work? A review of the research. *Journal of Engineering*  
11 *Education*, 93, 223-231, 2004.

12 Ruddell, B. L. and Schiesser, R. A.: Developing a Rational Method Hydrograph Model for the  
13 Urban Desert Southwest USA, unpublished material, Mesa, AZ, 2012a.

14 Ruddell, B. L. and Schiesser, R. A.: Calibrating a Rational Method Hydrograph Model for the  
15 Urban Desert Southwest USA, unpublished material, Mesa, AZ, 2012b.

16 Ruddell, B. L. and Wagener, T.: Grand challenges for hydrology education in the 21st  
17 century, *J. Hydrol. Eng.*, A4014001, doi:10.1061/(ASCE)HE.1943-5584.0000956, 2015.

18 Savery, J. R., & Duffy, T. M. Problem based learning: An instructional model and its  
19 constructivist framework. *Educational Technology*, 35, 31-38, 1995.

20 Schiefele, U. Interest, learning, and motivation. *Educational Psychologist*, 26, 299-323, 1991.

21 Schiesser, R. A.: Geological Disasters Case Studies and Analysis (and Lab 9 manual), 1<sup>st</sup>  
22 edn., Kendall Hunt, Dubuque, IA, ISBN-978-0-7575-5039-3, 2008.

23 Shulman, L. S. If not now, when? The timeliness of scholarship of the education of engineers.  
24 *Journal of Engineering Education*, 94, 11-12, 2005.

25 Smith, K. A., Sheppard, S. D., Johnson, D. W., & Johnson, R. T. Pedagogies of engagement:  
26 Classroom-based practices. *Journal of Engineering Education*, 94, 87-101, 2005.

27 Smith, L. W., & Van Doren, D. C. The reality-based learning method: A simple method for  
28 keeping teaching activities relevant and effective. *Journal of Marketing Education*, 26, 66-74,  
29 2004.

1 Thompson, S. E., Ngambeki, I., Troch, P. A., Sivapalan, M., & Evangelou, D. Incorporating  
2 student-centered approaches into catchment hydrology teaching: a review and synthesis.  
3 *Hydrology and Earth System Sciences*, 16, 3263-3278, 2012.

4 Uhlenbrook, S., & Jong, E. D. T-shaped competency profile for water professionals of the  
5 future. *Hydrology and Earth System Sciences Discussions*, 9, 2935-2957, 2012.

6 Wagener, T., Kelleher, C., Weiler, M., McGlynn, B., Gooseff, M., Marshall, L., Meixner, T.,  
7 McGuire, Gregg, S., Sharma, P. and Zappe, S. It takes a community to raise a hydrologist:  
8 The Modular Curriculum for Hydrologic Advancement (MOCHA). *Hydrology and Earth  
9 System Sciences*, 16, 3405-3418, 2012. doi:10.5194/hess-16-3405-2012.

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

12 Watters, J. J., & Ginns, I. S. Developing motivation to teach elementary science: Effect of  
13 collaborative and authentic learning practices in preservice education. *Journal of Science  
14 Teacher Education*, 11, 301-321, 2000.

15 Wood, D. F. Problem based learning. *Bmj*, 326, 328-330, 2003.

16 Yadav, A., Subedi, D., Lundeberg, M. A., & Bunting, C. F. Problem-based Learning:  
17 Influence on Students' Learning in an Electrical Engineering Course. *Journal of Engineering  
18 Education*, 100, 253-280, 2011.

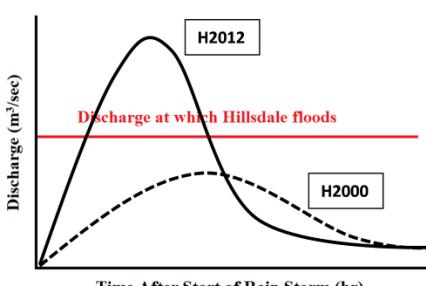
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1 **Acknowledgments**

2 This material is based upon work supported by the National Science Foundation under Grant  
3 No. 1043996. Any opinions, findings, and conclusions or recommendations expressed in this  
4 material are those of the author(s) and do not necessarily reflect the views of the National  
5 Science Foundation. Publication of this article in an open access journal was funded by the  
6 Oregon State University Libraries & Press Open Access Fund.

7

1 Table 1. Pre/Post Assessment Instrument with Model ‘Expert’ Answers

Question	Model Answer
(1a.) Compare Hillsdale 2000 with Hillsdale 2012: write a description of the effects of impervious cover and urbanization as the City has expanded.	<p><i>As the city has expanded over time, open areas that produce relatively little runoff are being replaced with urban areas that are impervious to rainfall and therefore produce more runoff.</i></p>
(1b.) Complete a hydrograph analysis on the axes below by doing the following:	<p>• Draw the flood hydrograph for an extreme rainfall event at the Hillsdale stream gage in 2000 before urban development expands; label this curve “H2000”.</p> <p>• Draw the flood hydrograph for an extreme rainfall event at the Hillsdale stream gage in 2012 after urban development expands; label this curve “H2012”.</p> 
(2) List at least two policies or practices that water managers can pursue to reduce the damage caused by flood events.	<p>a) Reducing urbanization      b) Reducing impervious area upstream      c) Enhancing retention of stormwater onsite      d) Reducing development in the floodplain      e) Building levees</p>
(3) What U.S. Federal agency is the primary provider of streamflow and surface water resource data?	<p><i>The USGS is the best answer, but NOAA is a good second choice.</i></p>
(4) What U.S. Federal agency is the primary provider of rainfall and weather data?	<p><i>NOAA is the best answer, but the USGS is a good second choice.</i></p>

<p>(5) What U.S. Federal agency is the primary regulator and provider of flood control services?</p>	<p><i>US Army Corps of Engineers is the correct answer.</i></p>
<p>(6a.) What kind of information are these hydrologists able to provide about the future risk, frequency, severity, or damages of flood events at your location, and what tools and knowledge make it possible to provide this information?</p>	<p><i>The hydrologists can use models to estimate the frequency and severity of floods at our location, based on assumptions about land cover change and urban development that control runoff and imperviousness, and simulations of future climate change that controls the frequency, intensity, and duration of future rainfall events.</i></p>
<p>(6b.) What questions should you ask in the meeting?</p>	<p><i>a) In your expert opinion, is this a good place to build a 50 year factory project?  b) If we build, what actions should we take when we build the factory to prevent flood damage?  c) Can you provide us with adequate warning of imminent floods so we can take action to prevent damage?  d) How could floods impact transportation, power, and other needs of our factory?  e) What kind of insurance do we need, and can we save money on the premiums by taking actions to prevent damage?</i></p>
<p>(6c.) What might happen to Compumarket if the company does not consider hydrologic risk in its business plans?</p>	<p><i>A flood could destroy the factory, or shut down operations for a significant period of time, costing the business a large amount of money in direct losses and lost sales and reputation. Insurance would cover some of the direct losses but could not compensate the business for all the impacts.</i></p>
<p>(7) Explain the importance of streamflow and rainfall gages for flood management.</p>	<p><i>Hydrologists need streamflow and rainfall data in order to forecast the severity of current flood events downstream of a rainfall, and to develop accurate flood models to predict the impacts of flooding.</i></p>
<p>(8) What is a mathematical flood model, and why is it important?</p>	<p><i>Mathematical models of floods allow us to predict the intensity and frequency of flooding in a given location, so that we can take steps to prevent damage from floods at that location, such as a city.</i></p>

1 Table 2. Examples of conceptual mastery for each of nine outcomes.

Outcome: Physical Concepts of Flooding	Examples
1. <u>Recognize that urbanization can increase impervious land cover and increase runoff and flooding</u> <u>Effects of Urbanization and Impervious Cover on Flooding</u>	-If urbanization decreases infiltration of rainwater, it may increase flooding
2. <u>Explain that higher rainfall duration and intensity, combined with high soil moisture or impervious land cover, causes flooding</u> <u>Physical Causes of Flood Frequency and Intensity</u>	-Higher rainfall duration and intensity combined with high soil moisture and imperviousness <u>leads to floods</u>
3. <u>Uses correctly in context the vocabulary of land cover change, rainfall and runoff processes, and flood discharge and stage</u> <u>Conceptual Vocabulary Applied in Context</u>	-The peak of the flood hydrograph exceeds the channel's discharge capacity
4. <u>Explains the effect of decadal timescale LULC Change on Flooding</u> <u>Effect of Decadal LULC Change on Flooding</u>	-Permanent conversion of wetlands and forests to farm field and cities can contribute to flooding
5. <u>Recognizes that Maximum Discharge Rates Determine Flooding (hydrographs)</u> <u>Maximum Discharge Rates Determine Flooding (hydrographs)</u>	-Higher discharge causes a higher flood peak, which can spill into floodplains causing flooding
6. <u>Explains the tools used in Flood Management</u> <u>Impacts of Flood Management</u>	-Stormwater detention basins can reduce peak discharges and reduce flooding
Outcome: Professional Role of Hydrologists	
7. <u>Identifies Flood Management Agency Roles &amp; Responsibilities</u> <u>Agency Roles &amp; Responsibilities</u>	-The U.S. Geological Survey monitors stream flows during floods
8. <u>Recognizes the value of Geoscience Knowledge for Flood Management</u> <u>Value of Geoscience Knowledge</u>	-Climate change can alter the frequency and intensity of rainfall, possibly increasing flooding
9. <u>Explains the utility of Mathematical Flood Models</u> <u>Utility of Mathematical Flood Models</u>	-A detailed hydrology model can predict the effect of land use and climate change on flooding

2

3



1 Table 3. Descriptive and Inferential Statistics for all analyses.

Learning Outcomes	DMDGC				DMDGC				F-value <sup>2</sup>	Effect size ( $\eta^2_p$ )		
	PP Pretest	Pretest	PP Posttest <sup>1</sup>	Posttest <sup>1</sup>	Mean	SD	Mean	SD				
Dependent Measure	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Group	Covariate	Group	Covariate
<u>1. Recognize that urbanization can increase impervious land cover and increase runoff and flooding</u> <sup>4</sup> . Effects of Urbanization and Impervious Cover on Flooding	.95	.47	1.21	.52	1.55	0.42	2.12	0.42	37.19**	14.47**	0.30	0.15
<u>2. Explain that higher rainfall duration and intensity, combined with high soil moisture or impervious land cover, causes flooding</u> <sup>2</sup> . Physical Causes of Flood Frequency and Intensity	1.09	.64	1.37	.56	2.11	0.45	2.37	0.43	7.05*	21.94**	0.08	0.21
<u>3. Uses correctly in context the vocabulary of land cover change, rainfall and runoff processes, and flood discharge</u>	.97	.61	1.14	.51	1.81	0.41	2.15	0.42	14.11**	29.95**	0.14	0.26

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and stage 3. Conceptual

Vocabulary Applied in Context

4. Explains the effect of

decadal timescale LULC

Change on Flooding 4. Effect of    .72    .88    .60    .72    2.33    0.93    2.28    0.93    0.06    0.77    0    0.01  
Decadal LULC Change on  
Flooding

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5. Recognizes that Maximum

Discharge Rates Determine

Flooding (hydrographs) 5.    .77    .69    .94    .63    1.98    0.66    2.32    0.68    5.15\*    9.27\*\*    0.06    0.10  
Maximum Discharge Rates  
Determine Flooding

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6. Explains the tools used in

Flood Management 6. Impacts    1.05    .59    1.37    .56    2.11    0.44    2.34    0.43    5.70\*    23.34\*\*    0.06    0.22  
of Flood Management

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7. Identifies Flood Management

Agency Roles &  
Responsibilities 7. Agency  
Roles and Responsibilities

8. Recognizes the value of  
Geoscience Knowledge for  
Flood Management 8. Value of  
Geoscience Knowledge

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9. Explains the utility of

Mathematical Flood Models<sup>9</sup>

Utility of Mathematical Flood Models

Models

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PP-Paper and Pencil Group, DMDGC-Data and Modeling Driven Geoscience Cybereducation Group

<sup>1</sup>adjusted based on covariate analysis

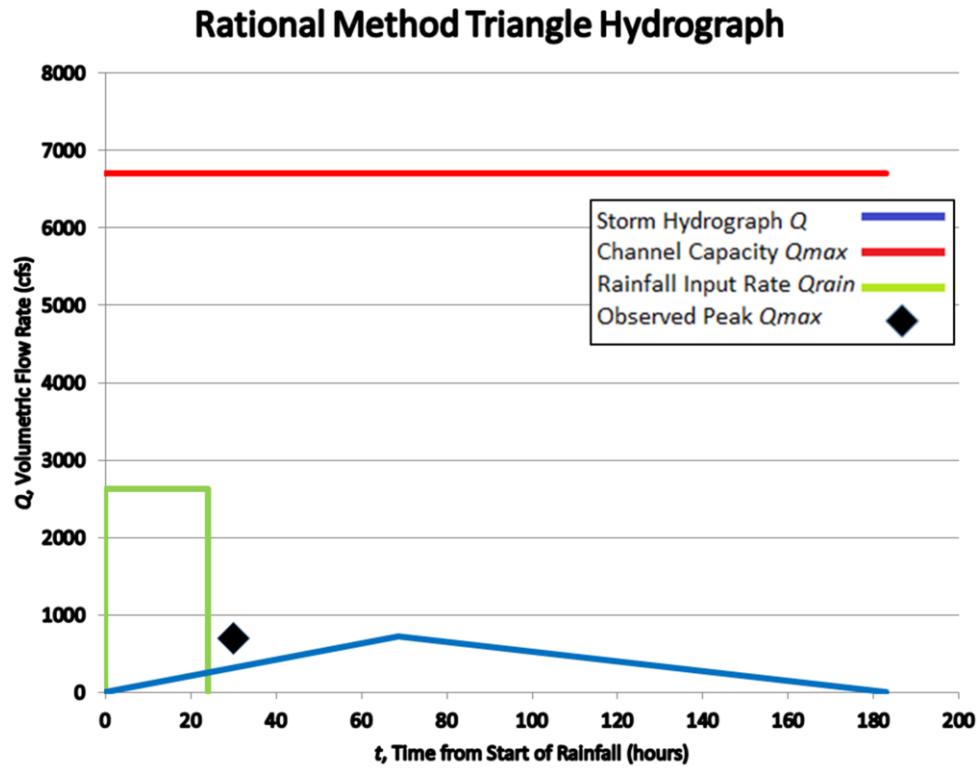
<sup>2</sup>  $df=(1, 85)$ ; critical  $F$ -value for  $p < 0.05$  is  $F > 3.95$

\* $p < .05$ , \*\* $p < .01$

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Figure 1. Illustration of the visualization produced by the DMDGC module. The Rational Method and a triangular Synthetic Unit Hydrograph are applied to model a rainstorm's streamflow hydrograph based on a rainfall input and watershed parameters, and this is visually compared with a calculated flow channel capacity to determine whether a flood will occur during a specified design storm event. The model can be calibrated such that the timing and magnitude of the observed flood peak (black diamond) matches the modeled streamflow hydrograph (blue triangle). Adapted with permission from Ruddell and Schiesser (2012).

1

		Pre/Post Assessment Instrument Sub-question Number										
		1a	1b	2	3	4	5	6a	6b	6c	7	8
Physical Concept Outcomes	1. Recognize that urbanization can increase impervious land cover and increase runoff and flooding		2	3	2			3	3	1	1	3
	2. Explain that higher rainfall duration and intensity, combined with high soil moisture or impervious land cover, causes flooding		2	3	2			3	2	2	2	3
	3. Uses correctly in context the vocabulary of land cover change, rainfall and runoff processes, and flood discharge and stage		2	3	2	2	1	0	3	2	2	2
	4. Explains the effect of decadal timescale LULC Change on Flooding			3								
	5. Recognizes that Maximum Discharge Rates Determine Flooding (hydrographs)			3							3	3
	6. Explains the tools used in Flood Management		2	3	2			3	2	2	3	1
Role	7. Identifies Flood Management Agency Roles & Responsibilities				2	2	1	0	3	2	2	3
	8. Recognizes the value of Geoscience Knowledge for Flood Management		2		2	2	1	0	3	2	2	3
	9. Explains the utility of Mathematical Flood Models		2	3		2	1	0	3	2	1	3
		Pre/Post Assessment Instrument Sub-Question Number										
		1a	1b	2	3	4	5	6a	6b	6c	7	8
Physical Concept Outcomes	1 Effects of Urbanization and Impervious Cover on Flooding	2	3	2				3	3	1	1	3
	2 Physical Causes of Flood Frequency and Intensity	2	3	2				3	2	2	2	3
	3 Conceptual Vocabulary Applied in Context	2	3	2	2	1	0	3	2	2	2	3
	4 Effect of Decadal LULC Change on Flooding		3									
Professional Role Outcomes	5 Maximum Discharge Rates Determine Flooding (hydrographs)		3								3	3
	6 Impacts of Flood Management	2	3	2				3	2	2	3	1
	7 Agency Roles & Responsibilities			2	2	1	0	3	2	2	2	3
Professional Role Outcomes	8 Value of Geoscience Knowledge	2		2	2	1	0	3	2	2	3	3
	9 Utility of Mathematical Flood Models	2	3		2	1	0	3	2	1	3	3

2

3 Figure 2. Example of a completed assessment matrix mapping learning outcome rubrics to  
 4 instrument question responses. This example student gave relevant responses to all questions  
 5 (i.e. no “0” ratings), and the matrix generally indicates an “Apprentice” level of conceptual  
 6 mastery.

7

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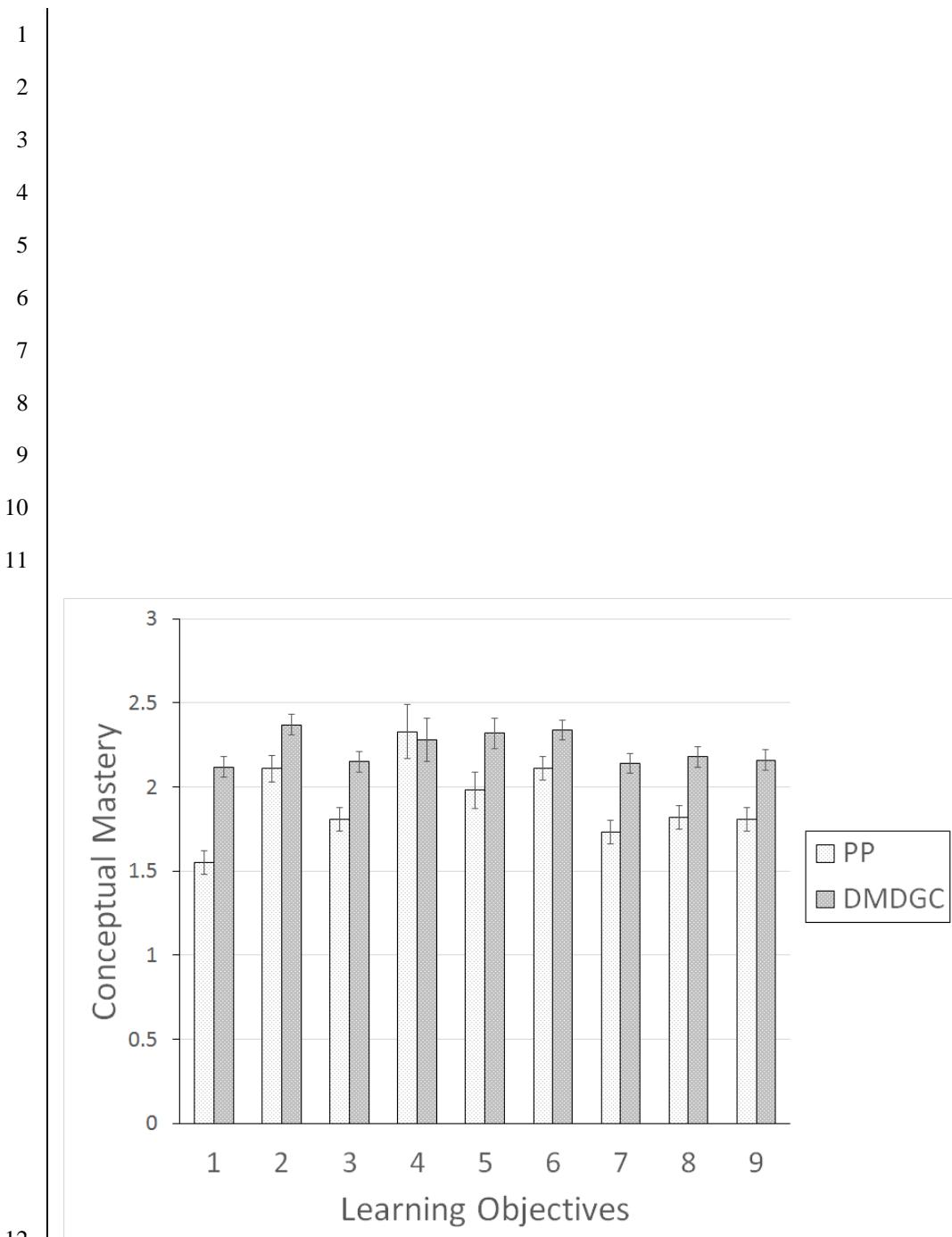


Figure 3. Conceptual mastery scores for each learning objective by group. Error bars represent the standard error of the mean. 1-Recognize that urbanization can increase

1 impervious land cover and increase runoff and flooding, 2-Explain that higher rainfall  
2 duration and intensity, combined with high soil moisture or impervious land cover, causes  
3 flooding, 3-Uses correctly in context the vocabulary of land cover change, rainfall and runoff  
4 processes, and flood discharge and stage, 4-Explains the effect of decadal timescale LULC  
5 Change on Flooding, 5-Recognizes that Maximum Discharge Rates Determine Flooding  
6 (hydrographs), 6-Explains the tools used in Flood Management, 7-Identifies Flood  
7 Management Agency Roles & Responsibilities, 8-Recognizes the value of Geoscience  
8 Knowledge for Flood Management, 9-Explains the utility of Mathematical Flood Models