HydroLearn: Improving Students’ Conceptual Understanding and Technical Skills in a Civil Engineering Senior Design Course

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Abstract
Engineering graduates need a deep understanding of key concepts in addition to technical skills to be successful in the workforce. However, traditional methods of instruction (e.g., lecture) do not foster deep conceptual understanding and make it challenging for students to learn the technical skills, (e.g., professional modeling software), that they need to know. This study builds on prior work to assess engineering students’ conceptual and procedural knowledge. The results provide an insight into how the use of authentic online learning modules influence engineering students’ conceptual knowledge and procedural skills. We designed online active learning modules to support and deepen undergraduate students’ understanding of key concepts in hydrology and water resources engineering (e.g., watershed delineation, rainfall-runoff processes, design storms), as well as their technical skills (e.g., obtaining and interpreting relevant information for a watershed, proficiency using HEC-HMS and HEC-RAS modeling tools). These modules integrated instructional content, real data, and modeling resources to support students’ solving of complex, authentic problems. The purpose of our study was to examine changes in students’ self-reported understanding of concepts and skills after completing these modules. The participants in this study were 32 undergraduate students at a southern U.S. university in a civil engineering senior design course who were assigned four of these active learning modules over the course of one semester to be completed outside of class time. Participants completed the Student Assessment of Learning Gains (SALG) survey immediately before starting the first module (time 1) and after completing the last module (time 2). The SALG is a modifiable survey meant to be specific to the learning tasks that are the focus of instruction. We created versions of the SALG for each module, which asked students to self-report their understanding of concepts and ability to implement skills that are the focus of each module. We calculated learning gains by examining differences in students’ self-reported understanding of concepts and skills from time 1 to time 2. Responses were analyzed using eight paired samples t-tests (two for each module used, concepts and skills). The analyses suggested that students reported gains in both conceptual knowledge and procedural skills. The data also indicated that the students’ self-reported gain in skills was greater than their gain in concepts. This study provides support for enhancing student learning in undergraduate hydrology and water resources engineering courses by connecting conceptual knowledge and procedural skills to complex, real-world problems.

Improving Students' Conceptual Understanding and Technical Skills in a Civil Engineering Senior Design Course

Engineering graduates need a deep understanding of key concepts in addition to technical skills to be successful in the workforce. However, traditional methods of instruction (e.g., lecture) are sometimes not effective in fostering deep conceptual understanding and make it challenging for students to learn the technical skills, (e.g., professional modeling software), that they need to know. Research indicates that engaging students in authentic tasks can help them make connections to deepen their conceptual understanding as they practice the real work of engineers [1]. Other scholars have also found that allowing students to grapple with high cognitive demand tasks (i.e., tasks for which there is not one correct solution) supports the development of students' conceptual understanding [2], [3]. Moreover, in the digital age, when so many engineering tools and data sources are widely available online, faculty can take advantage of these resources to design authentic, high cognitive demand tasks for their students [4] - [6]. This study builds on prior work to assess engineering students' conceptual understanding and technical skills before and after completing modules designed around authentic, high cognitive demand tasks.

Given the challenges posed by traditional methods of instruction, we designed online active learning modules to support and deepen undergraduate students' understanding of key concepts in hydrology and water resources engineering (e.g., watershed delineation, rainfall-runoff processes, design storms), as well as their technical skills (e.g., obtaining and interpreting relevant information for a watershed, proficiency using HEC-HMS [Hydrologic Engineering Center Hydrologic Modeling System] and HEC-RAS [Hydrologic Engineering Center River Analysis System] modeling tools). These modules integrate instructional content, real data, and modeling resources to support students' solving of authentic, high cognitive demand tasks. The purpose of this study was to examine changes in students' self-reported understanding of concepts and skills after completing these modules. The following research question guided this study:

> Are there differences in undergraduate students' self-reported learning gains in concepts and skills after participating in each of four online learning modules centered around authentic, high cognitive demand tasks, as compared to before participating in these modules?

Conceptual understanding and technical skills

This study focuses on the knowledge engineering students may gain during their specialized education in terms of conceptual understanding and technical skills. Rittle-Johnson et al. [7], define *conceptual understanding* as "implicit or explicit understanding of the principles that govern a domain and the interrelations between units of knowledge in a domain" (pp. 346-347). Past research indicates that learning is more effective when embedded within authentic contexts that promote the use of conceptual understanding and link it to real-world applications, tools, and technical skills [8], [9]. In this way, learners are more engaged in the concepts they are learning and can begin to make connections with other big ideas to develop more expert-like knowledge structures [10]. In their work, Sheppard et al. [11] expound on the importance of conceptual knowledge and its role in engineering practice by defining engineering practice as an integration of two components: (a) engineering as problem-solving (comprising the formal procedures used by engineers to identify and solve problems), and (b) engineering as knowledge (comprising the specialized knowledge that helps and motivates the process of problem-solving). Moreover, Streveler et al. [3] posit that gaining conceptual knowledge in engineering science is a vital factor in the development of competence and expertise as professional engineers.

As recommended by the Accreditation Board for Engineering and Technology (ABET), technical skills are one of the attributes that an engineering student must obtain by the time of graduation [12]. The term *technical skills* encompass the knowledge and abilities required to perform a specialized task. These skills are practical and have real-world applications. For students to develop these critical skills, engineering faculty must teach them in a constructive way. Past research suggests that the teaching methods should involve explicit instruction in a cooperative format [13] - [15], opportunities to practice the skill [16], the opportunity for frequent feedback [16], and include representational written, oral, and graphical communication opportunities [17], [18]. As part of their series of papers *The Future of Engineering Education*, Woods et al. [16] identify eight basic activities that promote skill development. One of the recommended activities is to provide thorough practice in the application of desired skills, using thoughtfully designed activities, and provide timely constructive feedback on the students' efforts. In an attempt to address the student learning outcomes (Criterion 3) of ABET [12], Pimmel [19] developed and tested a series of short modules aimed at teaching these skills. His results of the students' perceived confidence in their ability to use technical skills indicated that the use of those modules produced a successful and significant effect on student learning when compared to a control group that did not participate in the modules. These studies proposed the following strategies for developing students' conceptual understanding and technical skills: learning activities that involve cooperative work, contain opportunities to practice the skill and receive feedback, and incorporate written, oral and graphical writing in a professional context. While these studies suggest teaching methods to enhance student learning, there is a shortage of research assessing whether or not students report a positive gain in conceptual understanding and technical skills after application of these methods. In order to better understand the utility of various teaching methods, researchers need to examine changes in students' conceptual understanding and technical skills. Thus, the purpose of this study is to explore changes in students' conceptual understanding and technical skills after engaging in modules designed around authentic, high cognitive demand tasks.

Authentic, high cognitive demand tasks

Cognitive demand refers to the type and level of reasoning and problem solving that is expected of students to effectively engage in a task [20]. High cognitive demand tasks are those that are the most open-ended or unstructured and require learners to access their own content knowledge and engage in the problem-solving process. A task could be considered high demand if some guidance is given; however, if a task requires learners to mindlessly follow steps or apply a procedure, it would be considered low cognitive demand [21]. Low cognitive demand tasks can be characterized by requiring no or little deep understanding. Tasks that involve scripts (e.g., a list of instructions or procedures), or memorization (e.g., definitions, formulas) are considered low cognitive demand because the product of the task is only one correct solution, or is otherwise clearly and directly stated. Varying levels of cognitive demand can be related to the revised Bloom's taxonomy [22], [23]. The top three levels (analyze, evaluate, and create) are characteristics of high cognitive demand tasks. Alternatively, the bottom three levels (remember, understand, and apply) can be descriptors of low cognitive demand tasks.

Authentic tasks are a subset of high cognitive demand tasks. We define *authentic tasks* as tasks with an integrated application of concepts and skills that mirror the kinds of tasks in which professionals would engage. In their review of the literature, Herrington et al. [24] discovered broad design characteristics of authentic activities: (a) they have real-world relevance; (b) they are complex and ill-defined; (c) they encourage students to explore different perspectives; (d) they foster collaboration; (e) they involve meaningful reflection; and (f) they allow competing solutions and diversity of outcomes. Importantly, the tasks are similar to the type of work students will experience as professional engineers (e.g., hydrologic modeling, analyzing trends in data, and justifying decisions) and the product of the module is polished and realistic (e.g., an assessment report, a model, or code).

Previous research shows that student learning is greater in courses where tasks regularly promote high-level reasoning and problem-solving and lesser in courses where the tasks are scripted or procedural [25] - [27]. Litzinger et al. [28] researched the learning processes that support the development of expertise. Their findings indicated that engineering education should include a range of learning opportunities that enable students to create a deep conceptual understanding, improve their ability to apply technical skills fluently, and participate in a variety of authentic engineering tasks. Taraban et al. [29] replicated previous results demonstrating that students had greater cognitive activity with an interactive lesson on a computer screen as compared to a text-based lesson on a computer screen. They also found two benefits to promoting more higher-order cognitive processing: longer-term retention of information due to more elaborate cognitive representations of the knowledge, and major improvements in applying the knowledge to new contexts because the knowledge is not tied to particular rote situations or procedures.

Much work on the potential benefits of incorporating authentic, high cognitive demand activities in courses has been carried out in the mathematics and general sciences fields [30] - [32]; however, little research has been done to assess the impacts of active learning online modules with these attributes in upper-level undergraduate engineering courses. Given the potential of these types of tasks in supporting student learning, as well as the importance of developing both conceptual understanding and technical skills in engineering courses, research is needed that examines students' concepts and skills after participating in courses designed around authentic tasks.

Methods

This study used a pre/post design to measure students' self-reported learning gains with regard to specific concepts and skills that were covered in each of the four modules. Below we describe the online platform where the modules are hosted, the four modules themselves, and the context of the course in which this study is situated.

Context: HydroLearn

The four modules used in this study are all housed on HydroLearn (www.hydrolearn.org), a web-based platform for hydrology and water resources engineering faculty to create, share, and modify modules. The modules available on HydroLearn are created using research-based practices in education and are subjected to peer review and multiple rounds of revision. All modules include rigorous learning objectives as well as learning activities and content which are aligned to these objectives. One goal of HydroLearn is to support the development of learning modules that use authentic, high cognitive demand tasks to engage students in the work of engineers, as well as to help them build their conceptual understanding and technical skills. The modules used in the study are listed in the same sequence in which the students completed them. The time estimation for each module was measured by beta testers (i.e., graduate students who completed the modules and tracked their time to completion). We briefly describe each of the four modules used in this study below.

Development of Design Storms

Hydrologists are frequently required to design flood protection infrastructure to protect people and property from the impacts of flash flooding. One of the primary tasks in this design process is to develop a "Design Storm." Design storms are based on a given probability and duration and can be used as scenarios for the design of flood protection or drainage infrastructure (e.g., culvert, detention basin, reservoir). In this module, students are first introduced to basic concepts of probability and statistics that are used to quantify the variability of precipitation intensity and depth. Students then apply statistical methods to develop probability distributions appropriate for design values based on precipitation event frequency and risk. Students use precipitation data from rain gauges to construct Annual Maximum Series and calculate hydrological statistics, such as depth-duration-frequency and intensity-duration-frequency relationships. In the final learning activity in the module, students use these relationships to develop a design storm hyetograph for a given probability and duration using the Alternating Block Method (see Figure 1). Students also compare their design storms with those derived from the National Weather Service Precipitation Frequency Atlas of the United States. Calculations are performed using spreadsheet software or script programming. The module defines three primary learning objectives where students will be able to (a) derive Intensity Duration Frequency and Depth Duration Frequency curves using actual rain gauge data, (b) identify community resources for precipitation datasets and analyses, and (c) develop a design storm hyetograph using the alternating block method. By engaging in the activities in this module, students should gain a conceptual understanding of storm hyetographs and Intensity- and Depth-Duration-Frequency (IDF and DDF, respectively) as well as the technical skills to develop and apply design storms, analyze and interpret their results, and use engineering judgement to draw conclusions. This module takes approximately six hours of student effort.

Summary Questions

Imagine you are a scientist or engineer at the consulting firm tasked with designing the detention basin for Beau Bassin. Your boss requested that you familiarize the design team with the design storm hyetographs. Write a description of the design storm hyetographs to be used in the project. Things to consider when writing your description include:

1. What is the peak depth and intensity (depth/time) and when does it occur?
2. What is the total accumulated depth of rainfall? What is the total accumulated rainfall volume (i.e., total accumulated rainfall depth x area of the watershed = total accumulated rainfall volume)? If this entire volume were to runoff as streamflow over a 6-hour period, what would be the average rate of streamflow?
3. Considering this is an ephemeral stream, which very rarely flows, what do you think of the streamflow rate you just calculated? Does it seem high or low? How does it compare to the average annual streamflow of the watershed with a perennial stream somewhere else in the region?

Fig. 1. This is an example of an authentic, high cognitive demand task from the Development of Design Storms module.

Quantifying Runoff Generation

The second module students participated in for this study is called Quantifying Runoff Generation and it takes approximately six hours of student time to complete. Many hydrological design activities require quantification of the excess water (i.e., runoff) that is destined for local streams or channels streamflow that occurs in response to a given rainfall event. This module covers fundamental runoff generation concepts, including where water goes when it rains, how long water resides in a watershed, what pathway water takes to the stream channel, and how much runoff is generated from surface water input composed of rainfall. In this module, students learn the technical skills to quantify watershed and soil properties and then apply the Green-Ampt method for calculating runoff. The module also contains a modeling component where students learn technical skills associated with using the HEC-HMS software to analyze rainfall, infiltration, and runoff distributions and total depths for a specific design storm in a real-world watershed (see Figure 2). The learning objectives for this module include that the student will be able to: (a) describe various soil properties and infiltration methods, (b) identify the soil class and properties for a watershed using soil survey databases, (c) calculate infiltration and runoff depths using the Green-Ampt method, (d) navigate HEC-HMS software for future design applications and (e) use HEC-HMS to construct precipitation, infiltration, and runoff time series distributions.

Summary Questions

Imagine you are a scientist or engineer at the consulting firm tasked with designing the detention basin for Beau Bassin. Your boss requested that you familiarize the design team with the infiltration methods and results by answering the following questions:

1. Write a short description of the infiltration method that you used, the data and parameters that you needed to implement the method, and the overall results of your analysis. Discuss briefly other infiltrations methods that you could have used and how they are different or similar from the method you applied in terms of concept and data/parameter requirements.
2. Consider your results, including total depth, duration and timing of infiltration and runoff. Discuss how these compare to the those of the rainfall storm. Comment on why the amount and timing are similar or different, and why. How does the soil type, and therefore Green-Ampt parameters, influence these results?
3. Compare your results to those from the 100-yr 12-hr storm example in the spreadsheet that has the same soil type. This example storm was located in Utah. How do conditions in Louisiana compare to Utah and how does this affect your runoff results?

Fig. 2. This is an example of an authentic, high cognitive demand task from Quantifying Runoff Generation

Developing Storm Inflow and Outflow Hydrographs

A detention basin (reservoir) is one type of structure used to provide flood protection. An essential task in the design of a detention basin is to establish the inflow and quantify and analyze the resulting outflow from the detention basin. This task involves developing storm inflow and outflow hydrographs that quantify the timing of streamflow and reservoir responses to a storm event. In this module students use runoff data from a design storm to learn how to develop inflow and outflow hydrographs. The module uses runoff data produced from actual precipitation datasets from a rain gauge in Carencro, Louisiana. While the module is prepared for a specific location, its overall structure is general enough to be adapted for any other site. Students develop inflow and outflow storm hydrographs using the Soil Conservation Service Dimensionless Unit Hydrograph and Level Pool Routing Methods, respectively. Students also use the U.S. Army Corps of Engineers HEC-HMS modeling software [33] to develop the inflow and outflow hydrographs for the same site. Students then compare their manually-derived storm hydrographs to those derived using the HMS software. In the last activity of this module, students design a flood protection system including the size of the detention basin and its outlet orifice (see Figure 3). Students also analyze the flood protection benefits under various design parameters of the reservoir. Thus, this module is intended to develop students' technical skills in utilizing HEC-HMS modeling software to design a detention basin based using the storm hyetographs and hydrographs they developed in an earlier task and their conceptual understanding and applications of topics such as the Level Pool Routing and SCS Unit Hydrograph methods. This module takes approximately five hours to complete.

Summary Questions

FIRST: Imagine you are a scientist or engineer at the consulting firm tasked with designing the detention basin for Beau Bassin. Your client requested that you design the reservoir to achieve a 70% reduction in the peak of the incoming hydrograph (i.e., the outflow peak is no more than 30% of the inflow peak). Using the HEC-HMS model, design a reservoir that meets the desired goal of your client. Document your results using graphics and tables and write a discussion.

Now consider the following questions:

1. Discuss the effect of different design parameters (i.e., outlet size, detention basin volume and height) and the pros and cons of each design option. What are the implications of these design parameters from hydrologic, economic, and environmental perspectives?
2. Consider the location of the detention basin. What might be gained or lost by moving the detention basin closer or further from the Vermillion River? For example, upstream versus downstream coverage of the watershed, size of the detention base, ease of access for construction and maintenance, aesthetics to the neighborhood, impact on the Vermillion.
3. Based on your results, use the design that you selected to test it on a larger design storm with a 100-year return period, while keeping the same duration of 6-hour. How did the reservoir perform under this storm? What is the peak fraction for this larger storm?

Fig. 3. This is an example of an authentic, high cognitive demand task from Developing Storm Inflow and Outflow Hydrographs

Culvert Design using HEC-RAS

Hydraulic structures, such as dams, weirs, bridges and culverts, are needed along rivers, channels, and other bodies of water. This module focuses on the hydraulic design of culverts that are typically used to safely convey storm runoff or flood flows under roads and highways. The flow through a culvert is a function of variables such as roughness, slope, length, and the cross-sectional dimensions of the culvert. Improper design of any of these parameters can lead to the culvert having insufficient capacity, which in the case of a flood could lead to structural failure and overtopping of roads leading to unsafe conditions for traffic.

In this module, students learn how to analyze the hydraulic design of culvert structures using the industry-standard HEC-RAS hydraulic modeling software system [33] to complete the authentic, high cognitive demand task in Figure 4. The module starts with an introductory tutorial to the modeling platform using a hypothetical simple problem where students can analyze three different conditions: the original channel, a current structure, and a new proposed structure. By doing so, students also learn about practical tools and resources such as watershed delineation and the use of the Department of Transportation Hydraulics Manual to estimate peak flow rates. In the last section of the module, students perform their own design of a culvert structure in an actual waterway in south Louisiana (see Figure 4). The learning objectives of this module include: (a) setting up and implementing steady-state hydraulic simulations, (b) performing culvert design analysis using the HEC-RAS modeling software, and (c) analyzing steady water surface profiles and estimate flood-related impacts associated with culvert structures under different design storm conditions. Taking approximately five hours of student work, this module aims to develop students' conceptual understanding of watershed properties, peak flow, design storms and steady-state flow and technical skills for obtaining relevant rainfall data and building and analyzing culvert structures in the HEC-RAS modeling software.

Culvert under Coulee Mine Channel in Moncus Park

In September of 2005 a park known as the "Horse Farm" in the middle of Lafayette, Louisiana was under the threat of urbanization. However this area of green space had become an area that many people of the community cherished, so a movement was started to save the "Horse Farm". As a result of this movement a project has begun to preserve this area of nature. This area has now been renamed Moncus Park. Coulee Mine runs right through Moncus Park, so as a part of the new project a structure had to be built so that people could cross the coulee to access the park. A master plan of the park is shown below. Circled is the structure that was built for the project, which is a bridge. For your project you will model a culvert design for Coulee Mine in this place in HEC-RAS. To analyze the structure you will use the peak flows calculated from the last activity. For each design storm you will determine the smallest box culvert design that could handle the peak flow of each storm. To analyze the flow in HEC-RAS you will use a given section of Coulee Mine. This section is shown in the figures below.

Fig. 4. This is an example of an authentic, high cognitive demand task from Culvert Design using HEC-RAS

Participants and implementation of modules

The participants in this study were 32 undergraduate students at a southern U.S. university in a civil engineering senior design course. All students had previously taken fluid mechanics, water resources engineering, hydrology, and hydraulics classes which were taught using traditional lecture- and problem-set styles. The students were assigned these four learning modules over the course of one semester to be completed outside of class time. All students completed two of the modules: "Development of Design Storms" and "Quantifying Runoff Generation". After the institution went 100% virtual, due to the Covid-19 pandemic, the students were given two options: 1. Complete "Designing Storm Inflow and Outflow Hydrographs" and "Culvert Design Using HEC-RAS"; or 2. Complete an alternative module "Water Stress Across the United States", which is not part of this study. Option 2 was made available because some students were unable to access computers that were able to run the PC-based HEC-HMS and HEC-RAS software packages (e.g., students who used Macs were unable to run the software packages). For the purposes of this study, we focus on all students who completed the first two modules as well as those who chose Option 1, as most students chose Option 1.

Data collection

All participants completed the Student Assessment of Learning Gains (SALG; [34]) survey immediately before starting the first module (pre) and after completing the last module (post).

The SALG is a modifiable survey meant to be specific to the learning tasks that are the focus of instruction. We created versions of the SALG for each module that were aligned to the learning objectives for that module. The SALG has two parts that ask students to self-report: (a) their understanding of concepts and (b) their ability to implement skills that are the focus of each module. The concepts section starts with the statement: "Presently, I understand the following concepts that will be explored in this class" followed by three to 11 items representing the key concepts presented in that module. For instance, one of the concept items for the "Culvert design using HEC-RAS" module is "steady-state flow." The concepts section for each module is immediately followed by the skills section, which states: "Presently, I can…" and is followed by three to 11 skills. One of the skills for the "Culvert design using HEC-RAS" module is "delineate a watershed." Students rate each item on a 6-point Likert scale from 1-Not Applicable to 6-A great deal (see example in the Appendix). When examining survey data, it is important that the scales are consistent or reliable. Cronbach's α is a measure of reliability "that assesses the degree to which responses are consistent across a set of multiple measures of the same construct" [35, pp. 1081]. We calculated Cronbach's α for each scale (i.e., concepts and skills for each module). These reliabilities ranged from 0.75 to 0.96, where a value of 0.70 is generally regarded as acceptable. The concepts and skills for each module are included in Table I.

TABLE I

CONCEPTS AND SKILLS ASSESSED BY SALG IN EACH MODULE

	Development of design storms	**Quantifying runoff generation**	**Developing storm inflow and outflow hydrographs**	**Culvert design using HEC-RAS**
Concepts	● Flash Floods ● Return Period ● Storm Duration ● Hydrographs ● Hyetographs ● Design Storm ● Intensity-Duration-Frequency (IDF) curve ● Depth-Duration-Frequency (DDF) ● Alternating Block Method ● Probability Density Function (PDF) ● Cumulative Distribution Function (CDF)	● Soil porosity Soil moisture content ● Retention ● Infiltration methods ● Green-Ampt Method ● Runoff ● Hydrograph ● Hyetograph ● Darcy's Law ● Hydraulic conductivity ● Curve Number	● Flash flooding ● SCS Unit Hydrograph ● Storm Hydrograph ● Level Pool Routing	● Open Channel flow ● Hydraulic structures ● Steady-state flow
Skills	● Construct an Intensity-Duration- Frequency (IDF) curve ● Construct a Depth-Duration- Frequency (DDF) curve ● Use the Alternating Block method to develop a design storm	● Quantify design storm runoff ● Quantify design storm infiltration depths ● Identify the soil properties of a watershed ● Apply the Green-	● Develop a runoff hydrograph ● Design a detention basin to provide flood protection using HEC-HMS ● Construct a storm hyetograph using	● Build a culvert structure using HEC-RAS ● Analyze a culvert structure using HEC-RAS ● Delineate a watershed ● Conduct a steady-

	hyetograph	Ampt method to calculate infiltration depth ● Apply the Green-Ampt method to calculate runoff depths ● Determine the soil class of a watershed using the NRCS's SSURGO database ● Use HEC-HMS to construct precipitation, runoff and infiltration time series distributions	HEC-HMS ● Construct a storm hydrograph using HEC-HMS	state simulation in HEC-RAS ● Interpret output data in the form of graphs, figures, and tables

Data analysis

To determine if there were changes in students' self-reported concepts and skills after participating in each of the modules, we first averaged students' rating of their understanding of the items within concepts and skills for each module, creating mean concepts and skills scores for each module for each student. We then tested the mean differences using paired samples t-tests. We calculated means for each student based on how they rated each item within the concepts and skills section for each module at each time point, such that each student had a single score for concepts or skills at pre or post for each module in which they participated. Then we tested for differences from pre to post by conducting eight paired samples t-tests (two for each module used, concepts and skills). One limitation of conducting eight analyses is that it increases the probability of incorrectly rejecting the null hypothesis (i.e., the more statistical tests that a researcher conducts, the greater the chance they will find a false instance of statistical significance). To reduce the likelihood of incorrectly rejecting the null (i.e., Type I error), we used a Bonferonni correction to determine the level of significance [36]. A Bonferonni correction reduces the threshold level used to determine statistical significance. With an initial critical level $\alpha = 0.05$ and eight paired samples t-tests, our new critical level was $\alpha = 0.006$. In other words, rather than determining statistical significance at $p < .05$, as is traditional in educational research, we used the more conservative level $p < .006$ in order to determine statistical significance so as to reduce the likelihood that we would find statistical significance incorrectly.

We then calculated effect sizes for each statistically significant difference from pre to post. "An effect size is an index of … the magnitude of the difference between means, usually given in unit-free terms; effect size is independent of sample size" [35, pp. 1084]. Effect sizes are often used in educational research as a measure of the practical significance of a treatment. In the case of this study, we calculated Cohen's d [37], which describes the difference between the means in terms of the number of standard deviations.

Results

We present the results below by module. Means, standard deviations, and paired samples t-test results for concepts and skills are presented in Table II.

Development of Design Storms

The results from the paired samples t-tests for the Development of Design Storms module indicated that there were statistically significant differences for both concepts, $t(29) = -5.94$, $p < .001$, with a medium effect size, $d = 0.45$, and for skills, $t(29) = -5.87$, $p < .001$, with a medium effect size, $d = 0.71$ [37]. This indicates that students reported a greater understanding of concepts and skills after completing the module as compared to before beginning it.

Quantifying Runoff Generation

Additionally, results from the Quantifying runoff generation module showed a difference that was statistically significant for both concepts and skills. The paired samples t-test indicated statistical significance for concepts, $t(30) = -4.91$, $p < 0.001$, with a medium effect size, $d = 0.62$, and skills, $t(30) = -6.00$, $p < 0.001$, and a medium effect size, $d = 0.72$ [37].

Developing Storm Inflow and Outflow Hydrographs

Again we found statistically significant results from the paired samples t-test analysis of the Hydrographs module in both concepts and skills. The results for concepts were $t(23) = -3.96$, $p < 0.001$, with a medium effect size, $d = 0.63$. Results for skills were $t(23) = -5.21$, $p < 0.001$, and a large effect size, $d = 1.05$ [37].

Culvert Design using HEC-RAS

The analysis of the Culvert design using the HEC-RAS module suggested that students reported a statistically significant gain in technical skills, but not in conceptual understanding. The paired samples t-test results for skills were $t(23) = -3.54$, $p < 0.006$, and a large effect size, $d = 0.97$ [37].

Overall results

The analyses suggested that students reported statistically significant gains in both conceptual understanding and procedural skills in every module with the exception of concepts in the Culvert design using HEC-RAS module. Moreover, the effect sizes for all the statistically significant tests indicated a medium to large effect sizes which suggests that the differences from pre to post were not just statistically significant, but practically significant.

TABLE II
MEANS, STANDARD DEVIATIONS, AND PAIRED SAMPLES T-TEST RESULTS BY MODULE FOR CONCEPTS AND SKILLS.

Module	**N**	**Pre M (sd)**	**Post M (sd)**	**Paired Samples T-test**	**Mean Difference Confidence Interval**	**Cohen's *d***
Design Storm						
Concepts	30	4.25 (0.57)	4.74 (0.73)	*t*(29) = -5.94*	[-0.66,-0.32]	0.45
Skills	30	3.70 (0.88)	4.46 (1.02)	*t*(29) = -5.87*	[-1.02,-0.49]	0.71
Quantifying Runoff						
Concepts	31	4.27 (0.67)	4.81 (0.74)	*t*(30) = -4.91*	[-0.77,-0.32]	0.62
Skills	31	3.88 (0.62)	4.66 (0.91)	*t*(30)= -6.00*	[-1.04,-0.51]	0.72
Hydrograph						
Concepts	24	4.05 (0.56)	4.56 (0.69)	*t*(23) = -3.96*	[-0.78,-0.24]	0.63
Skills	24	3.36 (0.84)	4.48 (0.92)	*t*(23) = -5.21*	[-1.56,-0.67]	1.05
Culvert Design						
Concepts	24	4.31 (0.77)	4.71 (0.70)	*t*(23) = -2.66	[-0.72,-0.09]	0.74
Skills	24	3.74 (0.77)	4.44 (0.86)	*t*(23) = -3.54*	[-1.11,-0.29]	0.97
*Indicates statistical significance.						

Discussion, limitations, and implications

The results from this study provide an insight into how undergraduate engineering students' conceptual knowledge and procedural skills change after the use of online learning modules which integrated authentic, high cognitive demand tasks. Although we are not able to conclude that students' learning of concepts and skills was directly related to the use of these modules without a comparison group, these findings suggest that it is possible that the modules were related to students' learning, especially given prior research that has found positive correlations between using high-level problem solving and reasoning on student learning [25] - [27]. An interesting observation that emerged from the data comparison was that students seemed to rate their understanding of concepts higher than their ability to execute the skills at pre, although we did not test whether these differences were statistically significant. We think that this was due to the students having more exposure to the concepts of the modules, whereas the modules often served as the students' first time using the professional software in an in-depth way (e.g., HEC-RAS and HEC-HMS). Specifically, students had already taken fluid mechanics, water resources engineering, hydrology, and hydraulics. Many had probably been exposed to HEC-RAS in water resources engineering but only through low cognitive demand tasks. Additionally, given that students seemed to rate their conceptual understanding higher at pre, it is possible that there is a ceiling effect. In other words, the students would only rate themselves so high and they had already reached that ceiling earlier on for concepts than skills because they start higher.

Although the findings of this study were all statistically significant, what is most interesting is the practical significance, measured by effect size. The average effect size found in educational research is $d = 0.4$ [37]. Thus, the effect sizes found in this study [0.45,1.05] suggest that these modules have great potential and their impact on student gains in conceptual understanding and technical skills should be further explored. Moreover, these modules are freely available on the HydroLearn website for faculty to adopt. Thus the cost of implementing them is low (one could consider the time needed for faculty to review the modules as an opportunity cost) while the potential payoff in terms of student learning could be quite high.

The primary limitation of this study is that we were unable to collect data from a control group of students who were learning these same concepts and skills but did not use these modules. Collecting data from a control group might allow us to draw conclusions about the impact of the modules themselves; however, given the data we were able to collect we are not able to determine if it was participation in the modules or some other factor that influenced students' self-reported learning gains (e.g., faculty support, class lectures, independent reading). Nevertheless, given that they are freely available and that each module only takes approximately 5-6 hours of student work time, they show great potential to support students' development of concepts and skills at relatively low cost to faculty adopters.

The results have implications for faculty teaching hydrology or water resources courses, as well as those teaching engineering courses more broadly. Specifically, these findings suggest that faculty should attend to students' learning of both concepts and skills and that this can be done through online learning modules designed around authentic, high cognitive demand tasks. This study also provides support for enhancing student learning in undergraduate hydrology and water resources engineering courses by connecting conceptual understanding and procedural skills to authentic, high cognitive demand tasks. Students who engage in these modules appear to learn the concepts and skills targeted by the modules. Furthermore, these modules are designed to be self-directed and can be completed outside of class time. They are thus relatively easy for faculty to implement in their courses. They can also be modified so that instructors can change the hydrologic location being investigated in each module. For instance, the module on "Developing Storm Inflow and Outflow Hydrographs" tasks students with designing a detention basin for Beau Bassin, an intermittent stream in Southern Louisiana. However, instructors could easily copy the module and edit the content within the HydroLearn platform to situate the high cognitive demand task in a stream near their own campus, thus increasing the authenticity and relevance of the task to the students.

Faculty should continue to explore how engaging students in authentic, high cognitive demand tasks impacts their concepts and skills. Additionally, future research should compare a group of students who receive such instruction to those who do not in order to draw broader conclusions. Moreover, given Taraban et al.'s [29] findings that authentic tasks improved deep knowledge and retention, future research could examine students' retention of concepts and skills taught through these modules as compared to students who learned the same concepts and skills using low cognitive demand tasks (e.g., traditional lecture and problem sets).

As hydrology and water resources engineering faculty work to prepare students for work as engineers, they must support the development of their students' conceptual understanding of key engineering ideas as well as the technical skills needed to engage in design work and solve design problems. This study adds to the research base which suggests that situating students' learning in authentic, high cognitive demand tasks can help them develop deep understanding [28] and extends research on authentic, high cognitive demands tasks from mathematics and general sciences education into the field of engineering education research. The online learning modules we have created in HydroLearn show promise in supporting students' learning of these skills. The platform, which now includes a larger and more diverse set of modules, allows other faculty in hydrology and water resources engineering to use these modules in their own courses to support the development of future engineers' conceptual understanding and technical skills and prepare them for success in the workforce.

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Appendix

The survey instrument (SALG) from the Development of Design Storms module.

Presently, I understand the following concepts that will be explored in this class:

	Not applicable	Not at all	Just a little	Somewhat	A lot	A great deal
Flash Floods	○	○	○	○	○	○
Return Period	○	○	○	○	○	○
Storm Duration	○	○	○	○	○	○
Hydrographs	○	○	○	○	○	○
Hyetographs	○	○	○	○	○	○
Design Storm	○	○	○	○	○	○
Intensity-Duration-Frequency (IDF) curves	○	○	○	○	○	○
Depth-Duration-Frequency (DDF)	○	○	○	○	○	○
Alternating Block Method	○	○	○	○	○	○
Probability Density Function (PDF)	○	○	○	○	○	○
Cumulative Distribution Functoin (CDF)	○	○	○	○	○	○

Presently, I can:

	Not applicable	Not at all	Just a little	Somewhat	A lot	A great deal
Construct an Intensity-Duration-Frequency (IDF) curve	○	○	○	○	○	○
Construct a Depth-Duration-Frequency (DDF) curve	○	○	○	○	○	○
Use the Alternating Block method to develop a design storm hyetograph	○	○	○	○	○	○