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Effect of Integrating Hydrologic Scaling Concepts on Students Learning and Decision Making Experiences

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ABSTRACT

Proper understanding of scaling and large-scale hydrologic processes is often not explicitly incorporated in the teaching curriculum. This makes it difficult for students to connect the effect of small scale processes and properties (like soil texture and structure, aggregation, shrinkage, and cracking) on large scale hydrologic responses (like watershed runoff). An instructional module that introduces the concept of process-based scaling, as the framework to connect hydrologic processes and properties at different scales, was developed and evaluated. This paper examines how incorporating the concept of scaling into student curriculum impacts students' learning and decision making capabilities. It presents the evaluation of this module in an undergraduate environmental and natural resources engineering course. Evaluation results supported the hypothesis that introducing the concept of scaling and its application (using computer models) into undergraduate engineering courses enhanced students' learning and decision making skills. Students' levels of confidence in their knowledge of hydrologic systems also increased after the introduction of the scaling concept and following computer modeling exercises.

Keywords: Enhanced student learning, decision making, hydrology education, scaling.

1. INTRODUCTION

Hydrologic systems are mixtures of interacting processes that cut across various spatial and temporal scales. One of the most complex research challenges identified in the field of hydrology is the problem of scale (Gupta et al., 2000, Beven, 2001, Miller and Gray, 2002, Soulsby et al., 2002, Miller and Gray, 2008, Tartakovsky and Winter, 2008). From molecular to continental in spatial scales and from picoseconds to centuries in temporal scales, fundamental knowledge gaps in understanding hydrologic systems present major challenges for researchers and educators.

In academia, courses usually teach hydrologic principles at different scales. For example, basic science courses introduce concepts (such as atomic interaction, colloid theory, diffuse double layer, van der Waals attraction, and Navier-Stokes' flow equation) at the *particle* scale hoping that they will form a foundation for students' understanding of environmental systems. Soil physics courses, on the other hand, introduce concepts developed at the *laboratory* scale like soil bulk density, soil texture, structure, and organic content knowing that this knowledge is necessary for understanding soil-water interaction. Other courses introduce concepts and processes at the *field* scale including shrinkage and swelling, cracking, and heterogeneity. At the *watershed* scale, courses introduce concepts such as runoff prediction with the assumption that students are aware of the various related soil properties and interactions. Then, policy courses address issues like water allocation and best management practices at the *watershed* or *basin* scales assuming students' prior knowledge of smaller scale relevant processes as prerequisite.

What is lacking is a method or framework that establishes the connection between different processes at different scales taken from different courses. Although many instructors touch on scaling implicitly in their courses (by explaining the connection between the concepts they introduce and other concepts from close scales), students remain in need of a general scaling framework that helps them connect the different pieces of the puzzle (in this case, the multi-scale hydrologic principles puzzle). This framework is referred to as process-based scaling in this paper. For example, it is because of how clay particle interact at the particle scale that they have different shrinkage and swelling properties at the laboratory scale, which translates into the development of cracks and preferential flow at the field scale, thus affecting runoff prediction at the watershed scale.

Due to the absence of scaling from undergraduate and graduate education, Raia (2005) stressed the need for students "to undergo a fundamental shift of paradigm: from a linear causal thinking approach to a systems thinking approach" to account for the complexity and multiscale nature of environmental systems. Manduca et al. (2008) found a need to shift modern geoscience education to a more quantitative rather than qualitative field. Dickerson et al.

(2005) assessed student knowledge of scale in groundwater systems and indicated that many students hold an "inappropriate conception of hydrogeologic principles" due to incomplete understanding of issues of scale, thus calling for particular attention to scaling in teaching hydrogeologic principles.

Different methods of instruction have been used in explaining fundamental hydrologic concepts ranging from field observations and laboratory testing (Trop et al., 2000, Nichols et al., 2003) to computer simulation models (Mohtar and Engel, 2000, Gunn et al., 2002, Li and Liu, 2004, Macfarlane et al., 2006). We believe that computer models offer unique tools for understanding and integrating the multi-scale hydrologic processes where real observations and field monitoring fail due to the prohibitive time and cost required. Hydrologic systems are highly complex presenting special challenges especially for educators helping students learn about them and/or their components (Ex.: conceptualization and computation). Students must develop a good understanding of these hydrologic systems if they are to apply their discipline-based knowledge effectively to make educated and responsible policy-decisions based on fundamental understanding of the interactions between the multi-scale processes involved in their hydrologic problem. Given the complexity of the scaling problem (as described by NRC, 1999; Gupta et al., 2000; Miller and Gray, 2002; Miller and Gray, 2008 and others), and the urgency and necessity for the problem to be included in student curricula, new delivery methods and techniques to educate students about the various scales of natural resources and water quality systems are needed. Additionally, a system that allows students to simulate the hydrologic response or impact of their decisions at the local and large scale should improve their ability to make such decisions.

This paper presents a flexible educational module on multi-scale hydrology and provides results from an evaluation methodology to show improvements in students' knowledge and decision making skills. The hypothesis tested in this research was that student self assessment, knowledge, decision making skills and level of confidence in dealing with hydrologic systems can be improved by understanding the concept of scaling through appropriate lecture material and access to suitable hydrologic models. The module provides learners and educators in the interdisciplinary field of environmental and natural resources science and engineering with instructional material, case studies, and problems that enhance student learning of complex hydrologic systems and their decision making skills. These materials are interactive and Web-accessible (http://cobweb.ecn.purdue.edu/~mohtar/ASABE08workshop.htm). The Web-based modeling module was designed to enhance student learning and decision making by allowing students to focus their learning efforts on understanding the natural resource systems being simulated rather than on how to use the models. By doing so, students learn about the processes and the interactions of these processes.

2. METHODOLOGY

2.1 Goals and Objectives

The educational module was developed to address the following objectives: (1) improving the quality of education and instructional capability in the multidisciplinary field of hydrology; (2) assisting faculty preparation and enhancement for teaching scaling in hydrology; and (3) improving student learning and decision-making skills within the realm of complex hydrologic systems.

Upon successful completion of the module, students should gain fundamental understanding of the following:

1. How the temporal and spatial scaling of hydrologic processes affects environmental systems. This includes issues of scale within the soil column and at field scales through the introduction of the concept of pedostructure in hydrology (Braudeau and Mohtar, 2006; Braudeau and Mohtar 2004; Braudeau et al., 2004a; Braudeau et al., 2004b). They also include issues of scale at the field to watershed scales (Ex.: Blöschl and Sivapalan, 1995, Wallender and Grismer, 2002).
2. How the hydrologic cycle is affected by variability in precipitation, evapotranspiration (ET), landuse, and soil type.
3. How to simulate hydrologic responses using select hydrologic models representing different scales, including: (1) Kamel®, a computer hydrology model that incorporates the pedostructure scaling concept for field sites; and (2) a web based version of the WEPP® soil erosion model (http://milford.nserl.purdue.edu/wepp/abe325.php and http://topsoil.nserl.purdue.edu/nserl-web/weppmain/wepp.html) that simulates hydrology and erosion on hillslopes.

Given the interdisciplinary nature of the topic and the wide range of departments and disciplines involved in teaching hydrologic processes, this module was constructed to be flexible enough to accommodate different time allocations (varying from a single 50-minute lecture to one- and two-week lecture series coupled with hands-on computer labs), academic levels (undergraduate and graduate), and backgrounds (forestry, agricultural engineering, hydrology, agronomy, and others).

2.2 Evaluation Procedure

The complexities of large-scale hydrologic systems do not allow students or instructors to conduct quantitative, watershed-scale learning exercise within the classroom without the use of modeling tools. Many of these tools require complicated and time-consuming procedures to sort and organize input data, as well as interpret and visualize simulation results. Unfortunately, these constraints make the use of most research grade modeling tools by students difficult, if not impossible, without significant additional instruction and oversight. Therefore, it is extremely difficult to have a “control group” of students without the development of interfaces that hide the complexity of the problem and provide them with step-by-step procedures and annotations to help learn the program and understand associated issues. This investigation attempted to minimize the time and energy that students need to invest in working with the computer model while solving a case study, and optimize students' time allocation to achieve the learning goals.

In light of the above constraints, the outcome-based evaluation procedure developed by Mohtar et al. (2007) was adopted to measure the effectiveness of introducing of scaling and using hydrologic models on enhancing students' learning and decision making capabilities. This procedure is based on the understanding of three basic organizational levels, namely: developers, instructors or evaluators, and learners (Mohtar et al., 2007). Figure 1 outlines the necessary steps for an effective interactive learning process.

The educational module was evaluated twice over a period of two years (Figures 2 and 3). In both evaluations, students were asked to complete a pretest at the beginning of the first lecture

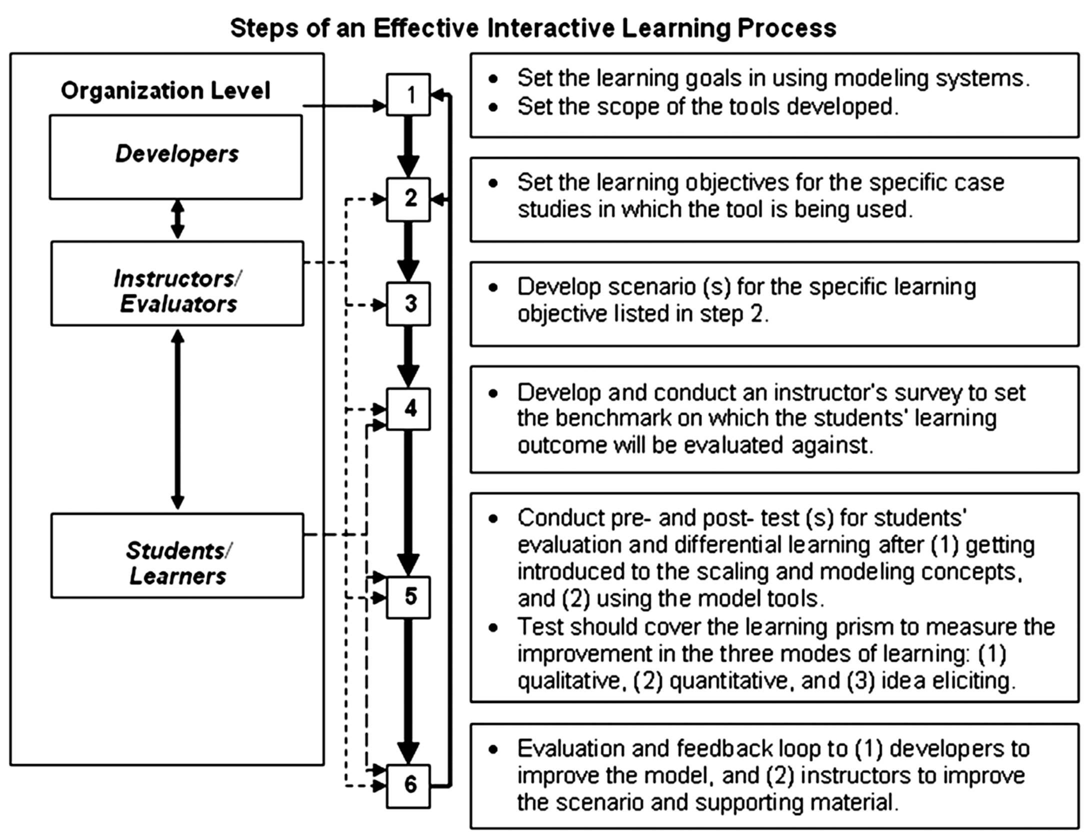

Figure 1: Steps for an effective interactive learning process (Adopted from Mohtar et al., 2007).

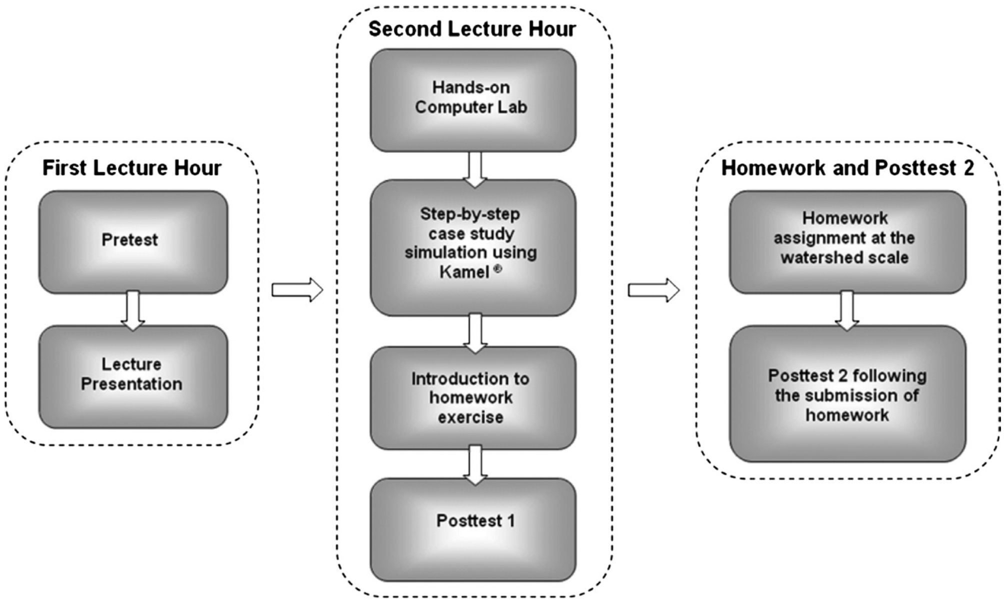

Figure 2: Schematic of the learning module evaluation procedure used for the first evaluation, in Fall 2006–2007.

to obtain a baseline of their knowledge of hydrologic/water quality systems within the emphasis areas of the modeling tools that are used in the module. This assessment was followed by lecture-type presentations that explained and introduced the concept of scaling in hydrology, hydrologic processes and their interactions, the pedostructure approach, and the effect of spatial and temporal variability on hydrologic response. Students were then asked to complete a series of hands-on computer laboratory experiences using the Kamel® and/or WEPP® models to solve case studies at the field scale. Students then completed a posttest (same as pretest) to evaluate improvement in student learning and decision making skills and were then assigned a homework based on a watershed scale case study. The posttest was administered a second time (posttest 2) after the completion of the homework assignment (due one week after the end of the module) in order to measure any additional improvements.

2.3 Evaluation Constructs and Instruments

Four evaluation constructs were used in this study: enhanced learning, decision making, self assessment of students' ability to better understand hydrologic systems, and level of confidence. Those constructs were assessed using three instruments: (1) self assessment questions; (2) enhanced learning and decision making questions; and (3) students' level of confidence in answering those questions.

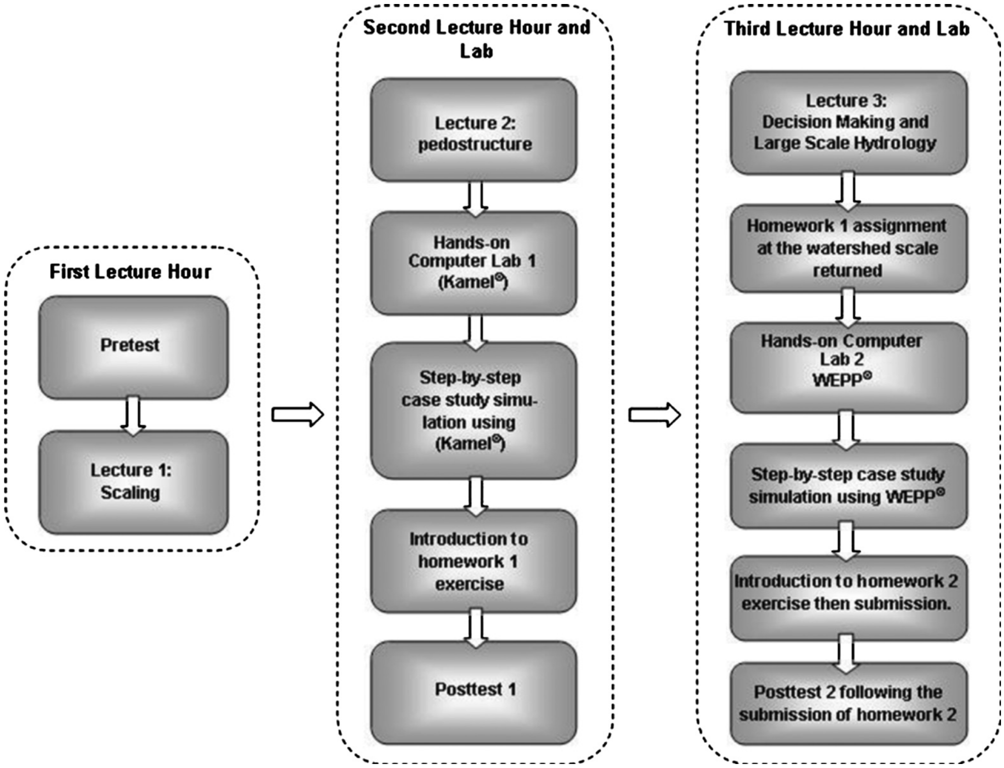

Figure 3: Schematic of the revised learning module evaluation procedure used for the second evaluation, in Fall 2007–2008.

Enhanced learning was observed in terms of the increase in the understanding of hydrologic systems following the introduction of the scaling concept. It was assessed with eleven general knowledge questions to measure the improvement in students' understanding of scaling in specific as well as hydrologic systems and responses in general (Appendix 1). Those questions were mainly about hydrologic systems whose answers required (or became clearer with) knowledge of scaling.

Decision making was observed as the ability to apply the knowledge gained to evaluate simple alternatives and select the best among them to solve a simple group of problems. Decision making, especially with the complexity of large-scale hydrologic systems, requires a special set of skills and knowledge. Enhancing such skills requires students to be explicitly aware of: (1) necessary content and knowledge and (2) the decision making process. In fact, becoming aware of the content forms the foundation to be able to apply, synthesize, evaluate and judge the problem at hand and to come out with the best decision from the realm of possible solutions. In our study, we focused on (1) providing the foundational knowledge required for making good decisions in this complex environment and (2) discussing the decision making process that must account for all the multi-scale components and processes within the hydrologic system. In the pretest and posttests, questions were not necessarily designed to evaluate students on advanced level decision making skills as this would be difficult to change in the time frame in which this module was delivered. However, six questions were designed to assess if students could make use of the information learned to make somewhat simple decisions about some basic environmental problems. The improvement in students' performance support our assertion that the module enhanced their foundational knowledge and increased their sense of the decision making process.

Self assessment was observed as students' self assessment of their ability to better understand hydrologic systems at various scales as well as the importance of scaling as a framework to improve their knowledge and abilities. It was assessed by seven self assessment statements such as *"I understand the hydrologic process at the small field"* and *"I understand the hydrologic process at the watershed level"* to measure students' appreciation and interest in hydrologic systems and issues of scale. In each assessment, students were asked to rate their opinions to each of the seven statements on a scale of 1 to 5 (from "strongly disagree" to "strongly agree") thus allowing for the measurement of change in self assessment following the module instruction. The internal consistency reliability (i.e., Cronbach's alpha) of the scale was 0.95.

Level of confidence (LOC) was observed as students' self assessment of how confident they were answering each of the 17 questions related to enhanced learning and decision making. A ranking for level of confidence was added next to each of the test questions to measure (on a scale of 1 to 5) students' comfort level (confidence) in answering the questions in the test. Coupling the results of this new construct/instrument with the test scores (from enhanced learning and decision making) provided valuable information on the effectiveness of the educational module. For example, if LOC increased while the performance in answering the questions decreased, then this was an indication that the module may have problems with oversimplifying the concept. Also, if LOC decreased while the performance in answering the questions increased, then this is an indication that the module may be confusing students on some issues. The target is an increase in both: the performance and LOC, which would support that the concept of scaling has improved students' understanding and made their confidence higher.

In general, Bloom's (1956) taxonomy of the cognitive domain guided test construction to reflect a focus on higher-order thinking skills (e.g., analysis, synthesis, and evaluation), especially as it related to the decision making questions. Content validity was assessed by course instructors in accordance with Standards of Educational and Psychological Testing (AERA, APA, & NCME, 1999). A table of specifications (i.e., a test blueprint) was developed by the content experts on the research team. This allowed for the concepts and number of items required to assess these concepts to be clear and appropriate given the time constraints of testing and the level of student knowledge. That is, the process allowed the team to align the content measuring each construct to the items (type and level of difficulty) to be used. This is a typical first step in instrument development to assist with score validity. After two rounds of testing the instrument with students (N = 19 for Year 1 and 18 for Year 2), some items were identified as problematic through an empirical item analysis. The students in this tryout phases were small but were representative of the target population. Specifically, a few items were too difficult (proportion passing $< 10\%$) or too easy (proportion passing $> 95\%$) to be useful. Upon review of the content of the items by the panel of experts, adjustments were made to item wording, the distractors, and in some instances the entire item was replaced.

2.4 Participants' Background

The influence of introducing the concept of scaling and providing hydrologic modeling case studies and exercises was evaluated within two consecutive sessions of the Junior level Soil and Water Conservation Engineering course at Purdue University (ABE 325) through a static group pretest-posttest design. This course was selected because it is the main course for the environmental option in the Department of Agricultural and Biological Engineering (ABE) and is designed and taught by one of the authors. As a prerequisite for the course, students have to take an introductory course in soil science and a course in hydraulics (fluid mechanics). Participating students represented the range of students expected to benefit from using these tools and materials. Typical class size is 18–25 students, with the majority being juniors and 88% of the participants being male.

2.5 Year 1 Module Feedback

After the first evaluation (Year 1: Fall semester of 2006), feedback was collected from students in informal focus groups to improve and refine the teaching materials (Table 1). Students and instructors recommended that more focus be given to the functional relationships (links) across hydrologic scales in an attempt to show the relevance of small scale (particle and laboratory) processes on hydrologic responses at larger scales (which is the scale at which decisions and policies are made). This link would trigger the students' interest in hydrologic processes across the various scales, and provide the connection between small- and large-scale processes and responses. The Module evaluation procedure in Year 1 (Figure 2) was revised (Figure 3) and evaluated in the following course session (Year 2: Fall semester of 2007) where considerable improvement in student learning and decision making skills was observed.

3. MODULE COMPONENTS

The educational module included different components including lecture materials, computer model user's manuals, computer lab exercises, homework, and evaluation tests. All materials are

Comment	Action or Change Implemented
Although every scale was addressed (particle, lab, horizon, field, watershed), the relationships between scales were missing. Students were interested in learning how a process at the micro scale would affect or induce a response at the macro scale.	Additional lecture slides were developed to specifically address these issues.
Students didn't see the relevance or importance of micro processes on macro scales where policies and decisions are made. This made them pay less attention to small scale processes.	
In Year 1, only Kamel® model was used but with computer lab after one lecture-hour. Students were concerned that the amount of lecture time was not enough to grasp the theory behind the model. The concepts of mobile and immobile water, micro and macro pores in the soil matrix, cracking network, as well as shrinkage and swelling were overwhelming or confusing.	Instead of one lecture that was allocated for the module in the first year, three lectures were given in the second year. The first targets the general concept of scaling, the second targets the pedostructure concept in specific, and the third target the effect of scaling on decision making.
Students wondered how models like Kamel® could help improve their decision making skills.	More time was allocated for discussion of the implication of soil properties on policy and decision making. Also, WEPP® model was introduced to assist students in observing the effect of soil type, slope, field size, and the introduction of a buffer strip on runoff and erosion generation.
The link between the lecture and the computer lab was missing and students observed them as two independent activities.	
Some of the questions in the tests contained technical jargon that was not clear to some of the students.	The pre- and post- tests were changed and more attention was paid to the language used.

Table 1: Summary of comments from feedback focus group following Year 1 Evaluation (N = 10).

available online and can be downloaded from: http://cobweb.ecn.purdue.edu/~mohtar/ASABE-08workshop.htm. The following is a brief description of those components following the order in which they are used for the module (Figures 2 and 3):

1. ***Pretest:*** The pretest was designed to assess students' initial level of knowledge about hydrologic processes and their ability to apply their knowledge to simple decision making problems. Questions involved both conceptual and intuitive subjects, with different levels of difficulty. Additionally, student's self assessment and LOC in their knowledge and decision-making skills were assessed. Both sets of these items were in the form of a Likert scale. Assessment of initial results (Year 1) showed that three questions in the pretest showed negative item discrimination values and contributed to lowering the overall posttest scores compared to the pretest scores. That is, the high scoring group was responding to these questions incorrectly more often compared to the low scoring group. This may have been due to the complexity and level of difficulty of those questions, and in particular the distractor responses. This information was used in the evaluation feedback loop. Those questions were improved, eliminated or replaced

as deemed necessary following the item analysis. The modified test (Year 2) included seventeen questions and students took approximately 12 minutes to complete the assessment (Appendix 1). Note that the assessment was meant to be brief and to be used in a variety of settings.

2. ***Lecture Presentations:*** Urbanization, deforestation, and agricultural managment practices are all examples of environmental issues that impact hydrologic processes. These processes span a wide range of scales and orders of magnitude in space and time. From pore spaces within the soil (less than a mm) to large watersheds (tens of thousands of square km), each scale is governed by its unique set of physical and chemical laws and is characterized by its own array of assumptions and boundary conditions. Proper understanding of scaling and hydrologic processes is not usually explicitly incorporated in the teaching curriculum. The lecture presentations were designed to explain the concept of scaling as it relates to hydrologic modeling. This includes the interaction between spatial and temporal scales as well as the sensitivity of the scale selection on the dominant processes and nature of the problem at hand. This was followed by an introduction to the pedostructure concept, which will be used as a case study along with a computer simulation tool (Kamel®) with the objective of further clarifying the concept of scaling and its effect on hydrologic modeling. The effect of spatial and temporal variability also was explained followed by an introduction to WEPP®, a computer model that simulates sediment and runoff at the hillslope scale.
3. **Hands-on Computer Labs:** Following lecture presentations, two computer labs were delivered. The first lab was assigned with the objective of increasing understanding of the effect of (1) soil variability; (2) evapotranspiration rate; and (3) rainfall intensity on hydrologic processes and responses. A presentation explaining the model (Kamel®) and showing qualitatively the short and long term effects of soil variability, evapotranspiration, and rainfall intensity was used to start the in-class lab session. Students then followed a step-by-step procedure to perform several model simulations of a field with selected sets of soil types, evapotranspiration rates, and rainfall intensities and durations. The second computer lab used the WEPP® model to demonstrate the effect of slope, landuse, and soil type on runoff and sediment response. Students used a series of defined hillslopes on which they could test the effect of introducing sand, grass, and/or impermeable buffer strips on runoff and soil loss. For both labs, handouts were provided (in addition to being accessable online) to cover the step-by-step procedures and the homework problem statements. This procedure familiarized the student with the models and provided a foundation from which the students could complete the assigned homework.
4. **Posttest 1:** Prior to leaving the in-class first computer lab session, students completed the first of two posttests (same questions as pretest). The objective of this posttest was to measure the

improvement in students' understanding and decision making skills after having been through the lecture presentations and the in-class labs using the field level computer models.

5. **Homework:** The homework exercises were designed to have the students apply their knowledge of process-based scaling (learned through the lectures and in-class lab exercises) to improve the understanding of the effects of soil texture and landuse variability, slope, evapotranspiration, and rainfall intensity at the field and watershed scales. The first homework (see Figure 3), which followed Lab 1, allowed students to simulate the differences in hydrologic response (using Kamel®) between two evapotranspiration patterns, two rainfall events, and four soil texture types. The second homework, which followed Lab 2, allowed students to further explore the effect of changes in slope type, slope length, soil type, landuse, and placement of a buffer strip, using the WEPP® model. The introduction of watershed scale processes using the Kamel® and WEPP® models (both designed for field scale) was done by developing simplified watersheds as a spatial aggregation of multiple fields with variable spatial and rainfall properties. The spatial and temporal variability of the soil, landuse, slope, evapotranspiration, and rainfall intensity were assumed to represent the transformation from the field scale to the watershed scale. This assumption ignores additional processes that take place at the watershed scale including channel and stream processes. Thus, students were asked to perform various simulations to represent fields within the watershed, which opened discussions into how those results might combine at the watershed scale.
6. **Posttest 2:** After completion of the homework, students were asked to complete the second posttest. This test was intended to measure changes in students' understanding of scaling concepts and decision making skills after completing all aspects of the teaching module.

4. RESULTS AND DISCUSSION

The combined students' performance in the enhanced learning and decision making questions were considered the main instrument to assess the effectiveness of the module. Self assessment and level of confidence also were considered in relationship to students' performance. Evaluations of Year 1 and Year 2 described in the following two sections show the improvement in students' knowledge and understanding.

4.1 Fall 2006 Evaluation (Year 1)

Year 1 evaluation results showed increased improvement in scores of pretest, posttest 1 and posttest 2. A summary of results obtained is provided in Table 2 and illustrates an increase in the

		Year 1		
Test	***Mean[1] (%)***	***Standard Deviation[1] (%)***	***Self assessment Score***	***Level of Confidence***
Pretest	69.6	13.3	3.29	3.77
Posttest 1	78.3	12.7	3.45	3.95
Posttest 2	84.7	13.9	3.68	4.06
		Year 2		
Test	***Mean[2] (%)***	***Standard Deviation (%)***	***Self assessment Score***	***Level of Confidence***
Pretest	53.3	11.5	3.45	3.17
Posttest 1	60.5	12.4	3.82	3.71
Posttest 2	62.4	13.7	4.12	3.67

[1]These scores are the outcome of analysis after removing results of three questions that gave negative item discrimination values. The real means including all questions for Year 1 are: 76.1 (pretest), 79.4 (posttest 1), and 77.7 (posttest 2).
[2]These scores are the outcome of the modified test in Year 2 with seventeen questions instead of thirteen in Year 1. Lower scores are the result of an increase in question difficulty and number rather than a change in student level from Year 1 to Year 2

Table 2: Summary of Year 1 and Year 2 Evaluation results.

mean score values from 69.6% in the pretest to 78.3% in the first posttest after students received the lecture and applied the computer model at the field scale. This score increased to 84.7% in the second posttest as students had more time and opportunites to apply the model at the watershed level. Similar trends were observed in the self assessment questions and level of confidence scores (Table 2). Dependent t-tests were used to judge the improvement and the associated effect sizes are reported. To assist in evaluating the magnitude of the differences in means, Cohen's d (Cohen, 1988) effect size (or standardized difference) also was computed, where 0.2, 0.5, and 0.8 are small, moderate, and large effects, respectively. The difference from pretest to posttest 1 was statistically significant ($t(22) = 2.30$, $p < 0.05$, $d = 0.48$). The difference from posttest 1 to posttest 2 was not significant ($t(19) = 1.79$, $p > 0.05$, $d = 0.46$). However, the moderate effect size in both cases suggests that there was a noteworthy improvement in performance. Note that data on three students were not available for the second analysis. Thus, lower statistical power for a smaller change could be one reason for the non-significant result from posttest 1 to posttest 2.

4.2 Fall 2007 Evaluation (Year 2)

Results of the t-test showed statistically significant improvements ($p < 0.05$) and large effects ($d > 0.80$) on students' self-assessment, learning, and level of confidence at addressing scaling related issues in Year 2. Table 3 summarizes the results of the d value of the t-test based on the evaluation of 18 students who attended the entire module and completed all assessments. For the test scores, the differences from pretest to posttest 1 were statistically significant ($t(18) = 2.37$, $p < 0.05$, $d = 0.60$). The difference from posttest 1 and posttest 2 was not significant ($t(18) = 0.51$, $p > 0.05$, $d = 0.15$).

	Self assessment Questions	*Knowledge (Learning & decision making combined)*	*Level of Confidence*
Pre test to post test 1	t (18) = 2.34 p = 0.0320 d = 0.62	t (18) = 2.37 p = 0.0296 d = 0.60	t (18) = 3.35 p = 0.0038 d = 0.77
Post test 1 to post test 2	t (18) = 1.59 p = 0.1304 d = 0.45	t (18) = 0.51 p = 0.6183 d = 0.15	t (18) = 0.06 p = 0.9519 d = 0.01
Pre test to post test 2	t (18) = 6.09 p = <0.0001 d = 1.40	t (18) = 3.20 p = 0.0053 d = 0.73	t (18) = 2.42 p = 0.0270 d = 0.6

$p < 0.05$ was used to indicate statistical significance

Table 3: Summary of Year 2 Evaluation results (Fall semester of 2007).

For the Year 2 evaluation (Fall semester of 2007), average scores (correct answers) increased from 53.3% on the pretest to 60.5% and 62.4% in the posttest 1 and posttest 2, respectively (Figure 4). This equates to approximately a 1.5 question improvement in correct answers. Average students' level of confidence also increased from 3.17 in the pretest (on a scale of 5) to 3.71 and a slight drop (3.67) in posttest 1 and posttest 2, respectively (Figure 5). However, the difference between 3.71 and 3.67 may merely reflect error and it is more likely that confidence remained stable. Moreover, students' confidence in scaling-related issues increased after taking the module. This was identified by the increase in scores in the self-assessment section. On a scale of one to five, students raised their assessment of their own ability to understand scaling related issues from 3.45 in the pretest to 3.82 and 4.12 in posttests 1 and 2, respectively (Figure 6).

Analysis of students' scores from the Pretests of Year 1 and Year 2 showed that the effect of scale interactions and governing processes at smaller scales on hydrologic responses at larger scales were not fully understood by students. Reasons for this may be attributed to the limited exposure to scientific classes that address small scale processes and link their contribution and effect to larger scale responses. Following the module, students became more aware of the connection between scales and the effect of micro processes on large scales.

5. SUMMARY AND CONCLUSION

An educational module that incorporates the concept of process-based scaling into students' curriculum was developed and has proven to positively impact students' learning and their decision making capabilities. An outcome based evaluation procedure was applied to measure its effectiveness.

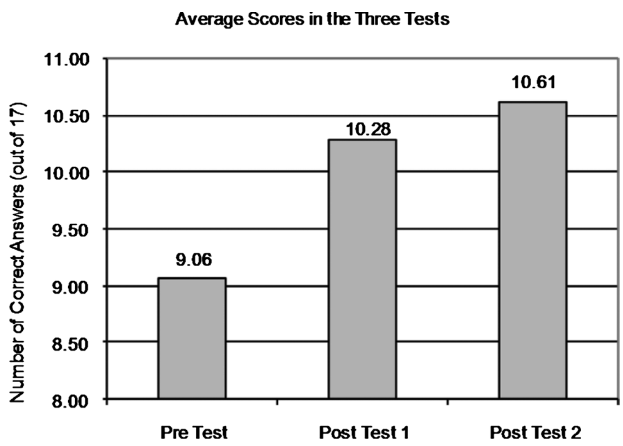

Figure 4: Average scores for the Year 2 evaluation (Fall semester of 2007).

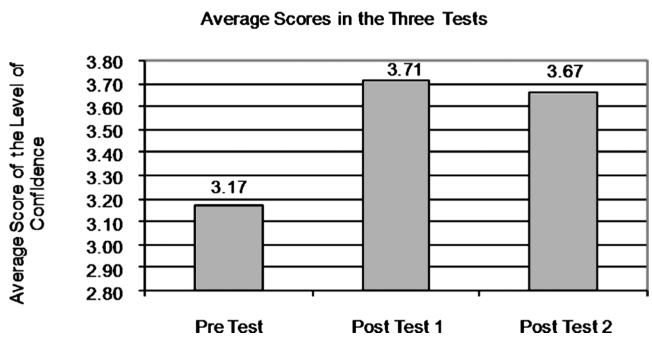

Figure 5: Average level of confidence scores for the Year 2 evaluation (Maximum score = 5, Fall semester of 2007).

Results of a two-stage evaluation process showed a significant improvement in students' learning and decision making skills (as defined in the methodology section). They also showed that the effect of interactions and governing processes at smaller scales to hydrologic responses at larger scales were not fully understood by students before taking the module. Students who complete the learning module may be more competent in and more prepared to deal with large-scale processes and scales. At the completion of the module, students are more aware of scaling effects and more appreciative of their contribution to large scale processes and effects.

The module included a combination of lectures, homework assignments, and computer scenarios. Given the interdisciplinary nature of the topic and the wide range of departments and disciplines

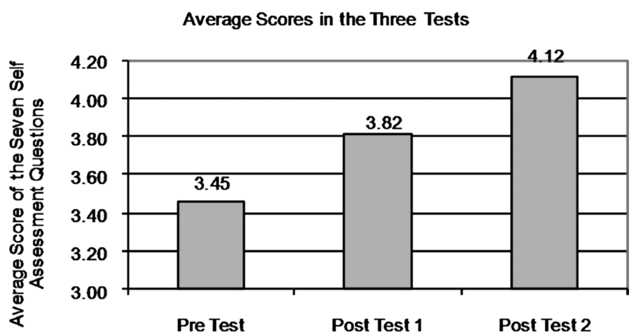

Figure 6: Average self-assessment, or "self assessment" questions, scores for the Year 2 evaluation (Maximum score = 5, Fall semester of 2007).

involved in teaching multi-scale hydrologic processes, the module is designed with the flexibility to accommodate different environmental disciplines and levels of interventions. Successful implementation of such programs should assist in enhancing student preparation for the future careers in environmental and natural resources engineering. The evidence provided in this project provides a foundation on which to build more evidence across program areas for the implementation of such curriculum programs. This project may serve as a model on which other such programs in various engineering areas can be constructed. Successful implementation of such programs can assist in enhancing student preparation for the future careers in environmental and natural resources engineering. Successful preparation of society's future engineering professionals is paramount given the role engineering plays in society.

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Appendix 1. Evaluation Test.

Name: ....

Please respond to the following statements by choosing a number between 1 and 5 that best reflects your opinion, with 5 being Strongly Agree and 1 being Strongly Disagree.	5 (Strongly Agree)	4	3	2	1 (Strongly Disagree)
I understand the hydrologic processes at the small field.					
I can make land/water – management decisions at the small field.					
I understand the hydrologic processes at the watershed level.					
I can make land/water – management decisions at the watershed level.					
I know the effect of scale on hydrologic processes.					
Understanding the effect of scale helps me make better hydrologic decisions.					
I know the problems associated with the averaging (assuming uniform properties of an area) technique.					

	Please answer with True or False. Also, check your level of confidence in answering the question, as follows:	Answer: True	Answer: False	Level of Confidence (High): 5	4	3	2	1 (Low)
1	An inch of rain produces the same amount of runoff from a 2-acre silt loam field if it falls for 2 or 4 hours.							
2	The hydrologic processes and physical interactions at the local scale (micro) are the same as those acting at the watershed scale (macro).							
3	Results obtained by experimentation in the lab can be directly applied to the field with no further adjustment.							
4	Preferential flow is a phenomenon that is driven by Darcy's law soil-water fluxes.							
5	Most of the soil-water chemical and biological processes take place at the field scale.							
6	The selection of Best Management Practices (BMPs) is concerned with watershed scale processes and may not require knowledge of local scale processes.							
7	The value/impact of a best management practice (BMP) at the watershed scale is the same irrespective of the practice location.							

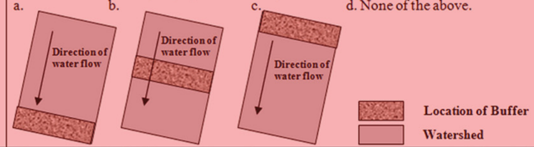
	Please circle the correct answer. Also, check your level of confidence in answering the question.	Level of Confidence (High): 5	4	3	2	1 (Low)
8	Spatial variability of soil texture (particle size, shape, and composition) plays a major role at ( ) scale in hydrologic systems. a. the watershed b. the aggregate c. the field d. all of the above					
9	Averaging of soil properties in a field having two soil types (1) sandy soil and (2) clayey soil provides an accurate understanding of its generalized hydrologic response a. this statement is true all the time b. this statement is false all the time c. averaging works only if we have more than three soil types d. none of the above					
10	The list ( ) correctly ranks the following scales from smallest (1) to largest (5): a. particle, core, aggregate, field, basin b. particle, aggregate, core, field, basin c. particle, aggregate, core, basin, field d. basin, core, aggregate, field, particle					
11	Channel Routing is an important process at the ( ) scale. a. particle b. watershed c. core d. field e. aggregate					

Assume you are an Environmental Engineer working with DNR. You are in charge of a watershed (currently with 5% residential areas), in a predominantly agricultural, high rainfall area. An earth dam to control runoff generated by the watershed rarely reaches 50% capacity under current landuse. Some technical problems / consultations that you might face are presented in the following list. Please place the correct number next to the solution you think is best.

	Problems	Answer (Solution)	Level of Confidence (High): 5	4	3	2	1 (Low)
12	Evaluate a new proposal to build 2 major additional residential complexes (change in landuse to 20% residential)						
13	Evaluate a new proposal to build 10 major additional residential complexes (dramatic change in landuse to 80% residential)						
14	Prepare over a period of 3-months a detailed hydrologic assessment of the watershed as requested by your boss						
15	You are asked to provide an initial assessment of hydrologic impact of some minor landuse changes						

	Solutions (not all solutions are used)
(1)	Look for averaged soil properties and representative rainfall data.
(2)	Re-evaluate the watershed zoning and housing permit policy
(3)	Analyze high resolution landuse and soil maps and weather records.
(4)	Assess Dam Capacity.
(5)	Refuse any change to the landuse.

	Assume a field in your watershed has simple geometry and uniform soil properties and topography that can be conceptualized into a rectangle with a fixed slope. The soil is clay and the field generates large runoffs that you want to control using a sand buffer strip. The soil strip will constitute around 5% of the total area of the field. Please circle the correct answer. Also, check your level of confidence in answering questions 16 and 17.	Level of Confidence: 5	4	3	2	1
16	Which location would you propose to locate your buffer strip? a. b. c. d. None of the above.					
17	If you analyze the field by averaging soil properties across the entire area, including the buffer strip, which scenario above (Question # 16) will provide a response that is closest to the average case? a. Option a: buffer is downstream of the field. b. Option b: buffer is in middle of the field. c. Option c: buffer is upstream of the field. d. Location of the buffer is irrelevant as long as the percentage of sand buffer area is fixed compared to the whole field.					



Self Assessment Questions | Enhanced Learning Questions | Decision Making Questions