Published January 4, 2018

Using Leaves as a Model for Teaching Watershed Concepts in Natural Resources Science and Engineering Programs

Aavudai Anandhi,* Yang Yang, and Michael Hubenthal

Abstract

This article examines the effects of using leaves, something most students see every day and have some familiarity with, as an analogy for the concept of watersheds in an undergraduate water resources engineering course. The ultimate goal of the leaf/watershed analogy and associated instruction is to increase students' understanding of hydrology principles, which in turn may facilitate better watershed management through increased public awareness, increased adoption of appropriate best management practices, and improved policy decisions. The assessment was performed with junior and senior undergraduate students enrolled in a Water Resource Engineering course. The assessment results showed that overall, students benefitted from the leaf analogy as a tool for learning watersheds. However, this effect varied depending on students' learning style preferences.

Core Ideas

- Watershed is an important concept in science and engineering of natural resources.
- Introducing watershed concept using a leaf that students see every day is novel.
- Using leaf analogy, watershed concept can be taught universally.

A *watershed* is a natural unit of land on which water from direct precipitation and snowmelt collects in a channel and flows downhill to a common outlet (Elshorbagy, 2005). The watershed is an important concept in engineering (e.g., civil, natural resources, water resources, ecological, and environmental) and sciences (e.g., geography, geology, ecology) because watersheds are more than just drainage areas in and around our communities. In engineering, they are the basis for the design of infrastructure and its management (Ruddell and Wagener, 2015). Watersheds are necessary because they provide many of us with our drinking water supply, support habitat for plants and animals, and provide us with recreational opportunities and aesthetic beauty to enjoy nature. It is the basic unit of all hydrologic analysis and designs and has three fundamental functions: (1) collection of water, (2) storage of various amounts of water for various durations, and (3) discharge of water as runoff (Elshorbagy, 2005).

However, the concept of watersheds can be challenging to teach in engineering courses for several reasons. First, like many human-defined, regional-scaled geologic features such as tectonic plates, a watershed is generally conceived at such a large spatial scale that makes it difficult for people to grasp (e.g., Libarkin, 2005). Second, the dynamic and stochastic nature of watersheds challenges teachers to teach and students to understand the concepts (Loucks et al., 2005). Understanding this nature and the uncertainties in the watersheds (e.g., incomplete process understanding) also requires systems thinking. That is, what happens at one point in the watershed can influence what we see in other parts. System thinking is a tool through which we develop a deeper understanding of the system's characteristics and behavior (Anandhi, 2017; Anandhi et al., 2016; Batzri et al., 2015). Third, students are often challenged by the landscape heterogeneity in watersheds, which requires an interdisciplinary understanding between hydrology, biogeochemistry, pedology, geomorphology, and ecology to understand catchment evolution and functioning. Predictions of hydrologic system response to natural and anthropogenic forcing are highly uncertain due to the heterogeneity of the land surface and subsurface. Landscape heterogeneity results in spatiotemporal

Published in Nat. Sci. Educ. 46:170020 (2017)
doi:10.4195/nse2017.09.0020
Received 1 Sept. 2017
Accepted 26 Oct. 2017
Available freely online through the author-supported open access option

A. Anandhi, Biological Systems Engineering, Florida Agricultural and Mechanical Univ., Tallahassee, FL 32307; Y. Yang, Dep. of Special Education, Counseling, and Student Affairs, College of Education, Kansas State Univ., Manhattan, KS 66506; M. Hubenthal, Education and Outreach Program, Incorporated Research Institutions for Seismology (IRIS), Washington, DC 20005. *Corresponding author (anandhi@famu.edu).

Abbreviations: FAR, Focus-Action-Reflection; ILS, Index of Learning Styles; SPSS, Statistical Package for Social Science.

variability of hydrological states and fluxes, scale-dependent flow and transport properties, and incomplete process understanding. Comprehending this level of complexity and ways to conceptualize watersheds requires higher-order, reflective, metacognitive, and critical thinking skills (Ngambeki et al., 2012). Finally, a purely theoretical coverage of watershed topics can be unexciting to today's engineering students who are better inspired by hands-on teaching methods (Aghakouchak and Habib, 2010). Due to these challenges, engineering and science students struggle with the initial idea of watersheds, which, in turn, make subsequent lessons dependent on the watershed concept more difficult.

The primary objective of this work was to develop and test the efficacy of model-based instruction, using something students see every day such as a leaf, to introduce the concepts of watersheds. Participants were junior and senior undergraduate students attending a large Midwestern land-grant research university. All participants were enrolled in a Water Resource Engineering course taught by the lead author.

RATIONALE

Given the challenges of teaching about watersheds, in this study instructors drew on the literature of analog and concept mapping to construct watershed lessons. In science instruction, models function through the creation of analogies (Leatherdale, 1974) where "objects, symbols, and relationships (the analog) represent another system (the target) in a different medium" (Gilbert and Ireton, 2003). Models may exist in many different formats including, but not limited to, physical or concrete models such as scale models, functional models that behave or operate like the target they represent, or mathematical models, including equations and graphs. The use of analogies in the teaching of science and engineering education enables learners to construct their own personal conceptual understanding by comparing something familiar—based on their own past knowledge, experiences, and preferences—with something unfamiliar (Harrison and Treagust, 2006).

The process of constructing linkages between the target and the analog is called *concept mapping* (Novak and Cañas, 2008). The underlying assumption of concept mapping is that learners' existing knowledge system is like a conceptual map; as learners relate or assimilate the new knowledge/concepts into their existing knowledge system, they are actively building a conceptual relationship and the new learning becomes meaningful (Novak and Cañas, 2008). Using concept mapping to construct models has been found to be very useful in scientific inquiry (Ebenezer et al., 2011). Furthermore, students who actively seek the underlying structures (of study materials) that made sense to them were found to have better academic performance (Yang and Bliss, 2014). Well-selected analogies also have an added benefit of having the power to interest and excite student learning (Harrison and Treagust, 2006).

Analogies have instructional value, but it is important to recognize they can also be "two-edged swords" as the learning they generate is often be accompanied by alternative ideas or misconceptions (Harrison and Treagust, 2006). This occurs because learners are unlikely to have the background experiences and knowledge on which to view the model from the same perspective as the instructor (Harrison and Treagust, 2006). Thus, it is not surprising that research has shown that the teachers' ability to influence student thinking around the similarities and differences of the analogy and target are an influential factor in the efficacy of a model/analogy in the classroom (Harrison and Treagust, 2000; Venville and Dawson, 2004).

Additionally, students often process and interact with information in different ways, which educators consider different learning styles. *Learning styles* are defined as "characteristic cognitive, affective, and psychological behaviors that serve as relatively stable indicators of how learners perceive, interact with, and respond to the learning environment" (Keefe, 1979). Many studies have found that students with different learning styles not only react differently to various forms of instruction, but also perform differently depending on the nature of the course/discipline. For example, students who prefer a linear and more structured learning style have more favorable views of lectures. Intuitiors perform better than sensors in theoretical engineering courses that focus on problem-solving abilities (Felder et al., 2002; Spurlin et al., 2003). Therefore, understanding students' learning styles is critical, as it can potentially allow instructors to tailor the way(s) they teach to make it more balanced and effective. Several theoretical models have been developed to examine learning styles, such as Kolb's Learning Styles and Experiential Learning Model (Kolb, 1984), the Myers-Briggs Type Indicator (Myers, 1978), and the Felder-Silverman Learning Style Model (Felder and Silverman, 1988). Although these models have addressed some overlapping aspects of learning styles, the Felder-Silverman Learning Style Model focuses on engineering students and intends to capture the key features of learning styles among engineering students in particular.

Leaf Analog Model

Watershed concepts are generally taught in a purely theoretical coverage of concepts using lectures, using a conceptual hydrological model (Aghakouchak and Habib, 2010; AghaKouchak et al., 2013), comparative analysis using conceptual models (Shaw and Walter, 2012), and conceptual mapping using driving question board (Rye et al., 2013). Each of these methods have their own advantages and disadvantages. We believe that introducing the concept of watersheds using something students see every day, a leaf, can be taught universally. Eudicot leaves generally have a number of physical and functional similarities that make them an ideal analog for the concept of a watershed. For example, both leaves and watersheds can be found in different shapes and sizes. The midrib and veins in the leaves can be analogous to the stream network in a watershed, while the lamina or leaf blade can be mapped to the watershed area.

Before implementing this analogy, the instructor consulted with six senior full professors (three engineering, two geography, and one plant sciences) to explore the content validity of using the leaf as an analog for the intended concepts of watersheds. All six expert reviewers felt that the leaf analog had merit and encouraged the idea of using the leaf analogy to teach the concepts of watersheds. At least three of these reviewers have since adopted the leaf analogy when teaching the concepts of watersheds in their own classes.

As previously mentioned, careful attention to the selection and use of models in science education is important. The Focus-Action-Reflection (FAR) Guide, was developed to assist educators in effectively developing and using analogies in instruction (Harrison and Coll, 2008). This approach serves as the foundation for the leaf analogy instruction and enable students to draw comparisons between a watershed and a leaf through in-class activities. In the first of this three-phase FAR approach, teachers are encouraged to "focus" or be mindful of the target concept complexity, prior student knowledge, and experience with the analog and make this information explicit to both the teacher and students. In the second phase, "action," students explore the analogical model (leaf), focusing in on both how it is and is not like the target (watersheds). In the final phase, "reflection," the instructor is encouraged to reflect on the clarity and usefulness of the analogy when mapping concepts between the target (watersheds) and the analog (leaf), and to re-focus on the previous phases as necessary.

Learning Objectives

The ultimate goal of the leaf–watershed analogy and associated instruction is to increase students' understanding of hydrology principles and watershed concepts. More specifically, students will be able to:

1. Define and draw diagrams of the important elements of a watershed, including watershed divide (watershed boundary), stream network, outlet, and direction of flow.
2. Describe the influence of geology and topography on the shape of the watershed divide and the pattern of the drainage network.
3. Draw diagrams and describe the watershed shapes and sizes.
4. Determine the topographic division of watershed (boundary) to delineate a watershed and describe the effect of topography on them.
5. Estimate and describe the distinguishing properties (characteristics) of the watershed.
6. Determine the relative size of streams (stream ordering) and differentiate first, second, and third order streams.

MATERIALS

This lesson requires leaves of multiple sizes and shapes for students to investigate. Students also need graph paper, plumb line, calculator, pencil, and an eraser for the activities. A document camera, so the instructor can project images leaves onto a screen while annotating them for comparison, would be ideal. However, if this is not possible, images, like the ones included in this article, can be used with a SMART board system.

Activities for the Learning Objectives

Completing all the activities as described below took approximately 3 hours. However, this could be adapted to as little as 30 minutes or as much as 5 hours, depending on the number of examples, activities, objectives, and students included. As designed, the instruction included individual work, small group discussions, and whole-class teacher led discussions.

Learning Objective 1: Define and draw diagrams of the important elements of a watershed.

Students were asked to bring their own leaves of multiple sizes and shapes to class for an introduction to watershed concepts. Students were divided into heterogeneous groups based on learning styles. Here, students made connections between what they saw on their leaves and their experiences with creeks and streams through an instructor-guided group discussion. Students identified a number of the watershed elements [watershed divide (watershed boundary), stream network, outlet, direction of flow] on their leaves and described their physical and functional similarities to streams and creeks. For example, the students compared midrib and veins in the leaves to the stream network, while the lamina or leaf blade can be mapped to the watershed area. Then the students were individually asked to draw these elements on one of their leaves and discuss the similarities and differences in their groups. Finally, Fig. 1 was shown and groups were asked to compare it with their drawings.

Learning Objective 2: Describe the influence of geology and topography on the shape of the watershed divide and the pattern of the drainage network.

This activity had three parts. In the first part, students identified different leaf margins (Fig. 1b). Students made connections between what they saw on the different leaf margins and the types of geology and topography that would create a similar watershed divide. In the second part, students identified different vein patterns and were asked to make connections between vein network and drainage types (e.g., dentritic, trellis, and radial). These were then related to geology and topography (Fig. 1c). In both parts, students applied their knowledge of geology and topography during the discussion, first by themselves and then in the group discussion. The third part of the activity (Fig. 1d) introduced some possibilities for topography, geology, and rainfall patterns that could cause the drainage patterns observed in the examples (Fig. 1d). The instructor introduced some leaves with unique leaf margins and vein networks, then guided the discussion toward the end of the project.

Learning Objective 3: Draw diagrams and describe the watershed shapes and sizes.

Each student was asked to calculate the Gravelius' compactness coefficient for a leaf (Fig. 1e). By tracing the leaf on a graph sheet and counting the squares, students calculated the area of the leaf. The leaf's perimeter was calculated by tracing its boundary using a thread and measuring the result. After successfully completed, students compared and contrasted their estimations with a neighbor who had a leaf with a different shape. The instructor guided the discussion toward the differences they observed in watersheds based on shape (e.g., highlight the differences in a circular watershed and an elliptical one), and size (e.g., area, perimeter). The students made connections between leaf sizes (Fig. 1f) and the watershed's classification based on size [e.g., sub-watersheds (200–400 hectares), river basins (<1000 hectares), etc.]. Students were also instructed on other classification approaches based on function (response to rainfall inputs), types of storage (e.g., no ground water storage), type of flow (overland flow), and so forth.

Learning Objective 4: Determine the topographic divisions of the watershed (boundary) and describe the effect of topography on them.

Students were guided to delineate the watersheds on their leaf by first drawing a circle at the outlet or downstream point of the river network. Then they located the river network that contributes water to it. Finally, they drew a line along both sides of the watercourse, starting at the circle (that was made in step one), working the way upstream toward the headwaters of the watershed. Students individually delineated the watersheds in the leaves, then discussed their results with their group. Correct watershed delineation is shown by the check mark in Fig. 1g. Due to improper understanding of topography, common errors made by students are illustrated with an X in Fig. 1g.

Learning Objective 5: Estimate and describe the distinguishing properties/characteristics of the watershed.

Students estimated watershed (leaf) characteristics using the leaf tracings on graph paper, thread, ruler, and calculator. Estimates of the length and area were input into the formulas provided (Appendix) to calculate the watershed characteristics. After they had successfully done this, students compared and contrasted results with a neighbor. The students were asked questions about the differences they saw in characteristics based on shape. The students applied their knowledge of geometry (e.g., centroid, area) in the estimation of leaf characteristics.

Learning Objective 6: Determine the relative size of streams (stream ordering) and differentiate them.

In this sixth activity, the students were introduced to another important component of watersheds: stream ordering. Leaf veins are ideal to practice stream ordering, which is a measure of the degree of stream branching within a watershed. They observed and learned to differentiate the first, second, and third order streams. For example, the students made connections between the unbranched tributary and first-order streams. The instructor then showed how to correctly order, and discussed some potential mistakes (check mark and X in Fig. 1h). Students can also learn about stream density by using this hands-on activity with leaves.

METHODS

Participants

Participants were junior and senior undergraduate students attending a large Midwestern land-grant research university. All participants were enrolled in a Water Resource Engineering course taught by the lead author. A total of 56 students volunteered (the entire class) to participate in the study. The demographic information of participants is presented in Table 1. Those who participated were given 3 credit points as compensation at the end of the study.

Learning Styles

We used the Felder-Silverman learning style model and its instrument Index of Learning Style to categorize students on four unique dimensions: active-reflective,

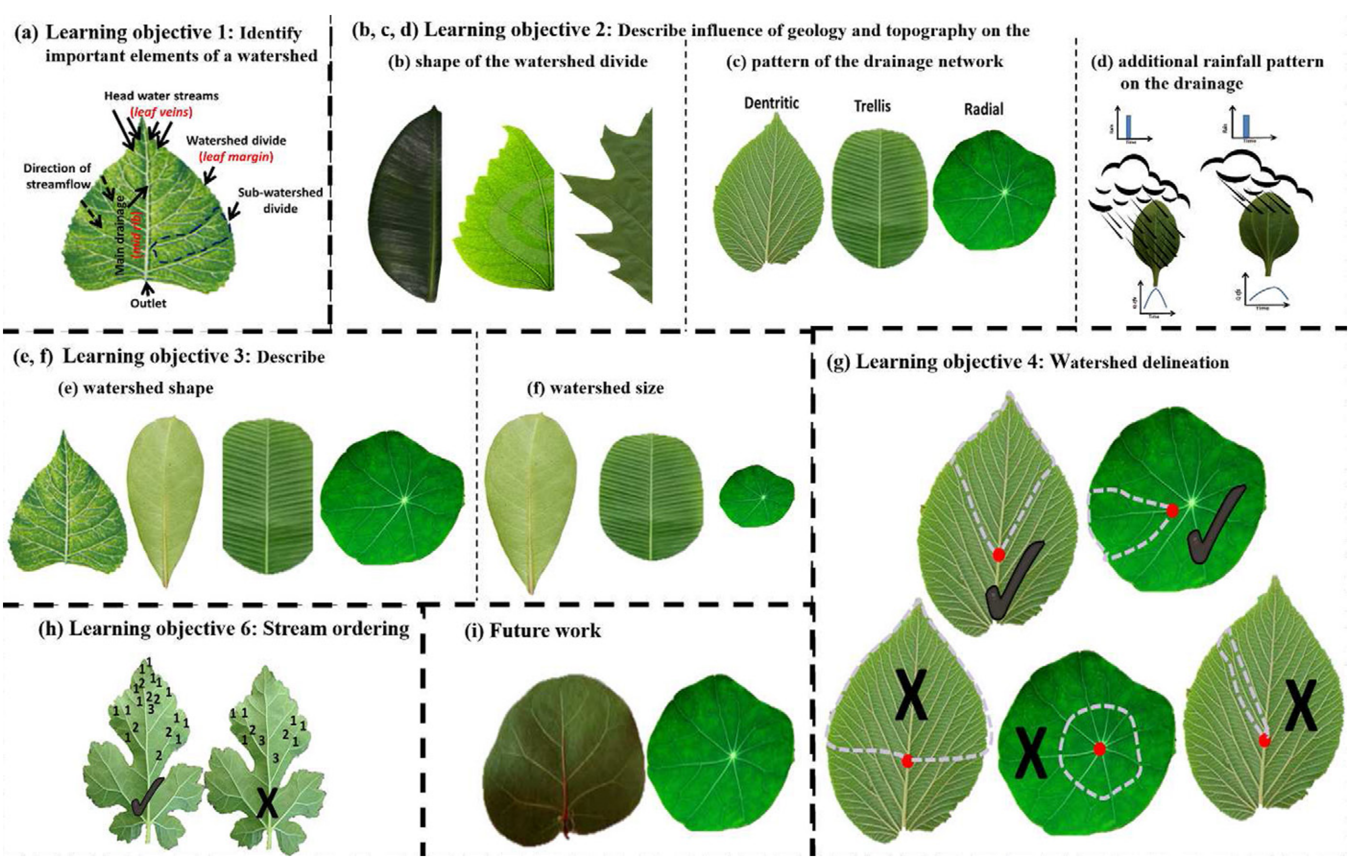

Fig. 1. The analogy of leaf to various concepts in watershed.

Table 1. Student participants' demographics.

Demographic	No. of students	Percentage
Gender		%
Female	14	25
Male	42	75
Program track		
Construction engineering	2	3.6
Environmental engineering	5	8.9
General engineering	31	55.4
Structural engineering	12	21.4
Transportation engineering	2	3.6
Unspecified	4	7.1

sensing-intuitive, visual-verbal, and sequential-global. The active-reflective dimension measures whether individuals prefer to learn by doing and trying things out rather than thinking through the whole process before actually doing it. Sensing-intuition measures whether individuals prefer to work with concrete information such as facts, data, or abstraction such as theories and models. The visual-verbal dimension measures an individuals' preference for visual demonstration of information such as charts, diagrams, or verbal and written explanations. The sequential-global dimension measures whether individuals prefer to process information in a step-by-step and linear manner or if they would be more comfortable looking at the larger picture in a more holistic fashion (Felder and Silverman, 1988)

At the beginning of the semester, students completed the Index of Learning Styles at their own pace, and most students were able to complete the questionnaire within 10 minutes. The Index of Learning Styles (ILS) is an established and widely used instrument to measure self-reported preferences on important learning style models (Felder and Spurlin, 2005). The instrument included 44 items asking individuals' learning style preferences on four different dimensions: active-reflective, sensing-intuitive, visual-verbal, and sequential-global. Each learning style dimension included 11 forced-choice items, using mutually exclusive categories, either "a" (active) or "b" (reflective), on all items. We calculated the scales in the same way that the original authors of the instrument have used (see Felder and Spurlin, 2005). Specifically, we assigned a value of 1 to a items, and 0 to b items, and calculated the total values of 11 items on each dimension. For example, on the active–reflective dimension, a items represent the active learning style and b items represent the reflective learning style. The more a items one selects, the higher the score on the dimension, indicating a stronger preference for active learning style. The reliability and validity of ILS, and its predictive power on academic performance in engineering education, have been well documented and can be found elsewhere (e.g., Felder and Spurlin, 2005; Felder, 2010).

Assessment Design

The efficacy of the leaf analogy as a tool for teaching watersheds was investigated using a non-experimental design over the course of 2 weeks (with 1.5 class hours each week). Data collected included (1) Index of Learning Styles survey (Felder and Silverman, 1988) (take home questionnaire), (2) an outcome-based post assessment measuring students' understandings of watersheds concepts (take home exam), and (3) a student feedback survey to measure students' perceptions of the instruction. Sample sizes varied across each analysis because some participants failed to complete all measures.

RESULTS

Learning Style Results

The results of learning styles are illustrated in Table 2 and are consistent with previous studies regarding students' preferences on each dimension of learning styles (Felder and Spurlin, 2005). On the active–reflective dimension, most students (>60%) indicated mild active (6–7) or mild reflective (4–5) learning style, followed by moderate or strong preference for active learning style. On the sensing–intuitive dimension, the majority of the students moderately or strongly favor sensing learning style. The majority of the students also indicated a moderate or strong preference on visual learning; no one had a salient verbal learning preference. On the sequential–global dimension, most students expressed a mild preference toward either learning style.

Student Feedback Survey Results

A student feedback survey was administered the next time the class met following the completion of the leaf analogy lesson. The survey consisted of four items, asking students the extent to which they agreed with each statement regarding using leaf analogy as a tool for learning watersheds. Responses were based on a 5-point Likert scale from 1 = strongly disagree to 5 = strongly agree. Table 3 shows that overall students

Table 2. Student learning style preferences.

Content	Results observed in the study		
Learning style	Moderately–Strongly active	Mild	Moderately–Strongly reflective
Number of students	14	36	5
Percentage	25.5%	65.5%	9.1%
Learning style	Moderately–Strongly sensing	Mild	Moderately–Strongly intuitive
Number of students	32	16	7
Percentage	58.2%	29.1%	12.7%
Learning style	Moderately–Strongly visual	Mild	Moderately–Strongly verbal
Number of students	33	21	0
Percentage	61.1%	38.9%	0%
Learning style	Moderately–Strongly sequential	Mild	Moderately–Strongly global
Number of students	18	33	3
Percentage	33.3%	61.1%	5.6%

Table 3. Student feedback survey results regarding using leaf analogy for learning watersheds.

Items	Strongly agree (5)	Agree (4)	Neutral (3)	Disagree (2)	Strongly disagree (1)	Mean
1. Did the physical analogy of a leaf assist you to better understand the idea of a watershed?						
No. of students	4	16	17	4	5	3.22
Percentage	8.7%	34.8%	37%	8.7%	10.9%	
2. Did the idea that the leaf margin is similar to the drainage divide make sense to you?						
No. of students	5	23	11	4	3	3.50
Percentage	10.9%	50.0%	23.9%	8.7%	6.5%	
3. Did the idea that leaves have different shapes help you understand that watersheds can have different shapes and sizes?						
No. of students	6	14	19	2	5	3.30
Percentage	13%	30.4%	41.3%	4.3%	10.9%	
4. Did the idea of leaves having different pattern in their veins help you understand that drainage basins can have different patterns for the streams within the watershed?						
No. of students	9	12	18	3	4	3.41
Percentage	19.6%	26.1%	39.1%	6.5%	8.7%	

believed they benefitted from (or were unaffected by) using the leaf analogy as a tool for learning watersheds. For example, 61% either agreed or strongly agreed that the idea of the leaf margin similar to the drainage divide made sense to them.

Previous studies indicated that students with various learning style preferences tend to have different academic experiences (see Litzinger et al., 2007 and Felder and Spurlin, 2005). Therefore, we compared responses from students with contrasting learning style categories. Felder and Spurlin (2005) suggest that students with mild preferences tend to shift between two categories instead of demonstrating learning behaviors of a single category consistently. As a result, examining students with moderate or strong learning style preferences and their behaviors or attitudes is more likely to yield robust results. Following Felder and Spurlin's recommendation, we examined only students with moderate or strong preferences on each dimension. Given the small numbers of participants in most categories on four dimensions, we performed bootstrapping method 1000 times using Statistical Package for Social Science (SPSS) software (version 22). Bootstrapping allowed us to estimate the statistical properties of the sampling distribution from our sample data, which is likely to yield more robust results from small samples (Field, 2013).

The average ratings on each feedback survey question from students with moderate or strong learning style preferences on each of the four dimensions are presented in Table 4. Overall, students with contrasting learning styles on each dimension indeed demonstrated different response patterns to feedback survey questions. Active learners expressed more favorable opinions on the teaching module than reflective learners. Intuitors gave some of the highest average ratings among students of all learning styles, who also held more positive views on the teaching model than sensors. We were not able to compare visual–verbal learners because no one in the sample had moderate or strong verbal learning preferences. Sequential learners expressed more favorable views on the teaching model than global learners. Overall, these findings are consistent with previous findings (Felder, 2010; Felder and Spurlin, 2005).

Post-Module Quiz Results

Students' understanding of the concepts were measured through an outcome-based assessment given 1 week after the module was taught. The quiz had one problem-based modeling design question, corresponding to the concepts from the different aspects of watersheds. The quiz had the description of a particular watershed with a couple of scenarios (baseline and future changes). Answering the question required knowledge of the important concepts, namely: elements of a watershed and its characteristics; its drainage pattern, shape; and size and relative size of streams. The quiz had a full score of 45 points. Students were assessed based on design assumptions and estimates. The points were divided among the assumptions (22 points) and estimates (23 points). Grades were provided by the instructor depending on the proportions they answered correctly in the above-mentioned areas. The students who stated all the assumptions got 22 points and students who had all design estimates right got 23 points. Points for each assumption varied between 2 and 5 points, whereas the points for each design estimate varied between 3 and 5 points.

Table 4. Average ratings on feedback survey questions from students with moderate or strong learning style preferences on a 5-point scale: 1 = strongly disagree, 5 = strongly agree.

Question	Moderately–strongly active	Moderately–strongly reflective	Moderately–strongly sensing	Moderately–strongly intuitive	Moderately–strongly visual	Moderately–strongly verbal	Moderately–strongly sequential	Moderately–strongly global
1. Did the physical analogy of a leaf assist you in better understanding the idea of a watershed?								
Mean	3.6	2.6	3.1	3.8	3.4	–	3.3	2.3
2. Did the idea that the leaf margin is similar to the drainage divide make sense to you?								
Mean	3.7	3.6	3.4	3.8	3.6	–	3.7	3.0
3. Did the idea that leaves have different shapes help you understand that watersheds can have different shapes and sizes?								
Mean	3.6	2.4	3.3	3.7	3.4	–	3.5	2.3
4. Did the idea that leaves having different patterns in their veins help you understand that drainage basins can have different patterns for the streams within the watershed?								
Mean	3.5	2.8	3.3	3.8	3.5	–	3.5	2.3

Table 5. Outcome-based quiz results.

Grade	A	A, B	A, B, C	D	F
No. of students	11	33	40	4	12
Percentage	19.6%	58.9%	71.4%	7.1%	21.4

Table 6. Average percentage points (out of 100%) on the outcome-based assessment quiz results from students with moderate or strong learning style preferences.

Moderately–strongly active	Moderately–strongly reflective	Moderately–strongly sensing	Moderately–strongly intuitive	Moderately–strongly visual	Moderately–strongly verbal	Moderately–strongly sequential	Moderately–strongly global
				%			
80%	86%	80%	79%	84%	–	83%	69%

Proportionately, points were deleted for every assumption not stated or design estimates not accurate. The test results, with a normalized grading system, are shown in Table 5.

Previous studies have indicated that students with different learning style preferences tend to have different academic outcomes (see Felder and Spurlin, 2005; Litzinger et al., 2007). Therefore, we also compared outcome-based assessment results among students with contrasting learning style categories. As mentioned above, we again adopted Felder and Spurlin's (2005) recommendation and examined only students with moderate or strong preferences for each of the four dimensions. As illustrated in Table 6, students who favor reflective learning style performed moderately better than active learners, despite active learners' more favorable opinions of the teaching module. Sensors and intuitors performed similarly on the problem-solving question. Sequential learners performed much better on the quiz than global learners.

Instructor Observations

The instructor noticed that the instruction appeared to ignite engineering students' curiosity when a leaf's relationship was compared to stream/creeks and watersheds. Students were more engaged in class (e.g., fewer students were checking email messages) during the activities. The comparison between watersheds and leaves seemed to foster learning as many students related the new concepts on watersheds to their past education and experiences. For example, they saw applications for principles of geometry, biology, and geology while learning new concepts in watersheds. Students also had the opportunity to observe how members of the group process information differently based on personal knowledge and experiences. For example, interpretation of geology and topography of leaf margins or watershed boundary varied with students' knowledge and experience. During group discussion and instructor-led discussions, some of the students shared recollections of their high school geometry/geology lessons and strategies to remember the concepts.

CONCLUSION AND SUMMARY

Watersheds are an important concept for students in natural resources and engineering, because the watershed is the basic unit of all hydrologic analysis and designs. However, the concept of watersheds can be complex for students to learn. We developed an instructional module to teach watershed concepts based on the existing literature of analogy and conceptual mapping. In this module, instructors introduce watersheds by connecting them to something students see every day, a leaf. Leaves and watersheds both come in different shapes and sizes. The midrib and veins in the leaves can be analogous to the stream network in a watershed, while the lamina or leaf blade can be the watershed area. Moreover, leaves may have similar sizes but different shapes—the same is true with watersheds.

This interaction and discussion with students in class provided opportunities to observe how effectively the students learning and understanding the concepts. The observations of the instructor suggested that students were more engaged in class (e.g., fewer students were checking email messages) while doing the activities. Student feedback indicated that they had moderate to positive opinions toward using the leaf analogy as a tool for learning watersheds. Student performance on the module assessment showed that most of them had a working understanding of the concept. It did appear that students with certain learning styles (e.g., active learners, intuitive learners, and sequential learners) benefited more from this type of instruction.

Although this preliminary study was conducted in a single classroom, the experience provided feedback necessary to improve the module further. For future classroom research, we plan to replicate the same instructional design using leaf analogy and examine whether the similar results will emerge in a quasi-experimental design. Further, we also intend to develop a quiz and grading system to more accurately assess students' understanding of each concept. Having activities that students with various learning styles use (e.g., text descriptions of the activities before class) is also proposed for future work.

Using the leaf analogy to introduce concepts such as hydrographs (a plot of flow rate vs. time) and hyetographs (distribution of rainfall over time) for a watershed could also be explored in future iterations. The effect of multiple rainfall events on different portions of the watershed would cover (1) an entire watershed, and (2) the upper third of the watershed by showing one leaf with a vein structure and shapes. Circular watersheds with outlets in different locations (Fig. 1i) resulting in a different hydrograph can also be brought out in class. Additionally, for multiple hyetographs, hydrographs for watersheds from different sizes and shapes can also be explored in future. A brief introduction to concept mapping and its relationship to students learning could have reduced the apprehensiveness of some students when unconventional methods of instruction were used.

ACKNOWLEDGMENTS

We thank Dr. Stacy Hutchinson and Dr. Lisa Harington, for the opportunity to teach this module in their class; Dr. John Harington for providing feedback; Dr. Jane Frakenberger, Dr. Dana Porter, Dr. Lauri Baker, and Dr. Thien for their valuable comments and edits in the initial version of the manuscript; and Ms. R. Lakshmi for assistance with leaves. The partial funding provided by Scholarship of Teaching and Learning (SOTL) mini-grant provided by the College of Agriculture, Kansas State University, National Science Foundation under Grant no. 1735235 awarded as part of the National Science Foundation Research Traineeship and USDA-NIFA capacity building grant 2017-38821-26405 are also acknowledged. The authors express their gratitude to the three anonymous reviewers for their constructive comments and suggestions on the earlier draft of the article.

APPENDIX

Formulas to Estimate Watershed Characteristics

Length to the centroid of area (L^{ca})

The distance measured along the main channel from the basin outlet to the point on the main channel opposite the center of area (centroid).

Shape Factor (L^l)

$L^l = (LL^{ca})^{\alpha}$

where L is the length of the watershed, and L^{ca} is the length to the center of watershed area (α = 0.3 for length measurements in miles).

Circularity ratio (F^c)

$F^c = P/(4\pi A)^{0.5}$

where P and A are the perimeter and area of the watershed, respectively.

Circularity ratio (R^c)

$R^c = A/A^o$

where A^0 is the area of a circle having a perimeter equal to the perimeter of the basin.

Elongation Ratio (R^e)

$R^e = 2/L^m(A/\pi)^{0.5}$

where L^m is the maximum length of the basin parallel to the principal drainage.

Activity I

Ask each student to calculate these characteristics. The student needs to find the centroid of the watershed. The student, using a plumbline and a pin, finds the centroid utilizing the following guidelines.

- The leaf is held by the pin inserted at a point near its perimeter in such a way that it can freely rotate around the pin; the plumbline is dropped from the pin.
- The position of the plumbline is traced on the leaf.
- The experiment is repeated with the pin inserted at different points of the leaf's perimeter.
- The intersection of the two lines is the centroid of the leaf.

The student can use the tracings using graph paper, thread, ruler, and calculator to estimate length and area. The values are input into the formulas provided to calculate the watershed characteristics. After they have successfully done this, the student compares results with a neighbor who has a leaf with a different shape. Ask students questions about the differences they see in characteristics based on shape.

REFERENCES

Aghakouchak, A., and E. Habib. 2010. Application of a conceptual hydrologic model in teaching hydrologic processes. Int. J. Eng. Educ. 26(4):963–973.

AghaKouchak, A., N. Nakhjiri, and E. Habib. 2013. An educational model for ensemble streamflow simulation and uncertainty analysis. Hydrol. Earth Syst. Sci. 17(2)445–452. doi:10.5194/hess-17-445-2013

Anandhi, A. 2017. CISTA-A: Conceptual model using indicators selected by systems thinking for adaptation strategies in a changing climate: Case study in agro-ecosystems. Ecol. Modell. 345:41–55. doi:10.1016/j.ecolmodel.2016.11.015

Anandhi, A., J.L. Steiner, and N. Bailey. 2016. A system's approach to assess the exposure of agricultural production to climate change and variability. Clim. Change 136(3–4):647–659. doi:10.1007/s10584-016-1636-y

Batzri, O., O.B.Z. Assaraf, C. Cohen, and N. Orion. 2015. Understanding the earth systems: Expressions of dynamic and cyclic thinking among university students. J. Sci. Educ. Technol. 24(6):761–775. doi:10.1007/s10956-015-9562-8

Ebenezer, J., O.N. Kaya, and D.L. Ebenezer. 2011. Engaging students in environmental research projects: Perceptions of fluency with innovative technologies and levels of scientific inquiry abilities. J. Res. Sci. Teach. 48(1):94–116. doi:10.1002/tea.20387

Elshorbagy, A. 2005. Learner-centered approach to teaching watershed hydrology using system dynamics. Int. J. Eng. Educ. 21(6):1203–1213.

Felder, R.M., 2010. Are learning styles invalid? (Hint: No!). On-course newsletter. 27 Sept. 2010. https://goo.gl/LyA1F6 (accessed 21 Nov. 2017).

Felder, R.M., G.N. Felder, and E.J. Dietz. 2002. The effects of personality type on engineering student performance and attitudes. J. Eng. Educ. 91(1):3–17. doi:10.1002/j.2168-9830.2002.tb00667.x

Felder, R.M., and L.K. Silverman. 1988. Learning and teaching styles in engineering education. Engl. Educ. 78(7):674–681.

Felder, R.M., and J. Spurlin. 2005. Applications, reliability and validity of the index of learning styles. Int. J. Eng. Educ. 21(1):103–112.

Field, A. 2013. Discovering statistics using IBM SPSS statistics. Sage Publishing, Thousand Oaks, CA.

Gilbert, S.W., and S.W. Ireton. 2003. Understanding models in earth and space science. NSTA Press, Arlington, VA.

Harrison, A.G., and R.K. Coll. 2008. Using analogies in middle and secondary science classrooms: The far guide–an interesting way to teach with analogies. Corwin Press, Thousand Oaks, CA.

Harrison, A.G., and D.F. Treagust. 2000. A typology of school science models. Int. J. Sci. Educ. 22(9):1011–1026. doi:10.1080/095006900416884

Harrison, A.G., and D.F. Treagust. 2006. Teaching and learning with analogies. In: P.J. Aubusson, A.G. Harrison, and S.M. Ritchie, editors, Metaphor and analogy in science education. Springer, Dordrecht. p. 11–24. doi:10.1007/1-4020-3830-5_2

Keefe, J.W. 1979. Learning style: An overview. NASSP's Student learning styles: Diagnosing and proscribing programs. p. 1–17. National Association of Secondary School Principles, Reston, VA.

Kolb, D.A. 1984. Experiential learning: Experience as the source of learning and development. Vol. 1. Prentice Hall, Englewood Cliffs, NJ.

Leatherdale, W.H. 1974. The role of analogy, model, and metaphor in science. American Elsevier Pub. Co., New York.

Libarkin, J.C. 2005. Conceptions, cognition, and change: Student thinking about the Earth. J. Geosci. Educ. 53(4):2.

Litzinger, T.A., S.H. Lee, J.C. Wise, and R.M. Felder. 2007. A psychometric study of the index of learning styles. J. Eng. Educ. 96(4):309–319. doi:10.1002/j.2168-9830.2007.tb00941.x

Loucks, D., E.v. Beek, J. Stedinger, J. Dijkman, and M. Villars. 2005. Concepts in probability, statistics and stochastic modelling. In: Water Resources Systems Planning and Management. An introduction to methods, models and applications. UNESCO, Paris. p. 169-229.

Myers, I. 1978. Myers-Briggs type indicator. Consulting Psychologists Press, Palo Alto, CA.

Ngambeki, I., S. Thompson, P. Troch, M. Sivapalan, and D. Evangelou. 2012. Engaging the students of today and preparing the catchment hydrologists of tomorrow: Student-centered approaches in hydrology education. Hydrol. Earth Syst. Sci. Discuss. 9(1):707–740. doi:10.5194/hessd-9-707-2012

Novak, J.D., and A.J. Cañas. 2008. The theory underlying concept maps and how to construct and use them. Technical Rep. IHMC CmapTools 2006-01 Rev 01-2008, Florida Institute for Human and Machine Cognition. http://cmap.ihmc.us/Publications/ResearchPapers/TheoryUnderlyingConceptMaps.pdf (accessed 21 Nov. 2017).

Ruddell, B.L., and T. Wagener. 2015. Grand challenges for hydrology education in the 21st century. J. Hydrol. Eng. 20(1):A4014001. doi:10.1061/(ASCE)HE.1943-5584.0000956

Rye, J., R. Landenberger, and T.A. Warner. 2013. Incorporating concept mapping in project-based learning: Lessons from watershed investigations. J. Sci. Educ. Technol. 22(3):379–392. doi:10.1007/s10956-012-9400-1

Shaw, S., and M. Walter. 2012. Using comparative analysis to teach about the nature of nonstationarity in future flood predictions. Hydrol. Earth Syst. Sci. 16(5):1269–1279. doi:10.5194/hess-16-1269-2012

Spurlin, J.E., Bernold, L.E., Crossland, C.L. and Anson, C.M., 2003. Understanding how freshmen engineering students think they learn. *age*, 8: 1.

Venville, G.J., and V.M. Dawson, editors. 2004. Integration of science with other learning areas. In: The art of teaching science. Allen & Unwin, Sydney, Australia. p. 146–161.

Yang, Y., and L.B. Bliss. 2014. AQ factor analysis of college undergraduate students' study behaviours. Educ. Res. Eval. 20(6):433–453. doi:10.1080/13803611.2014.971817