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WIP: Tracking Conceptual Growth and Misconceptions to Inform Instruction - A Pre/Post Study in Signals and Systems

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Abstract
This **work-in-progress** paper describes the use of evidence-based practice to develop high-quality educational research for learning and instruction. Signals and Systems is a mandatory course in the electrical engineering undergraduate curriculum at North Carolina State University. Not only does it apply past concepts from previous courses in the curriculum but also introduces new foundational topics that are important in subsequent courses. Therefore, it is important that students think critically about the new abstract concepts and applications they learn. One aspect of assessing student learning, that is important to understand, is both how and how much students learn in a course. One way to do this is to measure the students' conceptual understanding beyond mathematical formula manipulation. We seek to evaluate student learning in the signals and systems course using a validated concept inventory as a way of understanding students' conceptual learning. This idea is grounded in constructivist learning theory. For this study we conducted a pre-test at the start of the Fall 2025 semester using the Signal & Systems Concept Inventory developed by Kathleen Wage and John Buck, and then a post-test in the same two classes at the end of the semester. By assessing conceptual understanding before and after instruction, the Signals & Systems Concept Inventory enables identification of conceptual change and persistent misconceptions. This aligns with formative assessment principles, by using evidence of learning to inform instruction promoting reflective teaching practices.

Introduction
Signals and Systems is a foundational course in the undergraduate electrical engineering curriculum and plays a critical role in students' progression into advanced topics such as communications, control systems, and signal processing [1]. The course requires students to integrate prior mathematical knowledge while simultaneously developing new conceptual understandings of abstract representations, including time-domain and frequency-domain analysis. Due to the abstract nature of the material, students may succeed in procedural problem-solving without achieving deep conceptual understanding [2][3]. In engineering education, there is increasing recognition of the importance of assessing conceptual learning in addition to mathematical proficiency. Conceptual understanding supports knowledge transfer, long-term retention, and the ability to apply principles across contexts [4]. However, traditional assessments in Signals and Systems courses often emphasize formula manipulation, which may obscure persistent misconceptions [3][5].

This work-in-progress paper describes the use of an evidence-based assessment practice—a validated concept inventory—to evaluate students' conceptual understanding in a Signals and Systems course [6]. This paper provides the overall results of the pre and post tests. A previous paper [7] presented results on faculty and student perceptions of the usefulness of previously taught concepts in the context of the signals and systems course. Subsequent papers will provide matched pre and post test results, as well as faculty and student interviews.

Theoretical Framework
Constructivist learning theory posits that learners actively construct knowledge by integrating new information with prior understanding. From this perspective, learning involves conceptual change,

particularly when students confront misconceptions or incomplete mental models. Concept inventories align well with constructivist principles, as they are designed to probe students' conceptual reasoning rather than computational skill. By identifying both correct concepts and persistent misconceptions, concept inventories provide insight into how students make sense of course content and how instruction supports or constrains conceptual development. The history of the use of concept inventories is mixed. The most commonly used one is likely the Force Concept Inventory, which has been used since 1992. Concept inventories focus on concepts rather than mathematical manipulation. The benefit of this perspective is that students are not able to pattern match but must develop the type of understanding that allows them to transfer and integrate knowledge. This is part of the motivation for this current study, as we seek to understand and verify how courses fit into a scheme of pre and post requisites within the structure of a degree plan. Additionally, this work is informed by formative assessment principles. When used thoughtfully, assessment data can serve as evidence of student learning that informs instructional decision-making and promotes reflective teaching practices.

Background

Concept Inventories (CIs) have been widely used in engineering and physics education to assess conceptual understanding and instructional effectiveness. Instruments such as the Force Concept Inventory [8] have demonstrated the value of pre- and post-testing for identifying conceptual gains and instructional gaps. Within Signals and Systems education, the Signal & Systems Concept Inventory (SSCI), developed by Wage and Buck, has been validated as a reliable tool for measuring students' conceptual understanding of core topics [6]. Prior studies using the SSCI have shown that students often retain misconceptions even after completing the course, highlighting the need for instructional strategies that explicitly address conceptual reasoning. In addition to the existing literature on the SSCI, we also try to incorporate the idea of pre-requisite course influence on students' perceptions [7], especially in context of this validated CI.

Research Questions

The objective of this work-in-progress paper is to address key ideas around the following questions. What is the baseline conceptual understanding of Signals and Systems among students at the start of the course? How does student performance on the SSCI vary across major conceptual domains (Math, LTI, Filtering, Transforms, Convolution)? Which Signals and Systems concepts exhibit the highest prevalence of student misconceptions? Figure 1 shows where this paper fits in the scope of our larger project.

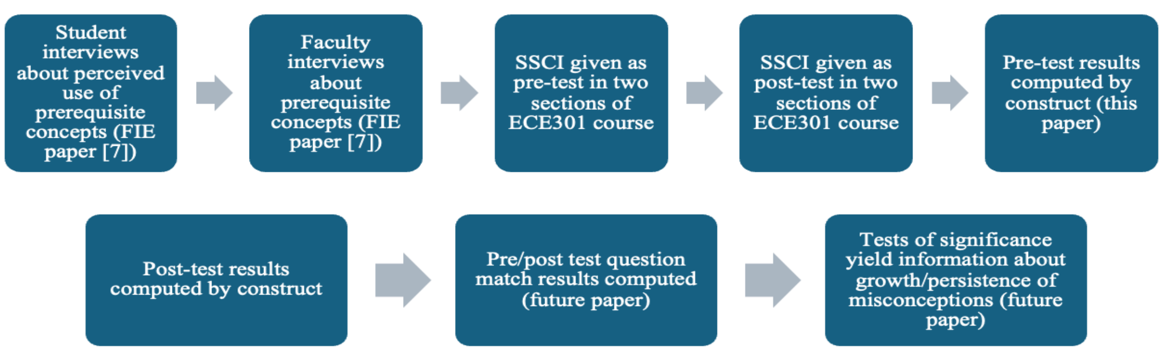

Figure 1: A mapping of the entire project and where the work of this paper fits.

Methods

The study was conducted at a large public university during the Fall 2025 semester. Participants included students enrolled in two sections of a required undergraduate Signals and Systems class, primarily composed of third-year electrical engineering majors. The two sections were taught by different instructors using similar course content but with some variation in instructional approaches. These variations will be discussed in future work. This work-in-progress paper presents results from the continuous time concept inventory. There is also a discrete time inventory, which we do not use, prepared by the same authors. The collected data were de-identified and results were analyzed to understand the base-level understanding of selected concepts by students at the start and end of this class. The data were coded for information like pre-requisite classes attended and whether students were taking the course for the first time.

A total of 208 students completed the pre-test at the beginning of the semester. Participation was voluntary. The post-test was completed by 185 students. Mapping of pre and posttests has yielded 168 matched sets for future work. This study was IRB approved under the protocol 28452. Before having the participants answer questions on the pre-test SSCI, we also collected the following information. Had participants taken the course before? Which of the prerequisite courses were taken at the same institution?

This study groups items the SSCI based on the procedure outlined in [6]. Previous work had identified five constructs defined by grouping questions from the inventory. The Math construct is composed of 5 of the 25 questions encompassing signal transformation, commutative property of convolution, and frequency of periodic time domain signals. The LTI construct is 3 of the 25 questions on time invariance, causality, and linearity. Filtering is formed from 2 of the 25 questions on low-pass filter magnitude and phase response. Fifteen of the 25 questions comprise the Transforms construct, which includes Fourier series, Fourier transforms and inverses, convolution, system properties of LTI systems, frequency filtering, Bode plots, and pole-zero plots. Finally, the Convolution construct (4 of the 25 questions) consists of questions on continuous time convolution, system properties of LTI systems, properties in time and frequency domain, cascade and parallel systems. Some questions belong to more than one concept.

Final results are expected to indicate conceptual growth and persistence of certain misconceptions in areas where current teaching methods require reinforcement. An additional effect that the complete study will capture is whether there are differences in outcomes by instructor. The instructor-dependent phenomena will be captured by interviewing the instructors on their approaches to teaching each concept as well as the SSCI outcomes. Pretest scores help understand class needs and what prerequisite knowledge students have. (This is particularly important, because some students have transferred course credits from other institutions).

Preliminary Results / Expected Outcomes

The highest score, meaning the group of questions on which students performed the best, was Math. The percentages for each of the groups (pre/post), are Math (70%/70%), LTI (40%/40%), Filtering (50%/55%), Transforms (35%/42%) and Convolution (33%/38%).

Figure 2 shows the pre/post-test results by construct. We do not present a question-wise comparison in this work-in-progress paper. The figure also emphasizes that students retain baseline mathematical concepts better than conceptual modeling tasks (LTI, transforms, convolution) before taking the class, but the post-test shows that they do better on procedural/math foundations than on single-domain operations, with filtering acting as a transitional hybrid concept. Therefore, the results collectively imply that: Students can perform math, but struggle to apply it in the transform domain. Performance in filtering exceeds transforms and convolution suggesting that students are able to reason about filtering without fully mastering transform-domain mechanics. This also ties back to their exposure to the topic in pre-requisite classes. Convolution appears to be the most burdensome concept.

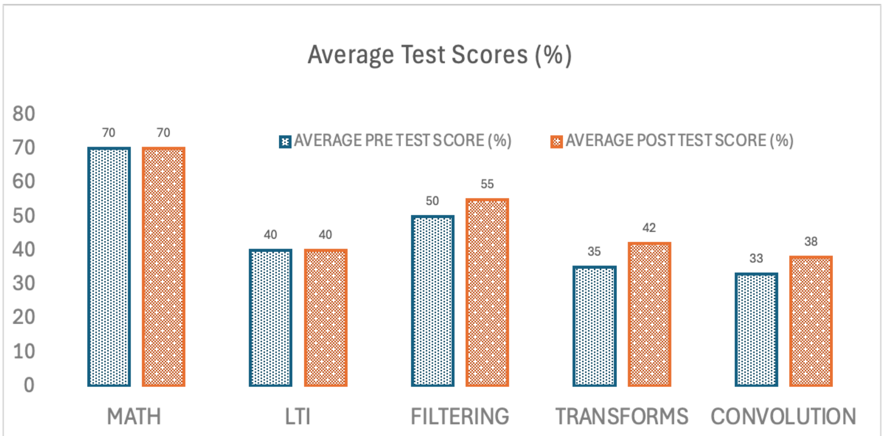

Fig 2. Composite scores from the pretest (N=208) and posttest (N=185), presented as a percent of correct answers across the five identified constructs.

The results of the pre-test are consistent with experience related by instructors. The results presented above show that students struggle with Convolution, Transforms and LTI system concepts. These findings emphasize that constructivist/formative methods are especially useful for improvement. For example, Buck points out that the SSCI specifically tests Fourier and convolution concepts and that teaching through active learning helps students to greatly outperform on those questions taught through lectures [9]. An example of this type of instruction includes Rao et al.'s labs, which put concrete signals (guitar notes) through LTI filters so students could see convolution in action; SSCI results showed significant gains on those topics after the labs [10]. These studies support the idea that when instructors anticipate common misconceptions (e.g. thinking convolution is "shifting without overlap") and use guided activities to create cognitive conflict, students revise their models more effectively.

Limitations

Several limitations surround this study. First, participation was voluntary, and student outcomes were dependent on response rates. Second, instructional techniques were not standardized across sections of the course. The pre-test experience for students has inherent variation because foundational may vary in efficacy. Any bias can be accounted for in the pre/post test design.

Conclusions and Future Work

Students in this Signals and Systems course appear to enter the course with more preparation in the Math domain, as defined by the CI. Growth was seen in the Transforms, Convolution and Filtering domains, but not in the Math or LTI domains. Future work will be guided by the following research questions: To what extent do students' conceptual understanding of Signals and Systems change from pre-instruction to post-instruction as measured by the SSCI? What misconceptions persist after instruction, and which concepts show the greatest or least conceptual gains (down to question-level granularity)? How do instructional approaches, as described by course instructors, relate to observed patterns in student conceptual understanding?

Pre- and post-test responses will be matched at the individual student level to measure conceptual change over time. In addition, semi-structured interviews are being conducted with both course instructors to document their pedagogical approaches to teaching key concepts assessed by the SSCI. The same exercise is being conducted in current classes to expand the dataset, which currently stands at N=168 (matched pre/post). We will also present results of any interventions that are implemented to improve the outcomes.

Acknowledgement
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