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# SigPrep: Open Source, Web-Based Prework for Signals and Systems

An introductory course in signals requires a wide background of prerequisites covering complex numbers, series, calculus, and basic mathematical logic. Students often fail to engage with the material and find the course difficult because they do not recall the prerequisites. Time and curricular constraints usually limit in-class review. To address these issues, we present SigPrep, a set of open source, web-based preparatory modules for introductory courses in signals. SigPrep is designed as a preclass assignment that students can do independently at a self-set pace. SigPrep is designed in WeBWorK, a widely used platform for free, open source problems for science and math classes. Using WeBWorK features, SigPrep provides students instant feedback and linkages to relevant external e-learning resources as a refresher for concepts in which they fail to exhibit adequate proficiency. Instructors are also able to track students' progress and performance. We outline the pedagogical design of SigPrep, which provides problems of particular relevance and applicability covering prerequisites for signals classes. Finally, we share results and feedback from our own experience with using SigPrep as part of our teaching of an introductory class on signals.

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## Introduction

The introductory course in signals (or signals and systems) in the electrical and computer engineering (ECE) curriculum is often considered to be one of the most challenging classes for undergraduate students [1]–[3]. We assume that such a course includes a discussion of continuous-time signals and systems, although; it may optionally also include discrete-time signals and systems concepts. The underlying difficulty of the course arises from a number of causes. First, the signals course requires prerequisite knowledge and skills from a wide spectrum of topics [4], including complex numbers, trigonometry, calculus, series, and mathematical logic. Second, the introductory signals course is often also the first significant introduction to abstraction in ECE curricula and poses a challenge for many students who are accustomed to other engineering classes that deal more with concrete examples than abstract and nonintuitive concepts, such as complex exponentials and noncausal systems [5]. During recent times, the challenge of the course seems to have been magnified by the increasing and ready availability of online information sources and symbolic calculation tools; instead of inferring answers, students get progressively more used to either looking them up on Google or obtaining them through online calculators [6], [7].

**Students often fail to engage with the material and find the course difficult because they do not recall the prerequisites.**

Several instructors have worked on improving student engagement in the signals class by incorporating hands-on, project-based learning [8] and other strategies [5]. However, a key challenge remains in that students entering the class are often inadequately prepared with the background and prerequisites that are required [9]. The importance of prerequisites and background knowledge is well recognized in pedagogical circles; Ausubel [10] states, "If I had to reduce all of educational psychology to just one principle, I would say this: The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly." This is particularly a challenge for the first signals course because, as already noted, the material for the class builds upon and synthesizes ideas from prerequisites spanning a broad spectrum of topics. Students rarely recollect materials from prerequisite classes with the level of proficiency that is required to see these concepts being applied in discussions of signals and systems.

There is the need to reinforce and brush up this prerequisite background prior to commencing the core material for the class. A failure to do such a

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review often makes it hard for students to follow even the material at the very beginning of the course, causing them to fall behind and quickly lose interest in the subject. From a pedagogical perspective, it is also important to avoid complexity and focus any review only on the specific topics that are actually needed, instead of simply reviewing all the material that students may have encountered in the formal courses required as prerequisites. However, scheduling considerations and the curricular requirements of the course itself make it rather challenging to do such a review within the time available for classroom instruction.

To address these challenges and better prepare students for a first course in signals, we present an open source, web-based series of modules called *SigPrep* [11], [16]. SigPrep is designed as a WeBWorK [12], [13] assignment that students can do independently at their own pace prior to taking an introductory class on signals. The modules provide sets of problems that test students' proficiency with the specific prerequisite background that is required for the signals class, covering complex numbers, series, calculus, and basic mathematical logic. Instead of aiming at an exhaustive review, SigPrep focuses on the particular subsets of concepts and techniques from these topics that are actually used in signals. Through the WeBWorK interface, students receive instant feedback on the problems they attempt and, in situations where they struggle repeatedly with problems addressing a specific concept, they are directed to e-learning resources that enable them to refresh their understanding.

Instructors can also track student participation, progress, and performance through WeBWorK. Assigned as prework a few weeks before the start of the first course in signals, SigPrep provides students the opportunity to refresh and digest required prerequisite concepts just in time, making them better prepared for the class. Thus, SigPrep directly addresses the aforementioned quote from Ausubel by helping students fill any knowledge gaps and making them ready for the first course in signals.

## SigPrep: Workbook for WeBWorK

SigPrep is developed in WeBWorK, which is an open source, online homework-delivery system used for math and science courses [12], [13]. Supported by the Mathematical Association of America and the National Science Foundation, WeBWorK has been in use for mathematics homework assignments since 1994. Mainly targeted at undergraduate-level courses, WeBWorK has problem sets for a variety of classes, such as algebra, discrete mathematics, probability and statistics, calculus, differential equations, linear algebra, and complex analysis. Having the main goal of providing a robust, flexible, and convenient online homework system for both students and instructors, WeBWorK enables students to get instant feedback. Consequently, WeBWorK has been used at more than 700 colleges and universities. It is freely available to institutions that wish to utilize it, and it has pedagogical support through active discussion forums and mailing lists. The open source framework for WeBWorK, ability to include problems involving symbolic manipulation (not just numerical computation), instant evaluation and feedback capability, and already-accepted wide usage motivated us to employ the WeBWorK platform for SigPrep.

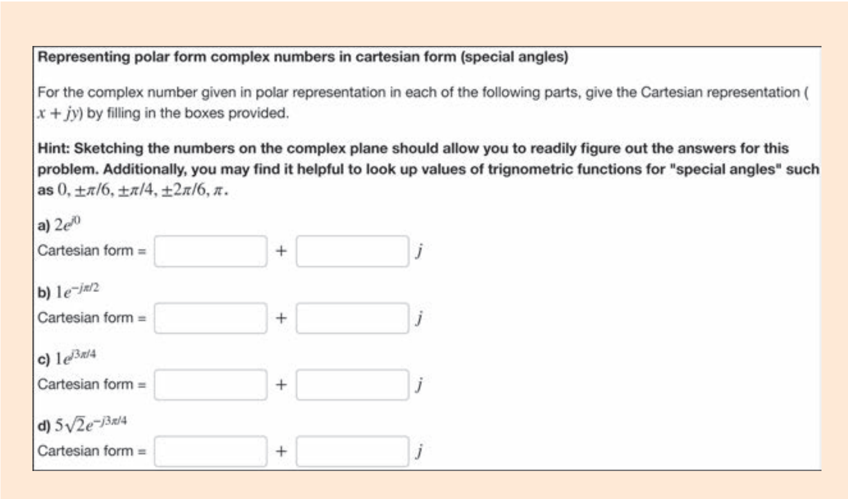
**Students entering the class are often inadequately prepared with the background and prerequisites that are required.**

As previously mentioned, the key objective of SigPrep is to provide students with a refresher in the diverse prerequisites required for the signals course. While these prerequisites are normally covered in prior courses in the curriculum, students often do not retain the material fluently enough to apply and build on the previously learned concepts in the signals course. The objective of SigPrep, however, is not to do a full rehash of the prior prerequisite courses. Instead, SigPrep focuses specifically on the subset of topics and the level of depth required for the signals course. Each topic is covered in its own module featuring a series of problems related to the topic. Each problem includes a descriptive title so that students are aware of the concept that is being covered. Additionally, the problems include video links as hints that are displayed when students encounter difficulty with a topic and repeatedly make mistakes when trying to solve a problem. The video links connect students to other openly available and trusted sources, such as the Khan Academy [14], where the concepts are explained. Problems also include hints about how to enter symbolic responses.

For numerical problems, using built-in WeBWorK features, parameters are randomized within specified validity ranges to ensure that instances presented to students are unique and that pupils solve them individually. The problems permit multiple attempts without a limit on the maximum number of tries, and hints are provided, usually after two unsuccessful efforts. SigPrep consists of eight modules, namely, complex numbers, trigonometric identities, series, differentiation, integration, differential equations, logic, and signal manipulation. We highlight the motivation for these topics and for the specific problems included for these topics in the ensuing sections, where we also illustrate several of the aforementioned features via examples.

### *Complex numbers*

Complex exponentials define the eigenfunctions of linear time-invariant systems, which are a key focus of a first course in signals. Therefore, complex number representations are integral to the signals course and are used throughout the class. SigPrep provides a module focusing on complex numbers, with an extensive set of problems covering complex exponentials, polar and Cartesian forms, powers, roots, and complex conjugation. While these concepts are used throughout the signals course, they play a particularly critical role in the discussion of Fourier series and in Fourier and Laplace transforms. Figure 1 illustrates SigPrep problems dealing



**Representing polar form complex numbers in cartesian form (special angles)**

For the complex number given in polar representation in each of the following parts, give the Cartesian representation ( $x + jy$) by filling in the boxes provided.

**Hint: Sketching the numbers on the complex plane should allow you to readily figure out the answers for this problem. Additionally, you may find it helpful to look up values of trignometric functions for "special angles" such as $0, \pm\pi/6, \pm\pi/4, \pm 2\pi/6, \pi$.**

**a)** $2e^{j0}$

Cartesian form = ____ + ____ $j$

**b)** $1e^{-j\pi/2}$

Cartesian form = ____ + ____ $j$

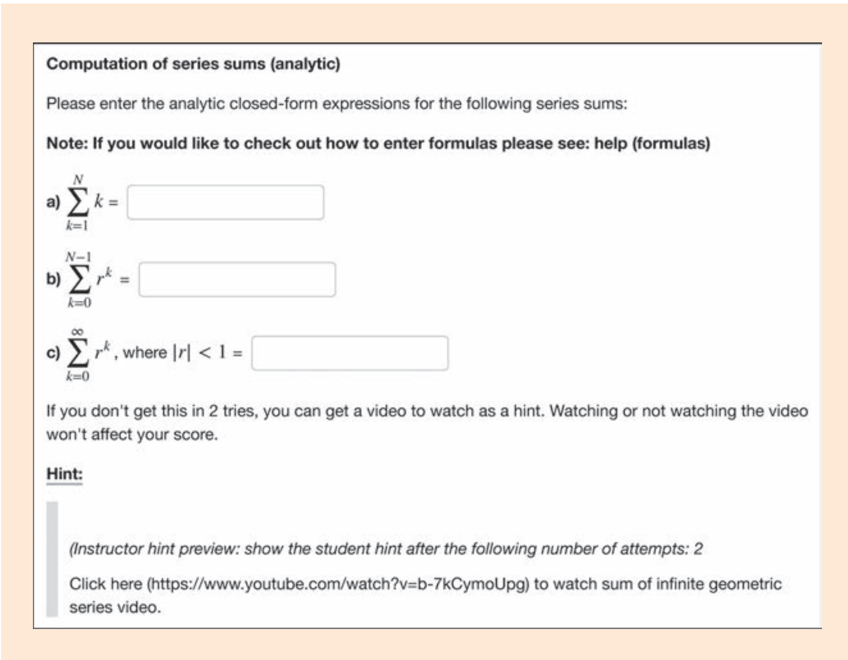
**c)** $1e^{j3\pi/4}$

Cartesian form = ____ + ____ $j$

**d)** $5\sqrt{2}e^{-j3\pi/4}$

Cartesian form = ____ + ____ $j$

**FIGURE 1.** Example SigPrep problems from the complex numbers module that illustrate polar and Cartesian representations.



**Computation of series sums (analytic)**

Please enter the analytic closed-form expressions for the following series sums:

**Note: If you would like to check out how to enter formulas please see: help (formulas)**

**a)** $\sum_{k=1}^{N} k =$ ____

**b)** $\sum_{k=0}^{N-1} r^k =$ ____

**c)** $\sum_{k=0}^{\infty} r^k$, where $|r| < 1 =$ ____

If you don't get this in 2 tries, you can get a video to watch as a hint. Watching or not watching the video won't affect your score.

**Hint:**

*(Instructor hint preview: show the student hint after the following number of attempts: 2*

Click here (https://www.youtube.com/watch?v=b-7kCymoUpg) to watch sum of infinite geometric series video.

**FIGURE 2.** Example problems from the series module in SigPrep. Note that the instructor view shows the hint that is built into the problem through the WeBWorK infrastructure and that provides a link to a video that covers the concepts involved. When students attempt the problem, the hint is displayed only after they fail to get the correct answers after two attempts.

with Cartesian and polar representations of complex numbers, where the hint specifically encourages the students to graph the numbers on the complex plane to gain better intuition.

### Trigonometric identities

Trigonometric identities play a key role not only in the signals course but in subsequent classes covering communication systems. Key among these is Euler's formula, i.e., $e^{j\theta} = \cos(\theta) + j\sin(\theta)$, which 1) provides students a connection between the real-valued sinusoids that they are familiar with from circuits classes and the complex-valued sinusoids that are the mainstay of signals and systems analysis and 2) facilitates a ready derivation of most of the other commonly used trigonometric identities. Trigonometric identities dealing with sums and the products of sinusoids provide intuition regarding the duality between multiplication and convolution in time/frequency domains and, importantly, illustrate the frequency components resulting from modulation. Therefore, SigPrep includes a module with problems regarding trigonometric identities.

### Series

Discrete signals are represented by series, and computing the convolution of discrete-time signals commonly involves series summation. Additionally, series also play a role in discussions of Fourier transforms and series and of sampling. SigPrep includes a module covering series, focusing particularly on geometric series, which are extensively utilized in introductory signals courses. Figure 2 illustrates problems from the module, which also includes embedded hints through WeBWorK that are selectively shown after students fail to get a correct answer following a specified number of attempts.

### Differentiation

Basic rules of differentiation, including the chain and product rules, as well as derivatives of common functions, such as polynomials and exponential functions, are generally required for problems in continuous-time signals and systems. SigPrep therefore includes a module focusing on differentiation that provides a refresher for these concepts. Note that the module particularly emphasizes the concepts from the differentiation required in the signals class and thus does not involve problems concerning the derivatives of various other functions that may be encountered in a first class about calculus.

### Integration

Just like differentiation, the basic rules of integration and a few common integrals are essential for the signals course. SigPrep includes a module about integration that reviews topic by parts and the commonly required integrals in a signals course, specifically, the integrals of polynomials and exponential functions and cosine/sine functions. Again, the emphasis is on covering the concepts that are directly required and in reinforcing students' intuition, rather than providing an exhaustive review of what pupils may have already seen in a calculus course.

### Differential equations

Linear constant-coefficient differential equations (LCCDEs) play an important role in a signals course for two key reasons. First, LCCDEs define causal linear time-invariant, continuous-time systems under auxiliary conditions of initial rest. LCCDEs are, therefore, a recurrent theme in the signals class, specifically during the initial discussion of system representations and then through the study of Fourier series and (continuous-time) Fourier and Laplace transforms. A second reason why LCCDEs are important in the signals course is because they arise naturally in the analysis of circuits constructed from passive resistive, inductive, and capacitive elements [i.e., resistor–inductor–capacitor (RLC) circuits]. Techniques for analyzing and solving LCCDEs representing linear time-invariant systems are covered within the signals course. SigPrep thus includes a brief module on differential equations (see the example in Figure 3) that focuses on helping students understand that LCCDEs represent a narrow class of differential equations when compared to those they have encountered in mathematics courses on the topic and to recollect that circuit equations for RLC circuits are naturally LCCDEs. Through the latter connection, this module of SigPrep also seeks to help students appreciate how the relatively abstract discussions of LCCDE systems in the signals course relate to what they have learned in prior physics and circuits classes.

### Logic

As noted in the "Introduction" section, the signals course is also often the first time that students encounter abstraction and abstract reasoning in the ECE curriculum. Problems that require students to demonstrate that a system satisfies certain properties (e.g., linearity/nonlinearity and causality) require such abstract reasoning and an understanding of basic logic and approaches to proofs. Such problems occur during the early phase of the signals class and are often challenging for students who have not previously taken a "proof-based" course. SigPrep, therefore, also includes a module (see example in Figure 4) covering logic that is designed to help students appreciate key concepts, such as the equivalence between a statement and its contraposition and that, while a counterexample can disprove a hypothesis, examples do not prove a hypothesis. Several of the problems in this SigPrep module have been adapted from the questions prepared by Warren and Norah Esty for the methods of proof class offered at Montana State University [15].

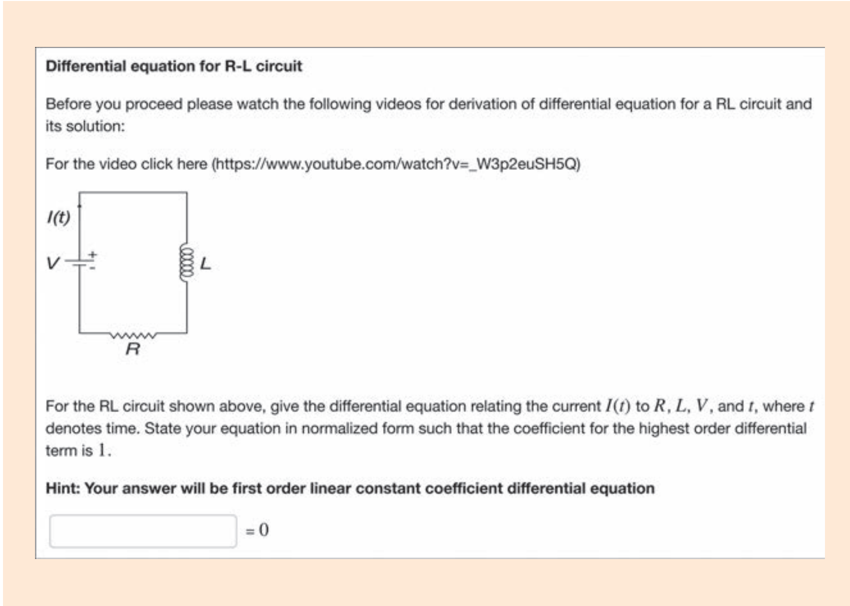



**FIGURE 3.** A problem from the differential equations module in SigPrep.

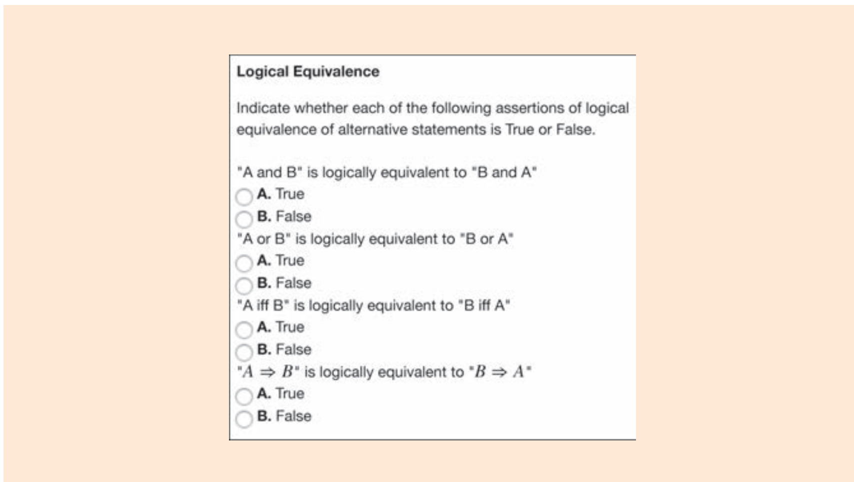



**FIGURE 4.** Example problems from the logic module in SigPrep.

### Signal manipulation

Early concepts introduced in the signals course are quickly reused in developing subsequent material in the class. Examples of such concepts include transformations of the "time" axis, even/odd signals, and periodic/nonperiodic signals. For students that take some time to become comfortable with these ideas, the quick reuse poses a challenge for staying abreast of the material being

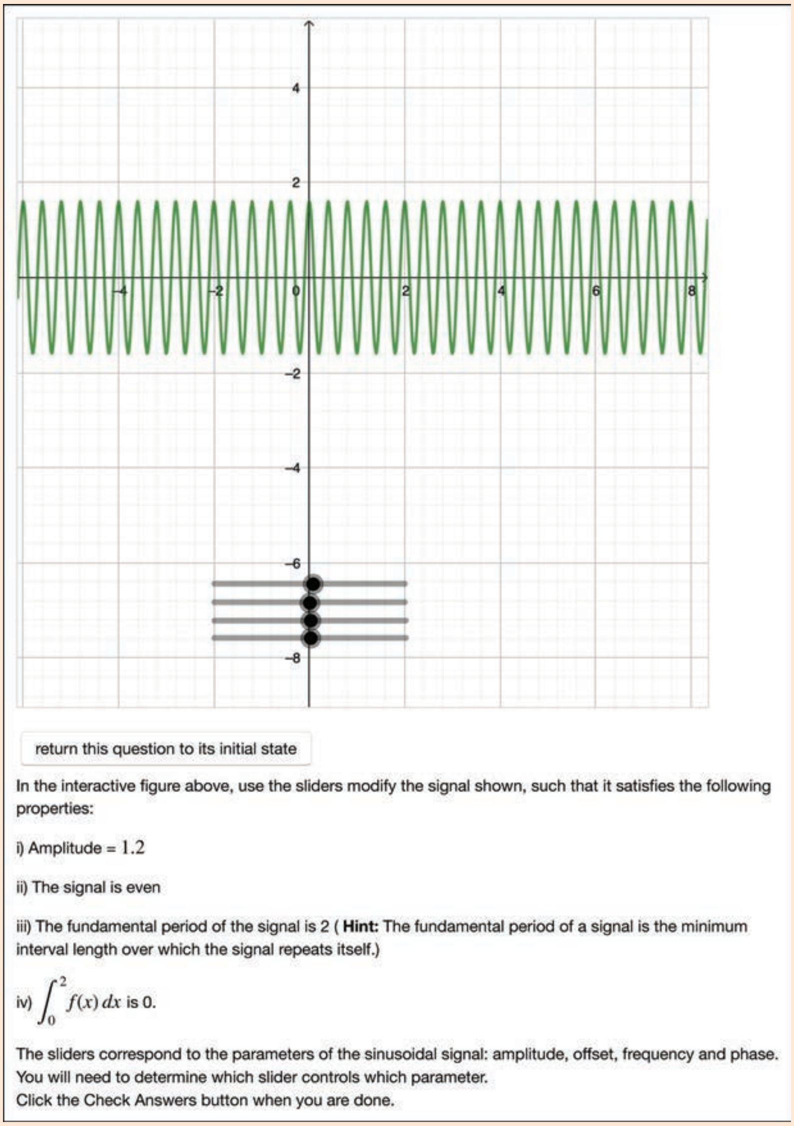



**FIGURE 5.** An example problem from the signal manipulation module in SigPrep that also illustrates the support in WeBWorK for interactive input and visualization.

presented. To mitigate this challenge, in SigPrep we also include a short module on signal manipulation that introduces these ideas and helps students to develop a more intuitive understanding by visualizing the manipulations expressed in the mathematical equations. Figure 5 shows an example SigPrep problem from this module that allows the students to use sliders to alter specific attributes of signals to match desired target values.

## Experience with SigPrep

We incorporated SigPrep into our teaching of the introductory class on signals and systems at the University of Rochester during the fall 2018 semester. In this section, we share our experiences with using SigPrep and present summary data from three sources. First, we summarize responses from a survey of students who were given SigPrep as a precourse assignment. In the survey, students were asked about the utility of SigPrep and the individual modules within the program. Second, we analyze data from WeBWorK, which provides detailed tracking information for individual problems; instructors can access the number of attempts and scores for each problem and also partial credits awarded on multiple-part questions. Finally, we present a comparative analysis of student performance between 2018, when SigPrep was first deployed, and the preceding year. We recognize that the data we present are limited and encourage other adopters of SigPrep to potentially explore a larger statistical study with appropriate upfront planning and suitably chosen control groups.

### *Student assessment of SigPrep helpfulness*

We surveyed students after they completed the introductory class on signals and systems at the University of Rochester, where SigPrep was assigned prior to the semester during which they took the class. The survey was relatively short and asked students to indicate whether or not SigPrep and the individual modules within the program helped in preparing for the material covered in the course. Each question included three possible responses: “helped a lot,” “helped,” and “did not help.” Additionally, the survey asked students if they used the web links embedded as hints within SigPrep that provide pointers to relevant review material for individual problems (e.g., at the Khan Academy) and if they found this feature helpful. A field in the survey also invited students to provide their own comments on SigPrep as free-form text. Thirteen students responded to the survey.

The students’ experience with SigPrep was quite positive. For SigPrep overall, all respondents indicated that they found the program helpful, and one respondent replied that it helped a lot. Figure 6 summarizes the students’ responses to the survey regarding the helpfulness of individual modules. Among the modules, complex numbers, integration, trigonometric identities, differentiation, and series seem to be most useful for students. On average, 90.6% of the respondents found these modules helpful. The two modules that had the most responses indicating that they “did not help” were differential equations and logic, where 41.6 and

23% of the respondents, respectively, replied negatively. These modules in SigPrep may potentially benefit from a better adaptation of the questions to material that is relevant to the introductory class on signals and systems. Seven of the respondents used the embedded links to external sources provided as hints within SigPrep, and all but one of them indicated that they found this feature helpful. The text comments that students provided were positive. One student stated, "It was generally very useful on having us figure out what kind of math was going to keep coming up in the course (which it did mostly effectively)," and another wrote, "I liked it. It gave me the opportunity to refresh math that I hadn't used in a long time."

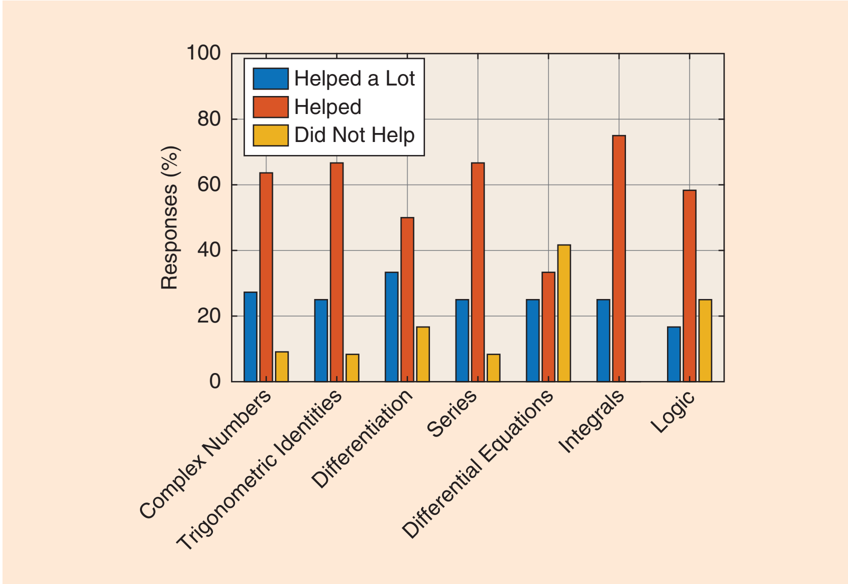



**FIGURE 6.** Student survey statistics concerning the helpfulness of individual SigPrep modules.

### *WeBWorK statistics for SigPrep*

We analyzed data from the WeBWorK platform for the different SigPrep modules from the precourse assignment for the fall 2018 class, which included 48 students that completed the assignment. Given that the goal of the SigPrep assignment is to provide students with a refresher for background prerequisites for the introductory course in signals and systems, pupils were allowed multiple attempts for each problem, where they could also refer to external sources between attempts. Figure 7 presents summary statistics for each SigPrep module, listing both the average percentage scores for the problems in the module and the average number of attempts per problem. The average percentage scores can be seen to be relatively high for each module, with several modules achieving close to the maximum possible 100% average. The average number of attempts per problem is close to five for the exercises in most of the modules, with the exception of the complex numbers and the series modules, which average more than 10 attempts per problem, and the logic module, which averages 2.99 attempts per problem.

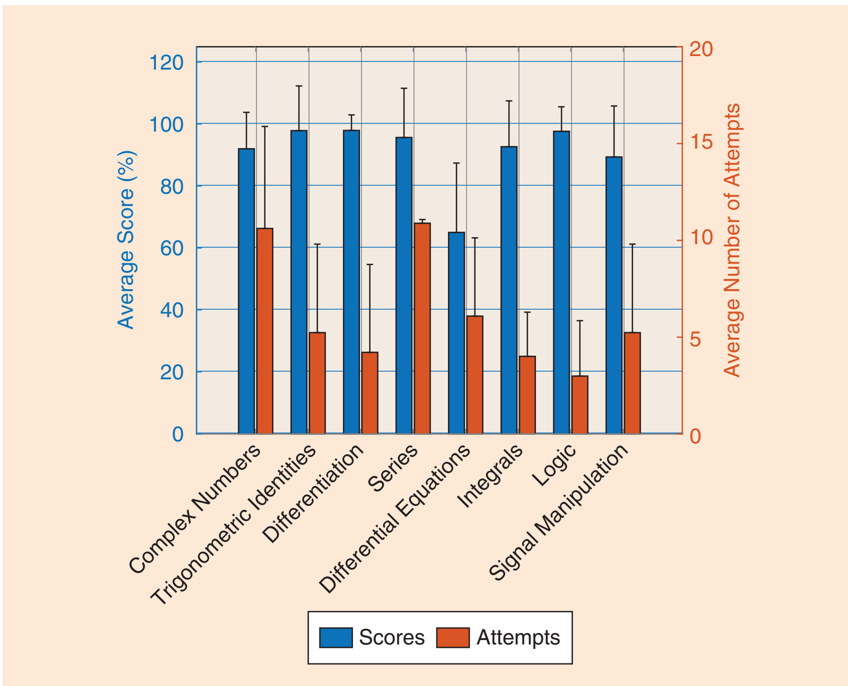



**FIGURE 7.** WeBWorK statistics related to the number of attempts and student scores for SigPrep modules. The bar plots indicate the average percentage scores and the number of attempts for problems in each module of SigPrep. The bar lengths correspond to one standard deviation.

The data indicate that, invariably, students attempted the problems until they got the correct answer. An exception to this appears to be the differential equations module, where the average score was 65.06% and significantly below the averages for the other modules. We note that the individual problems in the complex numbers and the series modules had multiple subparts, which likely contributes to the much larger number of attempts per problem for those modules. The fact that students reattempted problems until they got the right answers also indirectly highlights an advantage of constructing SigPrep as a self-paced WeBWorK assignment rather than a more conventional one, where students would submit responses to be graded by the instructor

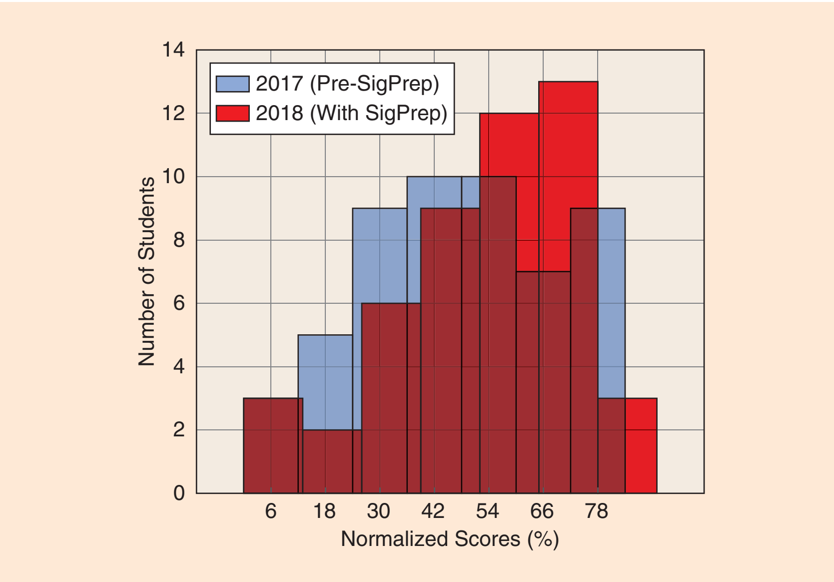



**FIGURE 8.** A comparison of the student score distributions for the final exams for the fall 2017 pre-SigPrep and the fall 2018 SigPrep editions of the introductory course in signals and systems at the University of Rochester. The histograms are shown on a transparent overlay along with the corresponding fitted normal distributions, where the 2017 data are presented in blue and the 2018 data appear in red.

or teaching assistant. Clearly, the immediate evaluations of the answers that WeBWorK provided to students upon the submission of their answers motivated the pupils to attempt problems until they got a correct answer, which is something that would be practically infeasible using the more conventional assignment format.

### *Comparison between classes with and without SigPrep*

Authors Sharma and Demir served, respectively, as the instructor and a teaching assistant for both the fall 2017 and the fall 2018 editions of the introductory course in signals and systems at the University of Rochester. The fall 2017 course was taught before SigPrep was developed, whereas, as already noted, SigPrep was given as a precourse, self-paced assignment for the fall 2018 class. To enable an, admittedly limited, comparison of student performance across these two years, a common set of problems was used on the final exams for both courses. Specifically, the 2018 final exam included the problems that were in the 2017 exam while including one additional question. For the subsequent analysis and discussion, we use only the data from the common problems. We also note that, during prior years, final exam problems were not reused. Also, the exam format required students to provide their answers within the spaces provided on the question paper, and (graded) final exams were not distributed back to students. In the 2017 and 2018 classes, 53 and 48 students, respectively, took the final exam.

Figure 8 compares the student score distributions for the two years, and the results are presented as histograms of the percentage scores on a transparent overlay. The mean for the fall 2018 class that used SigPrep was 53.7% and higher than the 47% mean score for the fall 2017 class that did not use SigPrep. The differences between the fall 2017 and fall 2018 distributions were found to be statistically significant at the traditional 5% significance level by using a two-sample Kolmogorov–Smirnoff (KS) test. Specifically, the KS tests rejected the null hypothesis that the score samples for 2017 and 2018 come from the same distribution, with a $p$ value of 0.0294. We observe that the performance improvement is even more noteworthy given that the 2018 exam included an extra problem, potentially subjecting the students to more time pressure. Also, while SigPrep was not available and not used for the 2017 edition of the class, the instructor did send a preclass announcement to the students that listed specific prerequisite topics to review along with pointers to appropriate web resources.

## Summary and outlook

We present and share SigPrep with signal processing educators and students. SigPrep is designed as an open [11], [16] web-based, self-paced precourse assignment that aims to refresh students on required mathematical prerequisites for a first class covering signals and systems. In this article, we shared the pedagogical motivations for SigPrep and its modules and preliminary data from our experiences with using the program in our teaching. We hope other signal processing educators will also find SigPrep useful in their teaching and that they will contribute both additional problems and data/analysis from their own experiences, which can help further refine and improve SigPrep.

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# READER'S CHOICE (continued from page 6)

with different characteristics. The proposed scheme combines a lower mm Wave band with exclusive access and a higher mm Wave band where spectrum is pooled between multiple operators. It is shown that, compared to traditional fully licensed or fully pooled spectrum-access schemes, this approach offers increased throughput and spectral efficiency as well as higher fairness.

*2017*

### Radar-Communications Convergence: Coexistence, Cooperation, and Co-Design

*Chiriyath, A.R.; Paul, B.; Bliss, D.W.*

This article studies the problem of radar communications coexistence and describes the challenges in achieving radar-communications radio-frequency (RF) convergence. The RF convergence problem is formulated as a joint information problem, and the estimation rate is introduced as a novel parameterization of radar performance. The meaning and interpretation of the estimation rate are discussed. Then, results for several joint radar-communications information bounds and their accompanying weighted spectral-efficiency measures are presented.

*2017*

### D-DASH: A Deep Q-Learning Framework for DASH Video Streaming

*Gadaleta, M.; Chiariotti, F.; Rossi, M.; Zanella, A.*

This article presents D-DASH, a framework that combines DL and reinforcement learning techniques to optimize the quality of experience of the dynamic adaptive streaming over HTTP (DASH) standard. Different learning architectures are proposed and assessed, combining feedforward and recurrent deep neural networks with advanced strategies. D-DASH designs are thoroughly evaluated against prominent algorithms from the state of the art using performance indicators such as image quality across video segments and freezing/rebuffering events.

*2017*

### An Overview of Dynamic Spectrum Sharing: Ongoing Initiatives, Challenges, and a Roadmap for Future Research

*Bhattarai, S.; Park, J.-M.J.; Gao, B.; Bian, K.; Lehr, W.*

This article considers the global paradigm shift to more flexible, dynamic, market-based ways to manage and share radio spectrum resources. It provides a comprehensive review of important trends, regulatory reform initiatives, and research challenges that are a part of the ongoing systematic efforts toward dynamic shared spectrum. It focuses on current efforts to implement database-driven approaches to manage sharing among multiple classes of users with heterogeneous access rights and radio network technologies and discusses open research challenges.

*2016*

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