Lessons Learned from the Application of Online Homework Generation Modules in a Signals and Systems Course

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Abstract—**Online engineering education tools present students with flexible access to local/distance learning resources and offer an opportunity to maintain student engagement via the use of dynamic interfaces. This paper addresses lessons learned from the creation and use of online homework generation modules in an electrical engineering signals and systems course. The nine modules address complex number calculations, complex conversions, signal graphing, zero input response, unit impulse response, Fourier series, and fast Fourier transforms. The primary goal was to create an innovative and engaging set of online learning experiences that would allow faculty to assess the transfer of mathematical knowledge from calculus and differential equations courses to subsequent electrical engineering courses. These modules offer student-specific problem generation and automatic grading, where the latter accelerates the feedback cycle and provides tool scalability to large numbers of students. The tools are easily upgradeable and offer the opportunity to track, through a database, elements of the student learning process that often go unrecorded but yield a rich data set for correlating performance on related subjects in current, previous, or subsequent semesters.**

The modules have been employed nine semesters to date, and student survey data from these experiences supplement data stored in the database files and data recorded from written examinations. Student reactions to these tools have been generally positive, where the ease of answer entry plays a large role in the experience. Quantitative correlations between module scores, grades on written examinations, and performance in previous mathematics courses have demonstrated variable clarity, but qualitative assessments of the technology-facilitated environment point to a clear increase in student learning and engagement. Instructor benefits are apparent with regard to grading time saved, grading consistency, confidence in student accountability for work submitted, and information regarding when/where students work that is difficult to obtain any other way.

Keywords—**Automated assessment, knowledge retention, linear systems, mathematics, online education, signals**

I. INTRODUCTION

A. Motivation

Internet-enabled engineering education tools are increasingly popular, as they offer flexible access to learning resources and help to maintain student engagement. Some of these resources, offered through universities and publishers, provide alternatives to traditional homework [1-6]. They incorporate automatic grading, which shortens the feedback cycle, releases instructors from this time-consuming task, and promotes tool scalability. Database support offers researchers the opportunity to track learning elements that are not often recorded but offer insight into the learning process [7-10].

EECE 512 – Linear Systems is a senior-level course taken by Kansas State University (KSU) Electrical Engineering and Computer Engineering students. The course covers time- and frequency-domain concepts germane to signals and systems, focusing on mathematics and computation. Faculty that teach Linear Systems see students struggle with calculus and differential equations concepts (the course prerequisite base), raising the issue of how much students learn in these courses and the amount they retain over time. One could ideally track knowledge transfer from semester to semester, but this is difficult because per-problem scores and the related concepts are rarely recorded in prerequisite courses. Further, methods to assemble and maintain academic performance data vary even in the same department, so obtaining a picture of cross-department performance over time can be elusive. Finally, students take Linear Systems at different points in their curricula, so while some students may have recently learned mathematical material, other students may have learned the material years earlier. Without problem-by-problem records dating back years, assessing retention in topic areas can be elusive.

Improvements are needed in (1) standards for concept-based partitioning and storage of assessment data and (2) tracking and data-mining tools that improve storage and analysis granularity. This expectation is realistic in quantitative science and engineering fields, where it is straightforward to bound most concepts and define metrics that map to concept learning. This toolset and its supporting cyber-infrastructure (e.g., databases, networks, etc.) must be scalable, as hundreds of KSU students take mathematics and engineering courses every semester. If information systems will play a large role, one can infer that computer-based learning tools will also play a role: not only are they better suited to database population than traditional homework methods, but they offer the potential to keep students engaged, improve student access to resources via Internet-enabled consumer electronics, and automate the homework process and release resources for use elsewhere.

B. Approach

The goal of this effort was to create online tools that would improve the homework experience and yield data sets useful to assess mathematical knowledge retention over multiple semesters. The KSU Department of Mathematics has developed online homework tools for Trigonometry, Calculus, and Differential Equations [7, 9, 10]. To facilitate the assessment of knowledge retention between these early mathematics courses and follow-on Linear Systems courses, the software architecture for the mathematics modules was mirrored in the online Linear Systems modules. This provides a consistent database structure between the courses, facilitating correlations. This architectural mapping also means that content developed by programmers in the Department of Mathematics or the Department of Electrical & Computer Engineering can be integrated more easily with content developed in the opposing department.

II. METHODOLOGY

A. Software Architecture and Information Flow

The software architecture for the automated homework modules is illustrated in Fig. 1. The main page that displays each problem set, receives student responses, and provides help is written primarily in PHP [11] embedded into HTML [12] scripts. The grading parser is programmed in Java [13], and the database is built with PostgreSQL [14]. Some JavaScript [15] code is used in the main page; it calls a Java parser function to check expression syntax. Relationships between these languages and the software capabilities of the online system are shown in Fig. 1. The client tier represents the system users and requires an Internet browser. The client computer must have the Java runtime environment installed. The middle (application) tier contains an Apache server [16], which fulfills basic web server requirements and supports PHP. The resource tier hosts the PostgreSQL database.

The online homework system consists of the problem generator, the expression parser, and the database. The problem generator creates problem parameters, prepares problem statements, determines solutions, grades answers, and creates help listings. The expression parser checks student input syntax and 'reads' the input functions. The PostgreSQL database stores student information, records student/system interactions, and saves problem set scores.

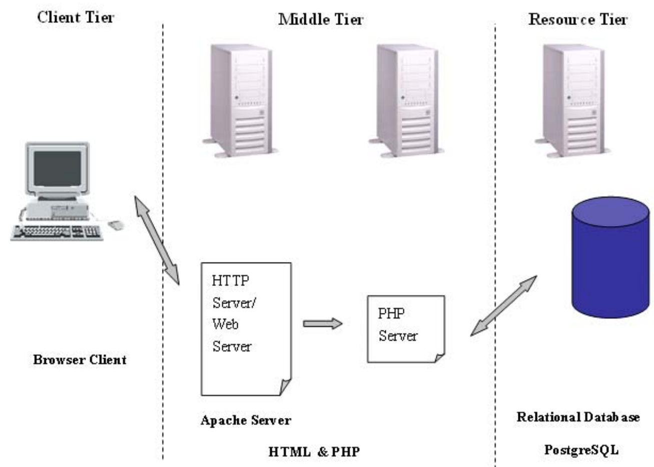

Fig. 1. Software architecture for the automated Linear Systems homework modules.

B. Session Approach

After login, the student requests a problem set, which is created uniquely for them using a bounded set of random parameters. The student can either work at the computer or save their session, returning later to submit and grade their answers. A parser checks the syntax of each expression entered by the student. If it cannot be parsed, it must be fixed prior to grading. Once answers are submitted, the computer shows the student which problems are correct. The student has one chance to fix incorrect answers (two-stage grading is a recent student-requested addition). After this final grading stage, the module calculates a score, and hyperlinks provide detailed problem solutions. A student can repeat a module as many times as desired before the due date; new problems are created for each repeated module. The highest score received for any problem set is stored in the database as the final module grade. For most modules, a student does not need to repeat the entire module if a perfect score is not obtained on a previous attempt. To receive additional credit, only the types of problems which were incorrectly solved must be reworked. After the module due date, the student can continue to work practice problems.

Modules take between 30 minutes and two hours, and browser locations can be off-campus. With few exceptions, students must enter completely correct expressions to receive points. Rational expressions must use integers in their numerator and denominator. The parser supports simple constructs such as *, /, sqrt, pi, cos, sin, and tan. Values such as a half must be entered as "1/2" and not 0.5. The standard order of operations is applied to nested groupings separated with parentheses. Fig. 2 depicts a Linear Systems student interacting with the online homework system.

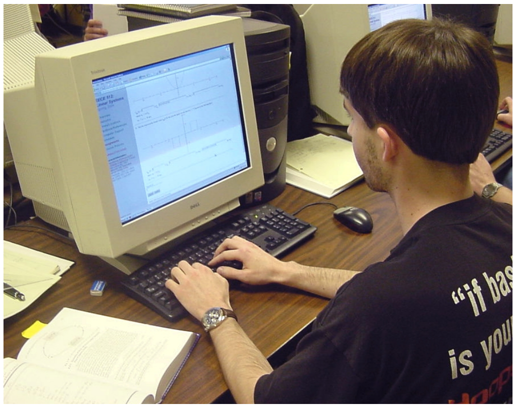

Fig. 2. Linear Systems student working a Fourier series problem.

C. Module Topics

Online module problems are similar to those typically assigned as written exercises, and they use course textbook notation [17, 18]. The module topics follow (refer to [17] for module details and to [8] for an example session):

1. **Complex Arithmetic:** The first complex number module addresses multiplication, division, and complex number magnitudes in Cartesian coordinates ($a + jb$).
2. **Complex Conversions:** The second module starts with Cartesian-polar ($ce^{j\theta}$) conversions then finishes with a problem to merge sine/cosine functions at the same frequency into one cosine with a magnitude and a phase.
3. **Signal Graphing:** Each of three multiple choice problems gives a mathematical expression that is a combination of impulse, rectangle, exponential, sinusoidal, and unit step functions. The student must choose one graph of four that matches the expression.
4. **Zero Input Response:** This transient response module seeks the output expression for an unforced 2^{nd}-order, time-invariant system. The differential equation and initial conditions are specified, and the student must enter the time-domain expression. Three problems address three types of eigenvalue (root) pairs: distinct real roots, repeated real roots, and complex roots.
5. **Unit Impulse Response:** The second transient response module seeks a system's unit impulse response given its differential equation. It addresses 2^{nd}-order systems with distinct, repeated, and complex roots.
6. **Trigonometric Fourier Series:** Given three problems, the student must calculate the Fourier coefficients for the sine and cosine basis sets used to rebuild each function. Time-domain signals consist of even/odd functions built from pulse, sawtooth, parabola, triangle, trapezoid, ramp, and exponent functions. Coefficients are entered as expressions of n, the harmonic index.
7. **Compact Trigonometric Fourier Series:** This module assumes a basis set of cosines with different magnitudes and phases. The coefficients can be complicated expressions of n, so the students find and enter numerical coefficients for $n = 0$ to 3.
8. **Exponential Fourier Series:** This module uses reconstructions that employ complex exponential basis sets.
9. **Discrete Fourier Transforms:** Given analytical signals, the student chooses sample rates and signal durations that retain important signal information.

III. Results and Discussion

A. Quantitative Results

These modules have been used for nine semesters. Attempts to correlate module scores with performance on exam questions offer mixed results. In fact, contrary to the desired outcome, final exam scores can in some cases be correlated more strongly to written homework scores than to online homework scores [17], making one consider the role of the question format in the respective domains as well as the level of learning required to respond to these questions.

Sensible reasons exist as to why correlations between module scores and exam scores are difficult. First, even students who study less or are less capable will work modules repeatedly to get desired scores. One then looks at the number of module attempts, inferring that good students will make fewer tries. This assumption can mislead, as good and poor students will often generate multiple problem sets to find easier problems. They will also generate multiple sets to gain access to help (worked problems) so as to obtain references for follow-on problems.

Even with these artifacts, earlier studies indicated that online homework data can quantitatively show transfer of learning between Differential Equations and Linear Systems, even so far as to predict which students will succeed in Linear Systems based upon performance in Differential Equations online modules. More specifically, speed of mastery of material in Linear Systems appears to be correlated to the acceleration of the speed of mastery of three assignments in differential equations relating to Laplace transforms [19]. However, this correlation is not stable when applied to all semesters. Current assessments seek to determine whether this relationship is coincidental or whether it depends on the instructor teaching the class.

The current reasonable conclusion is that these modules appear neither to improve nor harm learning (exam scores have not decreased), consistent with results from other investigators [4]. The issue then becomes one of student perception, understanding that student learning increases when students are engaged, when they like the experience, and when they receive rapid feedback on grades [20]. That is, student reactions to the learning experience are a powerful motivation to continue this development, even if learning benefits are hard to quantify. The next section therefore focuses on the student perceptions gathered from surveys.

B. Student Survey Feedback

At the end of each semester, students completed surveys that addressed their perceptions of the learning experiences.

Surveys were given nine semesters to a total of 359 students. The first page of the survey contained 21 statements with quantitative responses. Table 1 lists these questions and results. The second page consisted of open-ended questions:

- What did you like the most about the online modules?
- What did you like the least about these modules?
- How can the online learning experiences be improved?

Tables 2 and 3 list common answers for the first two questions and note their relative percentage (e.g., of the positive comments received on Spring 2004 (S04) surveys, 41.3% focused on the benefits of instant grading and feedback).

Breaking the statements into themes helps to interpret the first survey page (Table 1). **Theme 1 centers on *student accountability for their learning* and their tendency to address modules *alone versus in groups* (Questions 6, 8-12, 14, 15, & 21).** Students felt homework matched to individuals was fair (q6–4.1), and their attitudes about online experiences were unaffected by others' opinions (q9–2.3). It was nice to note that these students tended to work alone rather than in groups (q10–3.9), relied less on others (q11–3.4), and learned better on their own given the help provided by the modules (q21–3.9). Regarding accountability, students did what was needed to get scores of 100% (q12–3.9), and it can be understandably stressful to receive all points or none (q8–4.0). The authors find it surprising and admittedly disappointing that students believe they should get 100% if most of their answers are correct (q14–3.5). Equally disappointing was students' ambivalence regarding the link between learning and accountability for ensuring their answers were correct prior to entry (q15–3.1).

Theme 2 focuses on the students' like/dislike of the *process*, including module *features* (Questions 3-5, 8, 17, 18, 20, 21). It is not surprising that a lack of interpersonal interaction was not an issue (q17–4.0), as students interact often with machines. This makes outside access important (q18–4.7), since many of these students will wish to work at home. The immediate feedback motivator (q3–3.9) was clearly tempered by the presence of software bugs (q5–4.4), which can be hard to avoid with student-written code and frequent functionality updates. While students found it stressful to receive all points or none for a problem (q8–4.0), this is unavoidable, since a programmer cannot anticipate the myriad ways students might format expressions. Additionally, when a student gets little or nothing correct on handwritten homework but still shows work, some graders assign partial credit. In a computer-based system, no interim work is sought, and a computer cannot be expected to 'fix' an answer or look for pieces of a correct answer, so no partial credit is given. (Note: problems with multiple fields offer the possibility for 'partial credit.') Finally, students stated that online help was effective (q20–3.9) and that it facilitated learning on their own (q21–3.9). Surprisingly, few students took advantage of the practice feature (q4–3.1)

Theme 3 addresses *students' perceptions* of how their *learning* is affected by these resources (Questions 1, 7, 13, 15, 16, & 21). Overall, students noted that online modules are effective learning tools (q1–3.8) and that these tools aid learning on their own (q21–3.9). However, instructors that have noted how much more they learn when they are accountable to teach others will find it unsatisfying to read that students do not feel they learn more when they are accountable for entering correct answers (q15–3.1). It is disappointing but understandable to receive feedback that online tools do not make learning more efficient (q7–3.3). One message from this survey is that students do not have a sense for where they reside on the learning spectrum. They see little need for modules to move toward higher-level learning (q13–2.9), yet they state that the current modules do not lead to deeper understanding (q16–3.3).

Theme 4 addresses students' *general perceptions* of the online experience (Questions 1, 2, 7, 16, & 19). They believe online tools are effective (q1–3.8) and that more engineering courses should use them (q19–3.7). This contrasts with their assessed value of computer-generated versus handwritten problems (q2–3.0), their perception that online learning is not efficient (q7–3.3), and that these tools do not lead to deeper understanding (q16–3.3). This implies they like the process but find it hard to explain why.

From the **open-ended questions**, students clearly appreciate instant problem scoring (Table 2). Online answers and help (worked solutions) also optimize their time, and the ability to attempt modules until they receive desired scores has appeal. While the quantitative survey hints that students do not work practice problems in mass, the feature is clearly useful to a fraction of the students.

It is helpful to note the features the students did not appreciate (Table 3). As stated earlier, computer grading requires precise and parsable answers, forcing accountability not encountered in handwritten homework. The JavaScript syntax checker and second-stage grading help in this regard. Multiple choice questions might help, but they less effective from a learning standpoint. Also, since problem sets can be submitted until a student achieves the desired score, multiple choice questions would help a student obtain scores that do not reflect their level of understanding.

C. Other Comments

Automated homework systems allow educators to track student/system interactions that map directly to learning habits. Instructors can learn the number of attempts made on a given module, when students began their homework, how long they took to finish, and other information which has been traditionally unavailable without asking the students directly. The system also frees the instructor from a responsibility to create and assess homework problems, which can be a time saver in large classes. Additionally, since problem sets are randomly generated, instructors have greater confidence that students are responsible for their own work. Finally, worked problems alleviate part of the burden imposed on instructors during office hours.

Table 1. Quantitative survey questions and responses (reported as averages). Each column corresponds to a semester (e.g., S04 means Spring 2004). The final column incorporates the average student response for the nine semesters in aggregate.

Note your relative level of agreement with these statements using the following convention:
1 – Strongly Disagree; 2 – Disagree; 3 – Neutral; 4 – Agree; 5 – Strongly Agree

Number of Students	*46*	*38*	*34*	*59*	*59*	*37*	*26*	*27*	*33*	***359***
Statement	**S04**	**F04**	**S05**	**F05**	**S06**	**F06**	**S07**	**F07**	**S08**	**All**
1. Online modules are effective supplements to handwritten homework.	3.6	3.5	4.2	3.8	3.6	3.2	3.7	4.4	4.1	**3.8**
2. For homework problems where an expression is the final answer, I prefer computer-generated problems to handwritten homework.	2.9	2.7	3.6	3.2	2.9	2.4	3.1	3.4	2.8	**3.0**
3. I found the immediate scoring feedback to be a motivator.	4.1	3.8	4.2	3.9	3.8	3.7	3.8	4.1	4.2	**3.9**
4. I took advantage of the 'practice' feature in the online system, even if I had already received 100% on a given module.	3.3	3.3	3.4	3.1	2.6	2.8	3.2	3.0	3.1	**3.1**
5. The absence of software bugs would improve the experience.	4.5	4.6	4.2	4.3	4.4	4.3	4.4	3.7	5.0	**4.4**
6. These modules made homework fair in the sense that every student had equal access to resources (e.g., no student had solutions from previous semesters).	3.9	4.0	4.5	4.1	4.0	3.3	3.8	4.2	4.1	**4.1**
7. Online homework makes the learning process more efficient.	3.1	3.2	3.8	3.5	3.1	2.8	3.2	4.0	3.5	**3.3**
8. I found it stressful to receive 'all or nothing' (full credit or no credit) on answers that contained expressions.	4.2	4.3	3.9	3.8	4.3	4.3	3.7	3.5	4.0	**4.0**
9. My attitude toward these modules was affected (either positively or negatively) by comments made by other students in the class.	2.1	2.5	2.2	2.2	2.4	2.3	2.4	1.9	2.8	**2.3**
10. Because these problems were generated uniquely for me, I tended to work alone rather than in groups.	3.9	4.1	3.8	3.9	4.1	4.1	3.5	3.7	3.7	**3.9**
11. I found myself relying less on others because I knew that they had a different set of problems to solve.	3.3	3.7	3.6	3.2	3.4	3.5	3.4	3.3	3.2	**3.4**
12. I did whatever it took to receive 100% on each module, even if it meant working through the module several times.	3.6	4.1	4.3	4.0	4.0	3.5	4.2	3.8	3.8	**3.9**
13. I wish to see these modules migrate toward higher-level-thinking exercises rather than just problems that require numeric answers.	2.9	2.8	3.2	3.0	2.5	2.6	3.0	2.9	3.0	**2.9**
14. It makes sense that every one of my answers must be exact before I can get 100% on a homework set.	3.5	2.9	3.6	3.6	3.3	3.2	3.5	4.1	3.6	**3.5**
15. I learn more when I am accountable for double-checking my answers for accuracy prior to submission.	3.2	3.1	3.2	3.0	3.0	3.0	3.2	2.9	3.0	**3.1**
16. I have a deeper understanding of material when online work is a supplement to handwritten work.	3.0	3.1	3.7	3.5	3.2	2.8	3.4	3.9	3.6	**3.3**
17. The impersonal interaction with the computer is not an issue for me.	3.8	3.8	4.2	4.0	4.0	3.8	4.0	4.3	4.1	**4.0**
18. Access to online modules via external connections is more practical than access from only EECE computing laboratories.	4.8	4.3	4.8	4.8	4.7	4.6	4.6	4.8	4.9	**4.7**
19. More engineering courses should utilize online learning tools.	3.8	3.4	4.0	3.9	3.6	3.2	3.6	3.9	4.0	**3.7**
20. The online help and example solutions were effective supplements.	4.1	3.8	4.3	3.9	3.7	3.6	4.0	3.9	4.3	**3.9**
21. The online help made it easier for me to learn on my own.	4.0	3.5	4.2	4.0	3.7	3.5	4.0	4.0	4.0	**3.9**

Table 2. Features students liked the most.

Feature	**S04**	**F04**	**S05**	**F05**	**S06**	**F06**	**S07**	**F07**	**S08**
Instant grading and feedback	41.3	31.5	27	22	21	19	20	28.6	20
Online solutions and worked problems	39.1	26.3	48	20.3	28.3	30	25	14.2	12
Multiple attempts to achieve the desired score	34.7	31.6	19	28.1	16.4	32.4	25	32.6	20
Practice problems for test preparation	4.3	26.3	10	18	20	5.4	14.3	14.3	14

Table 3. Features students liked the least.

Feature	**S04**	**F04**	**S05**	**F05**	**S06**	**F06**	**S07**	**F07**	**S08**
Picky syntax	45.7	57.9	34.5	41.1	30.2	31.5	22.5	44.4	28
No partial credit	26.1	37	11	10	11.6	5.55	–	7.4	7
Software bugs	26.1	5.5	14.5	10.5	11.6	15	35	7.4	30
Too many attempts to get 100%	–	–	23.6	22.3	26.7	20.3	22.5	15	30

IV. CONCLUSION

This paper discussed an automated, online homework system and the lessons learned from its implementation in a Linear Systems course over the span of nine semesters. A primary motivation to create these tools was to track mathematical knowledge retention over multiple semesters. However, quantitative correlations between module scores, written examination grades, and performance in previous courses have yielded variable clarity. Overall, students have had positive experiences with these online modules, but they dislike the demand that the computer imposes in terms of syntax inflexibility and the requirement that all answers be correct in order to receive full credit. Instructor benefits are apparent with regard to grading time saved, grading consistency, confidence in student accountability for work submitted, and information regarding when/where students work that is difficult to obtain any other way.

Future work will include continued quantitative analyses of these increasingly numerous data sets in pursuit of statistically defendable conclusions regarding the effects of these tools on learning and their ability to identify means by which long-term retention can be improved. Additionally, work remains to move these experiences toward higher-level learning exercises which can benefit from the inclusion of improved interfaces and multimedia enhancements (graphics, animations, sound, etc.). These enhancements could have particular impact on the help offered by the modules. The removal and avoidance of software bugs are another clear goal. Modules which are syntactically difficult (e.g., the Fourier series modules) deserve an overhaul, which can be facilitated by means for easier answer entry and improved instructions for student/module interactions.

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