

RESEARCH ARTICLE

Incorporating Scientific Applications Into Engineering Education Through Interactive Simulation Software

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ABSTRACT

Many engineering courses primarily emphasize theoretical instruction, which not only impedes the development of students' practical skills but also diminishes their engagement. Various educational reforms have been introduced to enhance the real-world applicability and interactive nature of the classroom. However, these reforms often impose additional time and cognitive burdens on students. This study explores an approach to enhance teaching effectiveness and student engagement by combining extended knowledge with interactive simulation software. Specifically, we incorporate emerging photoacoustic computed tomography (PACT) technology into a university-level *Signals and Systems* course as a research case. The potential of this educational approach was assessed using Likert scale surveys, which indicated a promising improvement in students' understanding of complex concepts when utilizing interactive simulation software. Additionally, positive feedback from students further supports these findings. This study provides a comprehensive account of the implementation and potential advantages of these educational innovations, offering valuable insights for future developments.

1 | Introduction

There is a noticeable gap between engineering education and labor market demands, resulting in several social and educational challenges. Engineering education at many universities has not kept pace with the evolving skills required in the workplace, leaving graduates unprepared for employment [1–3]. A key factor in these challenges is the traditional educational model in engineering, which often prioritizes theoretical knowledge and foundational sciences at the expense of practical application, hands-on experience, and student engagement.

Accordingly, numerous educational reforms have been proposed to better connect higher education and market demands, such as the flipped classroom model [4], laboratory-based learning (LBL) [5], problem-based learning (PBL) [6], and industry–university collaboration (IUC) [7]. Among these, LBL has been widely adopted in many universities as an effective approach, as it allows students to grasp complex theoretical concepts more intuitively through experiments [5]. Moreover, advancements in computer technology and the emergence of simulation software have further facilitated the integration of classroom learning with laboratory work. Simulation software addresses significant challenges such as high laboratory setup

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costs, maintenance difficulties, safety risks for students, and location constraints, making LBL more accessible and efficient [8, 9]. Simulation tools have been a subject of research since the 1990s [10], with their widespread application initially in medical education [11–13]. Over the past two decades, the use of simulation tools in engineering education has also been extensively explored. Pejuan, Lévesque, and Luo have employed simulation tools for audio [14, 15] or biomedical signal processing [16], facilitating students' learning of complex course concepts. Meanwhile, Garcia and Vatansever integrated simulation tools with networking technologies, achieving notable teaching results in university-level engineering courses [17, 18]. Corral Abad further advanced these tools by developing mobile-accessible simulations, enhancing their portability and accessibility [19, 20]. Zhao, on the other hand, has transformed simulation tools into educational games, effectively increasing student engagement and interest [21]. Additionally, simulation tools have proven effective across various engineering disciplines, such as optics [22], power systems [23], electrical machines [24], and mechanical engineering [25]. However, some studies have highlighted potential downsides, suggesting that simulation tools could inadvertently increase cognitive load for students [9, 22, 26]. Therefore, the development of simulation tools needs to be carefully streamlined to strike a balance between providing useful content and avoiding overwhelming students [27].

Our study explores the feasibility of using simulation software to integrate cutting-edge scientific knowledge into university classrooms. The primary objectives of the research are twofold: first, to help students deepen their understanding of classroom concepts using simulation software; second, to enable students to explore advanced scientific developments and understand the application of classroom knowledge in the real world. Our study features three key characteristics: (1) relevance, ensuring that the extended content and technologies are directly applicable to classroom concepts; (2) low burden, simplifying the extended content to make it manageable; and (3) universality, ensuring that the approach is accessible to students with diverse educational backgrounds.

To investigate these objectives, we incorporate the framework of photoacoustic computed tomography (PACT) technology into a university-level *Signals and Systems* course. Specifically, we developed simulation software that aligns closely with the course content, designed to reduce cognitive load and simplify the learning process. It helps alleviate the burden of complex concepts by presenting them in a student-friendly way [28]. The simulation software uses graphical interfaces to present complex scientific parameters and engineering principles, allowing students to learn through hands-on experience [29]. Additionally, the software allows students to work at their own pace, fostering individual learning.

To explore the potential impact of this educational reform, we conducted a survey to assess students' experiences with the interactive software, their willingness to embrace future teaching reforms, and their learning backgrounds. The results, analyzed using a Likert scale, showed promising improvements in students' understanding of complex concepts. Additionally, students reported high satisfaction with the simulation tools and the teaching approach. This positive feedback supports the

broader implementation of this method, highlighting its potential to improve educational outcomes and increase student engagement. Overall, our research provides both a practical methodology and illustrative case studies to advance the education reform of *Signals and Systems*.

The remainder of this paper is structured as follows. Section 2 provides a comprehensive review of the *Signals and Systems* curriculum, along with an in-depth description of PACT, highlighting its relevance to our curriculum. In Section 3, we elaborate on the design and functionality of our interactive simulation software from various perspectives. Section 4 introduces our specific research methods, assessment techniques, and ultimate research outcomes. Section 5 discusses the limitations of this study. Finally, in Section 6, we summarize and discuss the findings of this study and outline future directions.

2 | Course Framework and PACT System

2.1 | Signals and Systems

Signals and Systems is a foundational and important course for undergraduates who pursue degrees in information science or attend related engineering programs. This course helps students understand the analytical tools used to study signals and linear time-invariant systems. The course also connects this theoretical knowledge to practical applications, such as audio and image compression, communication systems, and medical signal analysis. The textbook *Signals and Systems*, written by expert Oppenheim, provides mathematical proofs for many of the abstract concepts in the course, and it is widely used in universities [30]. In this course, the focus is primarily on teaching theory through lectures [31]. While this approach is effective for conveying knowledge, it does not fully engage students or help them build an intuitive understanding of signal processing.

In this context, educators struggle to develop a teaching model that incorporates practical experiments into the educational framework, such as integrating simple mechanical and circuit models into theoretical and mathematical courses. These approaches significantly increase students' comprehension of theoretical knowledge while simultaneously igniting their enthusiasm for real-world applications [32]. In our research, building on our prior experience, we integrate PACT medical signal processing technologies as a practical case study within our curriculum. To further simplify the learning process and enhance the practicality of the course, we adopt simulation software specifically designed to align with course content and reduce the cognitive load. This software will be detailed in Section 3.

2.2 | PACT

PACT is a promising biomedical imaging technique that has achieved significant advancements and garnered widespread attention over the past two decades. PACT combines the advantages of optical and acoustic modalities to offer high-contrast imaging and deep tissue penetration of ultrasound [13]. These advancements make PACT particularly valuable for various

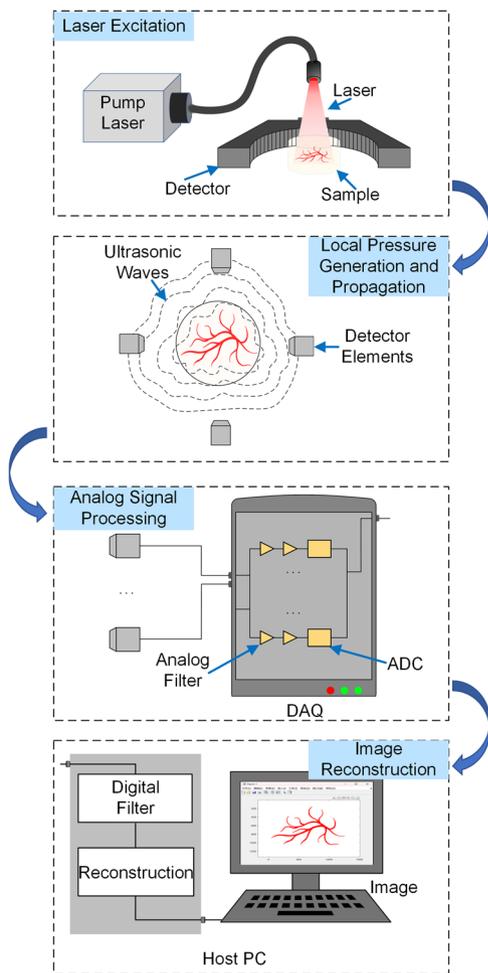


FIGURE 1 | Schematic illustrating the imaging process of PACT. ADC, analog to digital converter; DAQ, data acquisition.

biomedical applications because it enables the detailed visualization of tissue structures and aids in medical diagnoses. The core principle of PACT is the photoacoustic (PA) effect reported by Alexander Graham Bell [33]. When a target is illuminated with narrow pulse laser beams, the energy from the pulses is absorbed by chromophores in the biological tissues, causing rapid thermal expansion and subsequent generation of ultrasound waves. These ultrasound signals are detected and recorded by detectors and then processed by specific imaging algorithms to generate images that can depict the energy absorption distribution within the tissues. The entire PACT process described above is shown in Figure 1.

The process of generating sound waves via the PA effect and reconstructing a PA image includes several key stages, as shown in Figure 2. First, an acoustic signal is produced and travels through space according to the wave equation [34]. This acoustic signal is subsequently captured by a piezoelectric detector, which converts it into an analog electrical signal. Owing to the inherent bandwidth limitations of the detector and the analog front-end of the signal transmission system, the received electrical signal essentially represents an analog-filtered version of the original acoustic signal. Second, the analog electrical signal is subjected to analog-to-digital conversion, transforming it into a digital format that can be processed and stored by a computer. The digital signal is then

further filtered through digital filtering to yield a processed digital signal suitable for the next stage. Finally, this processed digital signal is used in a reconstruction algorithm to create the PA image, which may be further refined through post-processing. The entire process is illustrated in Figure 2.

2.3 | Connections Between the Course and PACT

As previously mentioned, this course serves as a foundation for analyzing medical signals and other practical engineering tasks, thereby rendering the concepts of *Signals and Systems* theory highly applicable within PACT. By acknowledging the pivotal importance of these concepts within PACT, we have integrated them across various stages. However, considering the potential for complex knowledge to overwhelm students and reduce their enthusiasm [35], we adopted a systematic approach by integrating relevant concepts into the corresponding stages of PACT while presenting unrelated or intricate topics as supplementary information in a simplified manner.

In PACT, the course has shown significant application value as follows: (1) spatial propagation of acoustic signals corresponds to Fourier transform-solving system problems; (2) transformation from acoustic signals to electrical signals via a detector corresponds to a continuous-time Fourier transform (CTFT) and a continuous-time filter (CTF); (3) analog-to-digital conversion corresponds to sampling; and (4) signal post-processing corresponds to a discrete-time Fourier transform (DTFT) and a discrete-time filter (DTF), as shown in Figure 2. The details of these stages are illustrated in Section 3. Afterward, students can convert original PA signals into reconstructed images via filtered back projection (FBP) [36], providing an opportunity for them to intuitively observe the applications of *Signals and Systems* in the field of PACT. These processes can be completed through interactive simulation software.

3 | Interactive Simulation Software

3.1 | Overview of the Software

To incorporate PACT principles and techniques into the *Signals and Systems* course in a student-friendly manner, we developed a user-friendly interactive simulation software called PA Imaging & Signals and Systems (PAISS). PAISS is specifically designed for students who have completed or are currently enrolled in the course. It provides an introduction to PACT, which comprises four main components, as depicted in Figure 3: signal generation via PA effect, analog filtering, sampling, and digital filtering. This introduction aims to provide students with a clear understanding of the fundamental processes involved in PACT and the specific challenges they will address throughout the course. Its structure seamlessly integrates theory with practice, enabling students to apply their knowledge within a practical context.

3.2 | PA Signal Generation

The first part focuses on the generation of acoustic signals, emphasizing the PA effect and the propagation of acoustic signals in space, which constitute the forward process of PA.

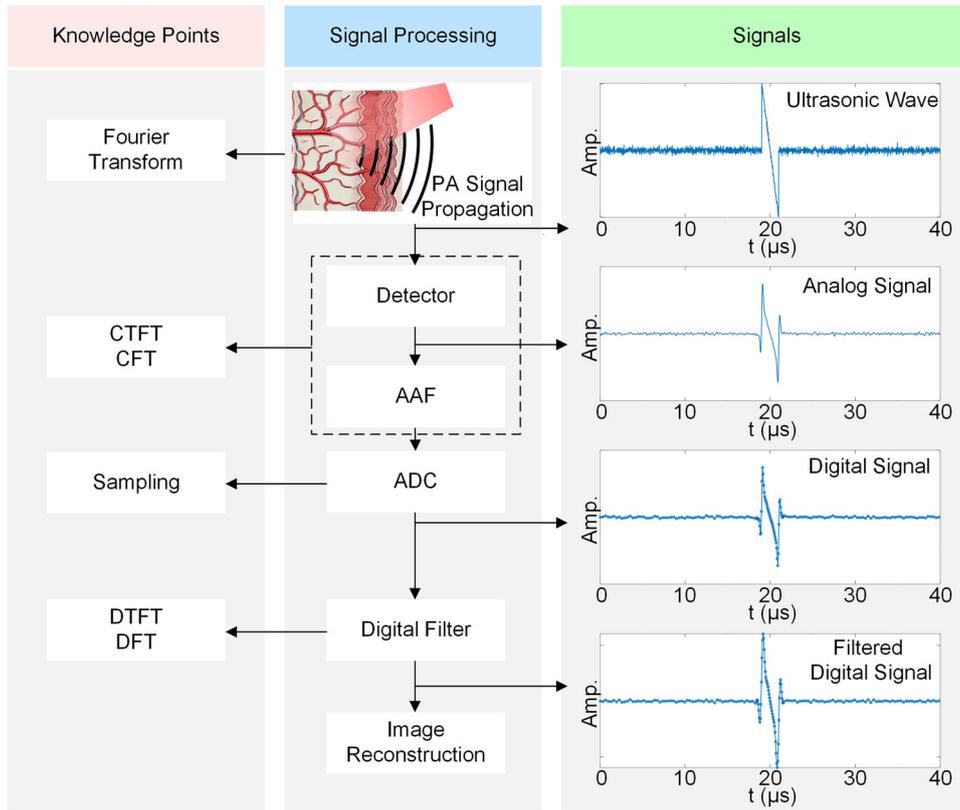


FIGURE 2 | From left to right are the knowledge points of *Signals and Systems* that are related to PACT, the signal processing workflow of PACT, and the signals corresponding to each step in the PACT signal processing workflow. AAF, anti-aliasing filter; ADC, analog to digital converter.

PA Imaging & Signals and Systems

Start Learning

Questionnaire

1

PA Signal Generation

2

Analog Filtering

3

Sampling

4

Digital Filtering

HOW?

FIGURE 3 | Homepage of the interactive simulation software PAISS.

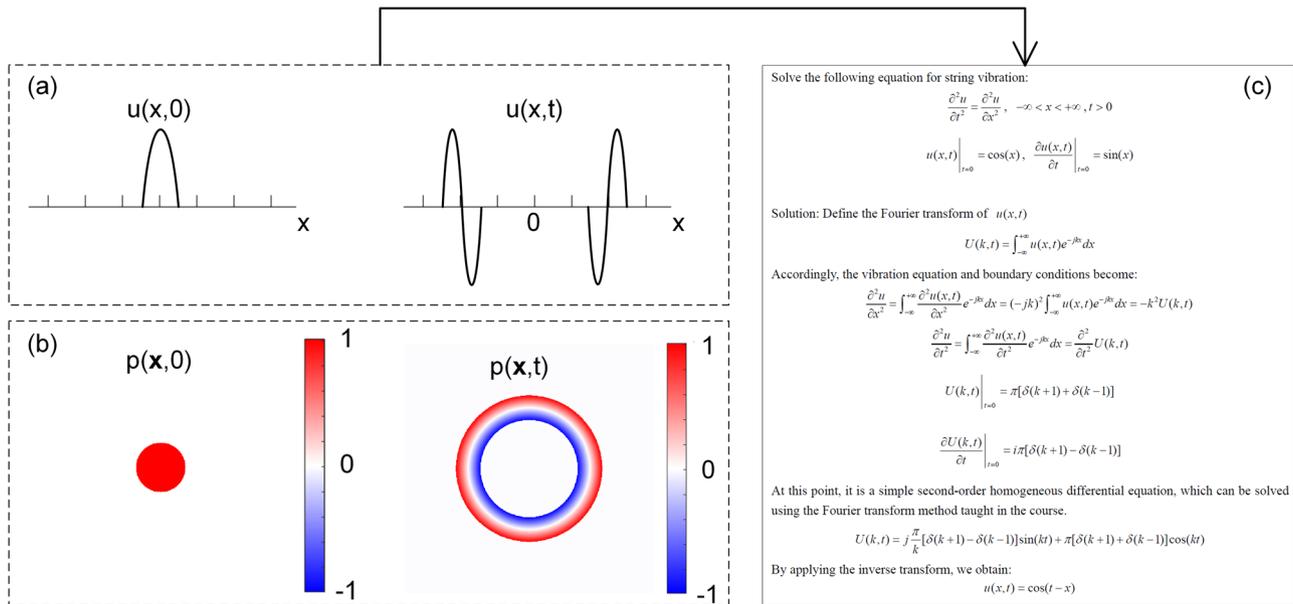


FIGURE 4 | Schematic of photoacoustic signal generation. (a) Schematic of one-dimensional string vibration. (b) Schematic of two-dimensional wave propagation. (c) Fourier solution process of the one-dimensional vibration equation.

To effectively model this forward process, we solve the wave equation using Fourier transforms and Green's functions [37]. To simplify the concepts, we begin with the equation for one-dimensional string vibration and use animations to help students visualize how waves propagate along a string. We then extend this idea to explain how sound waves propagate in two-dimensional space, allowing students to focus on how PA signals are generated and detected, as shown in Figure 4.

PAISS provides two choices of target sources for PA imaging. By clicking the "Start Generating Signal" button, students can observe the generation and propagation of PA signals in a two-dimensional space. This process is displayed in the simulation window, and the simulated signals are recorded. Note that these signals are based on a highly sampled simulation and do not represent actual analog signals.

3.3 | Analog Filtering

Analog filtering serves as a focal point of *Signals and Systems*. In PACT, this section focuses on the adverse effects of detectors. The bandwidth of a detector limits its ability to accurately record voltage signals, causing discrepancies between the recorded and actual signals [38]. Moreover, the size of the imaging target determines the center frequency of its PA signal. On the basis of previous research [39], the center frequency of the PA signal from a sphere can be estimated as follows:

$$f_c = \frac{v}{3a} \quad (1)$$

where v is the speed of sound in the medium and a is the radius of the sphere.

Selecting the right detector is crucial for high-quality PACT imaging. The detector's center frequency and bandwidth should

match the size of the imaging target. If the detector's center frequency is too low, it will miss the high-frequency components of the signal, ultimately leading to blurred image boundaries as shown in Figure 6a. Conversely, if the detector's center frequency is too high, it will miss the low-frequency components of the signal, which correspond to the main body of the image, resulting in an image with only edges remaining and a poor signal-to-noise ratio, as shown in Figure 6b [38].

In this section, students will use analog filters to observe how the filter's center frequency affects both the time-domain signals and their corresponding spectra, as shown in Figure 5. Reconstructed images are provided to help students understand how analog filters impact final image quality. Students will need to choose the appropriate filter to achieve the best balance between time-domain signals and image quality. This hands-on approach helps students understand the vital importance of analog filtering in PACT.

3.4 | Sampling

Sampling is the process of converting a continuous signal into a discrete signal. Specifically, it involves measuring the amplitude of the continuous signal at fixed time intervals to produce a series of discrete values. These values represent the state of the original signal at different points in time. Sampling allows us to use digital systems to process and store these signals. By choosing an appropriate sampling rate, we can accurately reconstruct the original signal according to the Nyquist sampling theorem:

$$f_s \geq 2f_{\max} \quad (2)$$

where f_s represents the sampling rate and f_{\max} represents the maximum component of the signal spectrum. If the signal contains frequency components higher than half the sampling

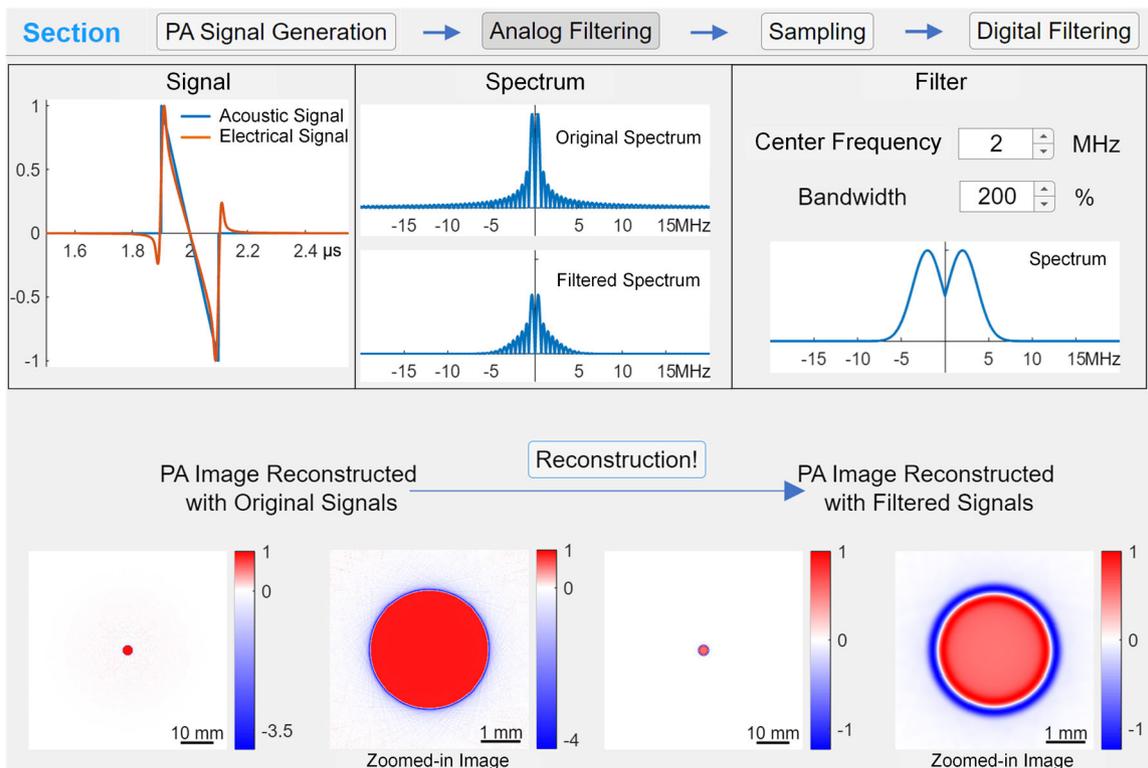


FIGURE 5 | The analog filtering section of PAISS.

rate, it will cause spectral aliasing and waveform distortion. This distortion is an irreversible corruption of the spectrum and is nearly impossible to rectify through post-processing. However, to overcome the limitations of traditional sampling theory, sub-Nyquist sampling techniques have been introduced [40]. Notable techniques include interleaved sampling [41] and bandpass sampling [42], which allow for sampling at lower rates without violating the Nyquist criterion.

In signal transmission and reception instruments, the electrical signals collected by detectors are processed through an analog front end before sampling. A key component of the analog front end is the anti-aliasing filter, which is inherently a low-pass filter whose cutoff frequency is a critically important parameter in PA signal processing. For simplicity in teaching, we exclude other functions of the analog front-end, such as low-noise amplifiers and DC-blocking filters. However, it is essential that the anti-aliasing filter's cutoff frequency be set correctly to avoid introducing artifacts into the PA image.

For the sampling section, graphical interfaces provide options for selecting the cutoff frequency and sampling rates, as shown in Figure 7a. Incorrect settings in these parameters can result in spectral aliasing and noise-like artifacts. For example, as shown in Figure 7b, when both the sampling frequency and the cutoff frequency of the anti-aliasing filter are set at 20 MHz, this configuration violates the Nyquist sampling theorem, resulting in spectral aliasing. Conversely, setting the cutoff frequency to 10 MHz avoids this issue. Consequently, when aliasing is pronounced, ringing artifacts appear in the PA image, as depicted in Figure 7c,d. This hands-on experience helps students realize the importance of accurate parameter settings in PACT.

3.5 | Digital Filtering

Digital filtering is a key process for manipulating or altering the characteristics of a digital signal, typically to enhance certain aspects of the signal or to remove unwanted components. This is accomplished by passing the digital signal through a mathematical algorithm that selectively modifies its content on the basis of specific criteria. Current digital filters can be roughly categorized into four types: low-pass filter permits the transmission of low-frequency signals while attenuating high-frequency signals. Conversely, the high-pass filter allows for the passage of high-frequency signals while suppressing low-frequency signals. Bandpass and band-rejection filters are employed to selectively permit or obstruct a specific range of frequencies.

In PACT, digital filters are essential for processing sampled signals before image reconstruction [43]. These filters improve signal quality by removing noise and unwanted interference, which are inevitably introduced during signal acquisition from environmental and equipment sources. Additionally, digital filters help mitigate signal aliasing by isolating specific frequency bands, thus extracting the desired components of the signal effectively. This preprocessing enhances the clarity and quality of the reconstructed images, making digital filtering a crucial step in signal preparation.

In this course, students examine both analog and digital filters, particularly infinite impulse response (IIR) filters, as detailed in Section 3. Analog filters are based on physical components such as resistors and capacitors, which leads to complexity and susceptibility to environmental factors. In contrast, digital filters utilize computer algorithms allowing for precise and easy

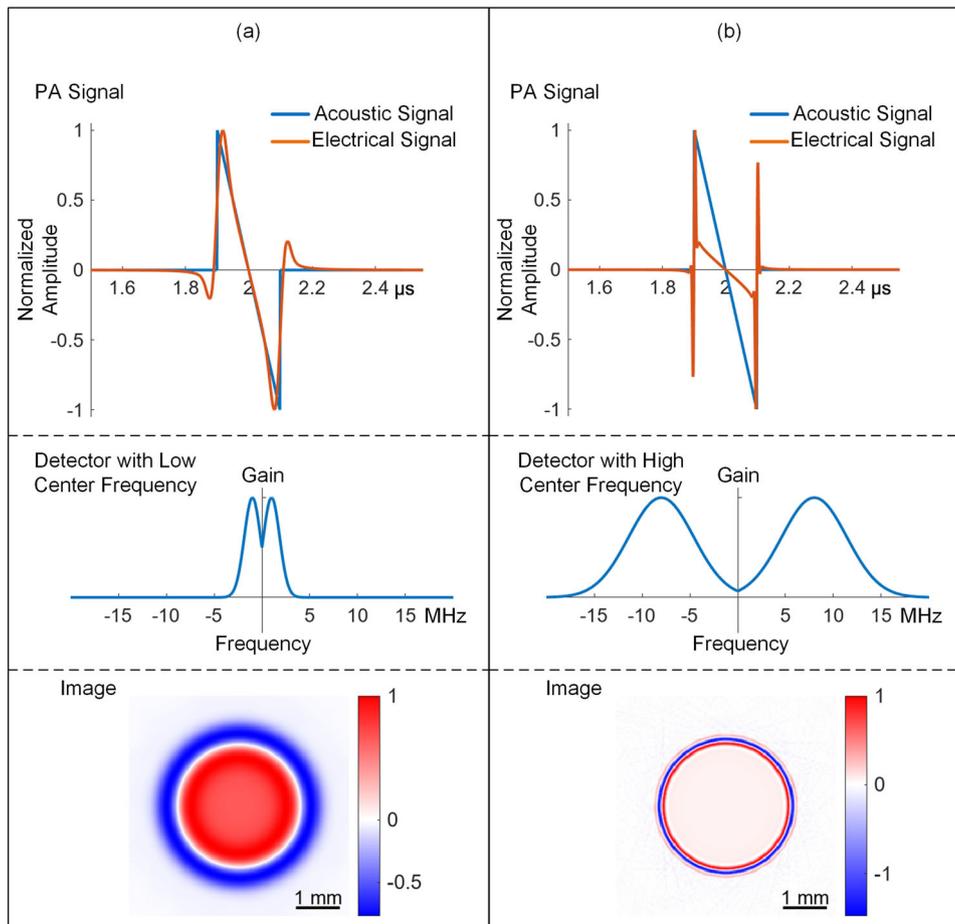


FIGURE 6 | After passing through two filters with different center frequencies, the PA signal undergoes distortions that impact the resulting image. (a) When the center frequency of the detector is low, the image edges become blurred. (b) When the center frequency is high, the interior of the image becomes hollow.

modifications to filter coefficients. This approach equips students with the ability to tailor filters effectively, enhancing their signal processing capabilities. By delving into these techniques, the course provides a thorough understanding of optimizing signal quality across the processing chain.

4 | Student Engagement and Assessment

4.1 | Student Engagement

Between 2022 and 2024, we conducted educational research at the University of Science and Technology of China and chose the *Signals and Systems* at the School of Engineering Science as the experimental course. During this period, the course was consistently taught by the same primary instructor, with support from a regular teaching assistant. In the semester, students spent the first 8 weeks learning the course *Signals and Systems*, including signal-time frequency analysis and Fourier transforms, as outlined in Section 2.3. In Week 9, a 20–30 min scientific lecture was organized to introduce PACT and its applications. At the conclusion of the lecture, we presented the PAISS, along with accompanying documentation that explains its features and usage instructions. Students were informed that participation in using the simulation software is voluntary, and they had the option to engage with the tool and provide

feedback through a survey. Throughout this period, we offered online support to address any questions or issues that arise as students interacted with the software. This project continued until Week 15, when the course concluded and the surveys were collected.

We chose voluntary participation primarily because of the variation in students' understanding of the course content, enabling them to dynamically decide whether to explore these supplementary materials on the basis of their circumstances. Moreover, mandatory learning can elicit resistance and anxiety among certain students, whereas voluntary participation tends to yield assessment results that more accurately reflect students' genuine opinions and learning outcomes [44]. To evaluate this study comprehensively, we incorporated a survey questionnaire link after the software, which necessitated students' responses to several survey questions. These questionnaire results served as the foundation for the assessment.

The students in the project primarily consisted of juniors and sophomores enrolled in undergraduate programs, predominantly aged 19–21. Approximately 90% of the students possessed backgrounds in mechanical engineering and instrumentation, whereas 10% hailed from information science, with a few individuals representing physics and computer science fields. Throughout the project duration, a total of 57 students

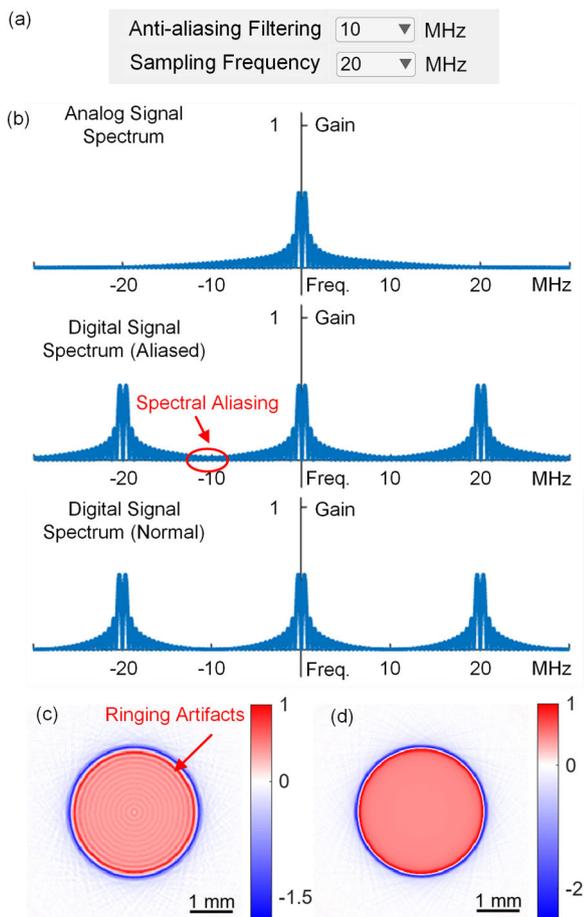


FIGURE 7 | The sampling section of PAISS. (a) Interactive interface. (b) Analog signal spectrum, digital signal spectrum (aliased), and digital signal spectrum (normal). (c) Image reconstructed with spectrum aliasing. (d) Image reconstructed without spectrum aliasing.

actively participated in the course, 25 of whom voluntarily engaged with supplementary learning materials and completed the questionnaire.

This study complies with China's *Academic Standards for Humanities and Social Sciences Research in Higher Education* and the *Ethical Review Measures for Life Sciences and Medical Research Involving Humans*. Before the commencement of the project, our research was filed with the Academic Affairs Office of the school and the Anhui Provincial Department of Education, receiving official approval. As a minimal-risk, non-interventional survey, all participants provided written informed consent and retained the right to withdraw at any stage. Moreover, raw data remained accessible only to the principal investigator and were stored in password-protected institutional servers.

4.2 | Assessment Method

We devised a questionnaire survey that required students enrolled in software learning programs to complete and provide feedback on their true assessments. Our questionnaire is developed based on references [21] and tailored to align with the objectives and specific characteristics of our teaching research.

TABLE 1 | The questionnaire used to assess the effectiveness of the educational reform.

Questions about user experience of the interactive software

1. Through the study of simulation software, you have a preliminary understanding of PACT.
2. Please rate the simulation software: The interface design is clear and easy to understand.
3. Please rate the simulation software: The difficulty level is appropriate.
4. Please rate the simulation software: The connection with *Signals and Systems*.
5. Please rate the simulation software: Explain PACT to me.

Questions about willingness for future teaching reforms

6. Do you think it would be beneficial to continue including the following topics in future *Signals and Systems* classes: Medical signal processing?
7. Do you think it would be beneficial to continue including the following topics in future *Signals and Systems* classes: More supplementary and popular science content?
8. How receptive are you to the following types of university classroom reform models: Expand knowledge?
9. How receptive are you to the following types of university classroom reform models: Combining theoretical classes with lab or simulation experiments?
10. How receptive are you to the following types of university classroom reform models: Problem-based learning?

Question about students' learning background

11. Before taking the *Signals and Systems* course, which of the following similar learning methods have you participated in during high school or university? Learning through software and programming, or learning with supplementary or only traditional classroom learning?

As previously mentioned, our aim is to create software that enables students to more easily grasp the principles of signals and systems, while also gaining some understanding of PACT. A preliminary pilot test was conducted with a group of students to ensure the clarity and validity of the questions. Consequently, the questionnaire encompasses three fundamental aspects: interactive software usage experience, willingness for future teaching reforms, and students' learning background. The details of this questionnaire are shown in Table 1.

- The aspect of interactive software usage experience aims to gather direct assessments from students regarding our teaching reform along five key dimensions: interface design, ease of use, content relevance, and teaching effectiveness.
- The aspect of willingness for future teaching reforms aims to investigate students' inclination toward continued utilization of similar instructional methods in the *Signals and Systems* course, as well as the potential for extending this

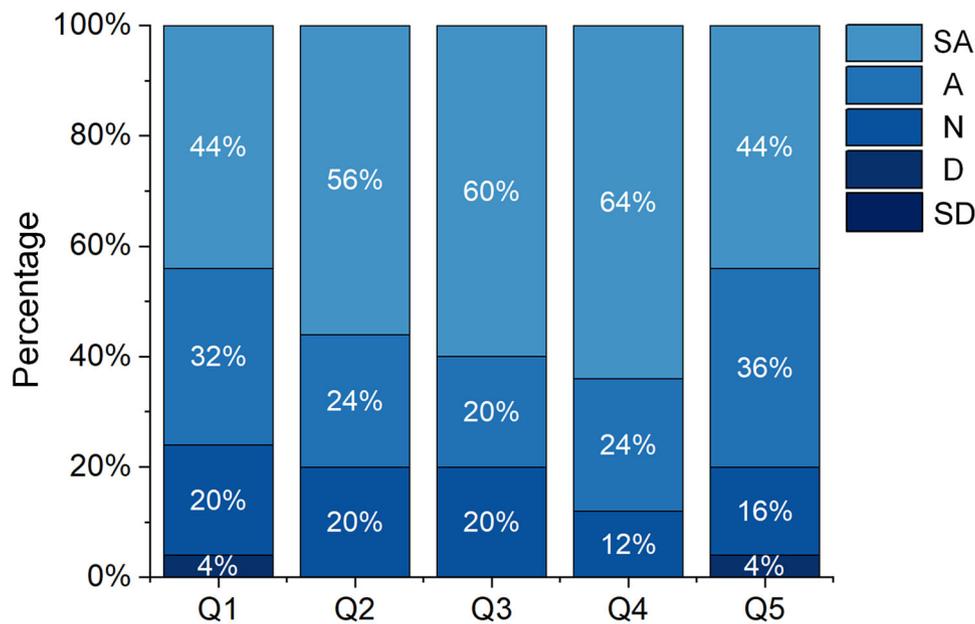


FIGURE 8 | Results of the questionnaire concerning user experience of the proposed interactive software.

pedagogical model to other courses. The outcomes of this aspect indirectly reflect the effectiveness, acceptance, and endorsement of students regarding the implemented teaching reforms.

- The aspect of students' learning background contains a single question, inquiring whether students had previously participated in any other educational reform initiatives before this course. Our objective is to ensure that all students can effectively engage in our project, irrespective of their educational background.

The initial 10 questions are assessed via a Likert scale, while the final question is presented in a multiple-choice format. The Likert scale offers five response options: strongly disagree (SD), disagree (D), neutral (N), agree (A), and strongly agree (SA). To facilitate statistical analysis, responses are scored on a scale of 1–5, corresponding to the SD to the SA, respectively. Through this questionnaire, we aim to obtain comprehensive feedback from students regarding the instructional methods employed, thereby facilitating further refinement and enhancement of our pedagogical strategies.

4.3 | Results of the Assessment

The results of the questionnaire regarding the usage experience of the interactive simulation software are presented in Figure 8 and Table 2. The data provides important insights into student perceptions of the software, focusing on its potential to enhance understanding of PACT, the clarity of the interface, the appropriateness of its difficulty level, and its relevance to the Signals and Systems course.

- Q1: A majority of students indicated that the software contributed positively to their understanding of PACT. The mean score of 4.16 (STD: 0.90) suggests that most students found the tool useful for comprehending complex concepts.

TABLE 2 | The questionnaire results of interactive software user experience.

Question no.	Mean ^a	STD
Q1	4.16	0.90
Q2	4.36	0.81
Q3	4.40	0.82
Q4	4.52	0.71
Q5	4.16	0.99

^aThe mean score is between 1 and 5.

Although the results are promising, the absence of a control group means we cannot definitively claim that the software had a direct effect on learning outcomes. Nevertheless, the positive responses from students point to the potential of the software in supporting the learning of PACT.

- Q2: The clarity and usability of the software interface were well-received, with a mean score of 4.36 (STD: 0.81). The relatively low standard deviation indicates that most students found the interface intuitive and easy to use. This feedback suggests that the interface design is conducive to student engagement, although further refinements might be needed to improve usability based on student feedback.
- Q3: The difficulty level of the software was considered appropriate by the students, with a mean score of 4.40 (STD: 0.82). This finding suggests that the software struck a suitable balance between being challenging and accessible to students.
- Q4: The software's relevance to the Signals and Systems course was highly appreciated, with a mean score of 4.52 (STD: 0.71). This indicates that students felt the software aligned well with the course content, helping to reinforce the theoretical concepts taught in class. The low standard deviation here reflects a strong consensus among students,

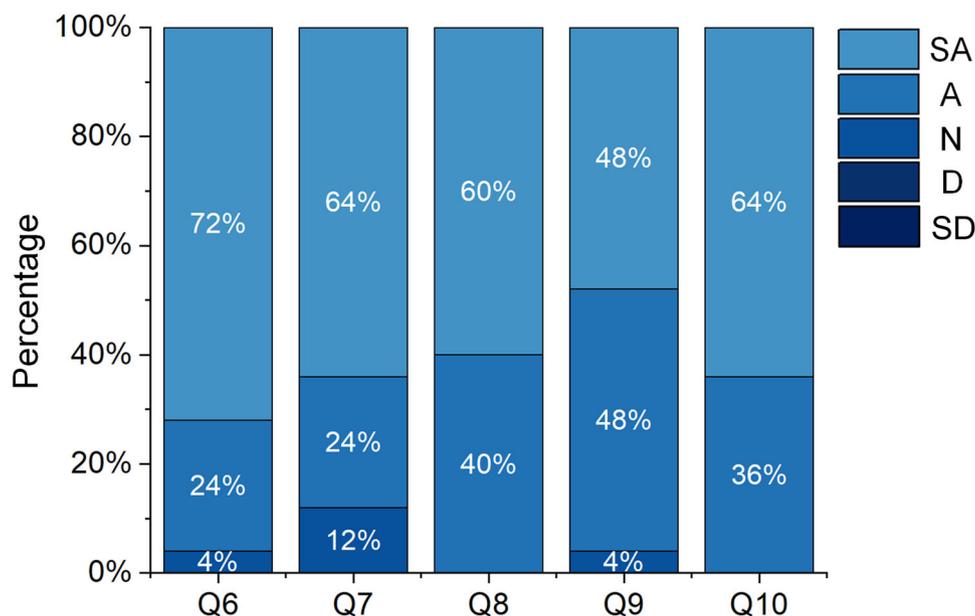


FIGURE 9 | Results of the questionnaire concerning willingness for future teaching reforms.

reinforcing the idea that the tool effectively supports the curriculum.

- Q5: Regarding the impact of the software on students' understanding of PACT, students provided a positive response, with a mean score of 4.16 (STD: 0.99). While the high score suggests that the software was helpful in enhancing comprehension, the higher standard deviation indicates that the degree of improvement may vary between students. This highlights the need for further investigation into how different student profiles engage with the software.

Figure 9 and Table 3 present the results from the section of the questionnaire concerning students' openness to future teaching reforms. These findings suggest a promising interest in further integrating new topics and innovative teaching methods into the curriculum.

- Q6 and Q7: students expressed strong interest in continuing the inclusion of topics like medical signal processing (Mean: 4.68, STD: 0.56) and incorporating more supplementary and popular science content (Mean: 4.52, STD: 0.71). This suggests that students see value in expanding the scope of the course to include real-world applications and interdisciplinary connections, which could enhance the overall learning experience.
- Q8–Q10: Students demonstrated a positive attitude toward teaching models that encourage active learning. They favored approaches that expand knowledge (Mean: 4.60, STD: 0.50) and those that combine theory with hands-on experiences, such as lab or simulation-based learning (Mean: 4.44, STD: 0.58). The PBL approach also received favorable feedback (Mean: 4.64, STD: 0.49), suggesting that students are interested in more engaging and practical learning methods. These results indicate that students are open to innovations in teaching, particularly those that offer practical applications of theoretical concepts.

TABLE 3 | The questionnaire results concerning the willingness for future teaching reforms.

Question no.	Mean ^a	STD
Q6	4.68	0.56
Q7	4.52	0.71
Q8	4.60	0.50
Q9	4.44	0.58
Q10	4.64	0.49

^aThe mean score is between 1 and 5.

As depicted in Figure 10, a significant proportion of students (36%) have experienced only traditional classroom teaching thus far. However, a considerable portion (28%) has been exposed to both software-based learning and supplementary materials. The findings reveal that even students who have exclusively encountered traditional classroom teaching exhibit enthusiasm comparable to that of their peers with diverse learning experiences. This suggests that our proposed teaching reforms are well-received across different student groups.

The results from the questionnaire indicate a promising level of student satisfaction with the interactive simulation software. The positive feedback, particularly regarding the software's effectiveness in supporting learning, its usability, and its alignment with the course content, suggests that this tool could be a valuable addition to the curriculum. Furthermore, the students' interest in future teaching reforms, including the integration of medical signal processing and more interactive learning models, points to a growing desire for more dynamic and applied teaching approaches. However, it is important to note that these results are exploratory, and further research is needed to assess the long-term impact of the software and teaching reforms. The study lays a foundation for future investigations into how such tools can be expanded and refined to improve learning outcomes in engineering education.

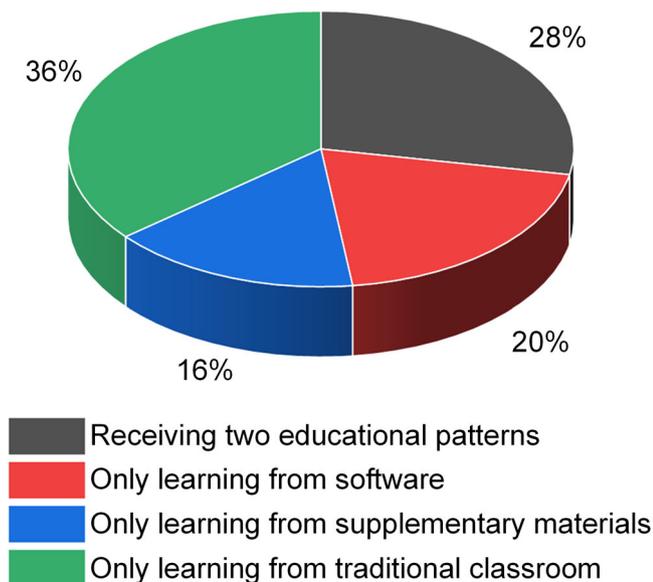


FIGURE 10 | Surveys on students' learning experiences.

5 | Limitations

Despite the valuable insights provided by this study, several limitations should be acknowledged. First, the small sample size ($N = 25$) may limit the generalizability of the findings, as the data collected were insufficient to fully capture the diversity of student responses. This constraint is partly due to the optimizations of the teaching reform over 3 years, which resulted in limited comparable data from the previous survey. Larger-scale implementations involving more students are needed to validate the results.

Second, the absence of a control group, such as parallel classes not participating in the teaching reform, makes it difficult to fully isolate the effects of the intervention from other confounding factors. Future research could incorporate control groups and adopt more rigorous survey methods to improve the validity and reliability of the findings.

Finally, the findings are highly context-specific, being tied to a particular course and teaching tool. This may limit their applicability to other disciplines or instructional methods. Future studies could consider expanding the scope by designing similar simulation software for other courses and conducting comparative evaluations to assess its broader effectiveness.

These limitations should not undermine the value of the study but rather serve as opportunities for further research to refine and expand its contributions to teaching innovations.

6 | Conclusion

This study discusses the challenges encountered by current educational reforms aimed at improving teaching quality and practical skills, noting that these reforms have significantly increased the time cost and learning burden on students. In our research, we propose a solution by leveraging a university-level *Signals and Systems* course as a foundational platform,

integrating the framework of PACT technology. We reformed the course by incorporating extended knowledge and innovative pedagogical tools, such as user-friendly and interactive simulation software. By introducing simulation software, we aimed to reduce the cognitive load and enhance student engagement, while making complex scientific concepts and engineering principles more accessible.

Our findings suggest that the interactive simulation software helped students better understand complex concepts in PACT, with positive feedback on its usability, difficulty, and relevance to the course. While the absence of a control group limits conclusions about direct effects, the results indicate that the software is beneficial for most students. Additionally, students showed strong interest in expanding the course to include more interdisciplinary topics and favored teaching models that emphasize active learning and hands-on experiences. This points to the potential of the proposed reforms to enhance both theoretical knowledge and practical skills.

The research demonstrates the feasibility and potential benefits of integrating PACT with simulation software in university courses, highlighting its potential as a transformative educational reform approach. This innovative integration creates an inclusive and engaging learning environment that accommodates diverse student backgrounds, making it a potentially effective model for enhancing both theoretical knowledge and practical skills. Future research should focus on refining these methods aimed at reducing cognitive load and exploring their potential benefits across different disciplines and educational levels.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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