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The Inclusive Glossary: An Embedded, Interactive Approach to Accessible and Inclusive Learning

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Abstract

To assist students in engineering and related STEM disciplines, we report on the motivation, design, implementation, and evaluation of the *Inclusive Glossary*, a novel embedded interactive educational tool. The Glossary explains technical terms when the student encounters new terms in video and written content. The Glossary was motivated by two equally-important factors. Firstly, to add American Sign Language (ASL) signing of technical terms as a first-class, inclusive educational outcome, and within the normal learning environment of university students. Secondly, to help mitigate the ongoing readiness-to-learn effects due to the lowered learning outcomes from the 2020-22 COVID-19 pandemic and inequity in students' prior high school education experiences. The Glossary takes a strong inclusive design stance; for all students there are valuable context-specific just-in-time learning opportunities to address "Knowledge-Gaps" that create barriers to learning the current topic of study. It also enables ASL signers to learn the growing and evolving corpus of engineering, physics and computer science signs.

The Glossary's design and implementation is introduced from three perspectives: ASL, Universal Design for Learning (UDL), and Active Learning. ASL – a complete natural language with its own unique grammar and terms – is the first and primary language of some students who are Deaf or Hard of Hearing (DHH). The principles of UDL promote a user-configurable design that provides multiple forms of modality, engagement and interactivity. Scholastic research into Active Learning suggests student-initiated knowledge-seeking actions, when embedded into video-based and text-based learning experiences, improve learning outcomes and reduce the difficulty or perceived difficulty of a course. The Glossary is implemented as a web application that uses an automated workflow to efficiently find, download, and index domain-specific terms, definitions, and explanations in two primary languages, English and ASL, in text and video form. The automated workflow extracts domain terms from both the audio transcription and visual text from video content. Definitions and explanations of the glossary terms in English and ASL are automatically curated from open web-sources with zero or minimal instructor time required. Explanations in different lengths are provided for students with different interest levels, learning needs, and attention spans. ASL video entries are provided in three sign forms; as an isolated sign, a sentence definition, and an example usage. Students can view both English and ASL explanations. By embedding the Glossary into ClassTranscribe, we describe the user interface comprised of i) A glossary appendix inside the course notes, ii) Web page popups in the video player, and iii) An online gallery page to browse, edit, and search for glossary terms of the course. The extraction efficiency, precision and recall of the system were evaluated using a corpus of 300 candidate domain-specific terms automatically extracted from 8 videos. For English entries, 241 (80.3%) glossary items had a corresponding English explanation available. For ASL entries, 39 (13.0%) glossary items had a corresponding ASL definition available, and 20 (6.7%) items had ASL sign, example and definition available. Preliminary results suggest this is a promising educational technology that has the potential to help all students thrive in their engineering disciplines.

1 Introduction

Students in engineering classes have a wide variation in their prior knowledge and skills, which is due to several factors including large variations in high school learning opportunities, individual variations in knowledge acquisition modulated by challenges of moving to COVID online instruction, and students who have taken alternative degree pathways (e.g., transfer from another college). These factors may lead to "knowledge-gaps," meaning a student may be inadequately prepared to understand a new topic because they have insufficient grasp of the supporting terms and knowledge. In the extreme case, remediation might require enrolling in a supporting or prerequisite course, or additional one-on-one help. Our work focuses on the smaller knowledge-gaps that can still inhibit learning but can be remediated "in situ" i.e., with-in context and as part of a more advanced learning goal. The value of providing with-in context information is substantive and is even included as an explicit sub-goal in the principles of Universal Design for Learning (UDL), which we discuss later.

Acquiring and relying on technical terms in a particular domain of study is necessary but often challenging for students. Terms may be subject-specific, content-specific, abstract, and require a precise definition to be used correctly. An inaccurate definition, misinterpretation, or incorrect use can quickly result in incomplete comprehension of a concept or application. For example, if a student conflated "Laplace Transform" with "Fourier Transform," they might struggle or become frustrated or confused when learning about the analysis of electronic circuits. An in-context reminder or explanation of Laplace Transform might have been sufficient to overcome the student's learning barrier. In addition to an English glossary, we also examine the benefits of an American Sign Language (ASL) glossary. For some students who are Deaf or Hard of Hearing (DHH), especially for students whose primary language is ASL, we hypothesize an ASL explanation of technical terms may reduce the cognitive load and thus promote better understanding and memorization of the technical terms. For these students, by providing a glossary definition and explanation in ASL, the need to mentally translate English explanations is avoided, enabling students to improve their focus on the original pedagogical objectives.

Secondly, engineering and STEM terms do not exist solely in English. Developing a strong ASL technical vocabulary is essential for DHH students who use ASL to be able to discuss newly learned technical concepts with their fellow classmates and instructors in forms other than written English. By embedding ASL domain terms and modeling their usage, as part of their engineering education, the student is able to further their ASL technical vocabulary.

Thirdly, captions and ASL that are readily apparent within normal educational experience are a reminder to nascent student engineers of the value of universal design approaches. Specifically, that the best human-focused designs are often inclusive i.e., support a diverse set of human needs and abilities.

Recognizing such needs, we proposed and implemented a Glossary system which realized the following goals, 1) Extract explanations of a list of glossary terms from online sources accurately and efficiently, 2) Extract English explanations of different lengths and ASL explanations of multiple categories, and 3) Facilitate technical term understanding and learning via informative user interfaces. More detailed descriptions are presented in sections 5 and 7.

The performance of the Glossary system was evaluated based on a dataset of 300 candidate domain-specific terms extracted from 8 lecture videos of multiple engineering disciplines. The Glossary system was able to achieve an acceptable performance for real production by accurately curating high-quality English explanations for most of the input domain-specific terms (82.0% in Precision) within a short processing time (less than 1 minute for a 50-minute video). For ASL entries, the system was able to provide 39 (13.0%) domain-specific terms with a corresponding ASL explanation.

Several user interfaces were proposed, designed, and deployed into ClassTranscribe to present glossary explanations to students, including 1) Web page popups inside the traditional video-based lecture modality, 2) Glossary appendix pages inside the I·Note, a new text-based lecture delivery modality, and 3) Online gallery page of the glossary terms. Both instructors and students were able to add, remove, edit, or rate glossary explanations via the provided interactive interfaces. The Glossary system is available as an open source project (github.com/classtranscribe) for instructors and educators who would like to adopt or extend the Glossary system into their teaching. We hope this work will provide insights and encourage more research on addressing the knowledge-gaps on domain-specific terms for college-level engineering students.

The rest of the paper is structured as follows. In section 2, we discuss motivations and guiding principles of the Glossary system. Section 3 provides a formal description of the problem, affiliated challenges, and related approaches. Section 4 offers a general introduction to ClassTranscribe in which the Glossary system is deployed. A detailed discussion of the explanation extraction workflow and design considerations are included in section 5. The evaluation results of the explanation extraction workflow are reported in section 6. Section 7 presents 3 different user interfaces with screenshot demonstrations. The feedback and comments from students who have utilized the Glossary system for lecture learning is included in section 8. Section 9 concludes the paper and proposes new research questions created by this work.

2 Motivation

The inclusive design of the Glossary system is motivated by American Sign Language for Engineers and the principles of Universal Design for Learning and Active Learning, which we discuss next. Further the Glossary directly satisfies the UDL sub-goal of "support decoding of text, mathematical notation, and symbols[22]," which is part of the "multiple means of representation" UDL objective.

2.1 American Sign Language

A common misconception by non-signers is that American Sign Language is simply a signed version of the English language. Instead, American Sign Language is a first-class language that uses upper-body movements and facial expressions to efficiently communicate with a grammar distinct from that of English.

Sophisticated, precise technical language underpins the ability to think and reason but to also communicate and express ideas, and to use understood terms as foundations to construct another level of understanding. Thus, as part of the student's university-level education, when new technical ideas are introduced, defined, and later referenced, there is value in defining a technical term in both English and ASL. In this way, the foundations are set for technical discourse in either language.

2.2 Universal Design for Learning

Universal Design for Learning is an educational framework proposed by Professor David H. Rose[21], inspired by Universal Design, which defined how physical spaces could be designed to accommodate everyone's needs [11]. A common example of Universal Design would be the introduction of a ramp entrance in addition to a stairs in a building, which reduces or removes the difficulty of anyone who desires to enter the building. Similarly, UDL suggests that considerations for individual differences among students should be taken into consideration when designing educational activities, content, and assessments. A full description of UDL is beyond the scope of this paper. The interested reader may refer to [22] for more information. Briefly, UDL proposes the following three top-level objectives for an inclusive education design[19], which are further decomposed into multiple smaller goals and sub-goals [17, 21].

- Multiple means of representation. For example, lecture content could be presented in a video or a text file of audio transcription.
- Multiple means of expression. For example, students are allowed to demonstrate the course project through written report or oral presentation.
- Multiple means of engagement. For example, students can ask questions and share opinions in the classroom or through the online forum.

2.3 Active Learning

Active Learning is a well-known and widely studied set of educational practices and principles that suggests students create higher order knowledge and understand more effectively when they engage in learning activities that are beyond passively receiving information[6]. Active Learning is supported by Cognitive Constructivism, a theory of knowledge approach to learning where understanding is created by active assembly and assimilation of ideas by the internal mental processes of the learner. Prior research has shown that use of Active Learning improves student learning outcomes[9]. The Active Learning literature focuses primarily on large course design changes (e.g., [7, 10, 16]), for example, design of a pre-lecture online exposition and integrated problems, allowing the in-person lecture time-slots to be repurposed into a more advanced problem-review and active discussion.

In our work, we acknowledge that exposition of engineering content is still necessary but there are opportunities to create moments of *self-directed knowledge-seeking by the student* during the exposition, in a sense, a micro active learning experience, where the student chooses to construct knowledge. For example, definitions and concepts of domain-specific terms are generally imparted to students in a relative passive manner through either in-class explanations or after-class quizzes. We believe that a platform that facilitates and encourages exploration will further the students' understanding of domain-specific terms. The Glossary system was designed to promote active exploration and recollection of domain-specific terms using interactive interfaces and crowd-sourced editing, which is aligned with the philosophy of Active Learning.

3 Problem Description

3.1 Goal

The primary goal of the Glossary system is to assist students to overcome small knowledge-gaps and enable efficient learning or reviewing of topical domain-specific terms that are used as part of learning more advanced content. Domain terms are provided manually or by automatic extraction from the course video[12]. The system is comprised of two components 1) Accurate and efficient explanation extraction workflow to acquire glossary content, and, 2) A web-based application to present domain-specific terms and explanations for students to learn and review.

3.2 Challenges

3.2.1 System Concerns

Acquisition of high quality explanations in English and ASL is the first system concern. Online resources may not include explanations for certain sophisticated terms. Even for terms that are available, the English explanations from the online sources may not be correct or related to the course context. In addition, the meaning of technical terms, especially for those from cutting-edge fields, are evolving. Therefore, the explanations previously curated may not be up-to-date. Furthermore, certain technical terms can have ambiguous meanings. For example, the word "python" means a programming language in Computer Science, but a family of snakes in Zoology. In the context of engineering education, only the Computer Science meaning is desired. Ideally, the error rate of the explanations (fraction of unrelated explanations) provided automatically by the Glossary system should be lower than 20%. This value was somewhat arbitrarily chosen by the researchers based on the subjective goal to have 4 out of 5 glossary entries be useful. Note, the instructor and students may retroactively correct or hide unrelated glossary entries, to improve the observed accuracy of the glossary items experienced by the student. The researchers believed that if at least 4 out of 5 items were correct without further editing, then faculty and students would judge the Glossary to have immediate value.

Ideally all Glossary items would have an ASL entry. Although online ASL sources, including Quantum ASL and DeafTEC, offered professional and accurate ASL explanation videos, due to the limited number of STEM-related ASL videos available, it is unlikely that every glossary term extracted from a course will have a corresponding ASL entry. The researchers did not attempt to define a minimum fraction as valuable to students; but rather noted that missing ASL items still provided value to the greater community; they represent the next set of technical terms that will ideally be published in future versions of popular online ASL video dictionaries.

Platform	Captioning	Transcriptions	ASL Glossary	English Glossary
Coursera	Yes	Yes	No	No
Khan Academy	Yes	Yes	No	No
Linked-In Learning	Yes	Yes	No	No
YouTube	Yes	Yes	No	No
Bilibili	Yes	No	No	No

Table 1: Features provided by the popular video platforms which offer educational content. None of the popular services provided an in-context domain term explanation in ASL or English.

Low processing time is another requirement. Instructors and students would like to see their lecture content published to students within a short time after being uploaded or captured, which places a constraint on the time available for video-based and text-based processing. For a typical 50-minute lecture the desired processing time should be under 5 minutes.

3.2.2 Interactive Design Choice Challenges

The following design choice questions were considered in the design and implementation of the interactive web component of the Glossary system.

- What categories of English explanations should be provided for students to satisfy their different needs and preferences?
- What categories of ASL explanations should be provided for DHH students to maximize their understanding of the meaning and application of a glossary term?
- What user interfaces should be designed to present the glossary terms and explanations in a clear and informative manner?
- What interactive components should be involved in the user interfaces to prompt active knowledge exploration in glossary terms and related concepts?

3.3 Related Systems

We reviewed 3 popular online course platforms and 2 general video platforms that offer educational video content. The features provided by the platforms are summarized in Table 1. All of the platforms supported captioning. In addition, all of the platforms, except for Bilibili, a popular platform in China, allowed users to view the full organized transcription as a text document. However, to the best of our knowledge, none of them are equipped with in-context explanations of domain-specific terms in written languages or sign language. Although YouTube and Bilibili allow users to post live comments, the comment content can be unrelated to the video and may not contain relevant information on the domain-specific terms introduced in the video.

4 Background

4.1 ClassTranscribe

ClassTranscribe is a web-based learning system and video lecture platform that has more than 13,000 users. Some of its features have been previously presented at ASEE [4, 23, 15]. Its adoption has led to measurable and statistically significant improvements in learning outcomes [5] and large scale studies of the importance of UDL for engineering students with and without disabilities, for example, [2, 14]. ClassTranscribe was created at the University of Illinois Urbana-Champaign and is used as one of the instruction tools in engineering courses across multiple disciplines. Using UDL principles, ClassTranscribe provides students with an accessible interface including accurate captioning, caption search, and lectures delivered in video and text-based modalities [13].

To automatically create a list of relevant glossary entries it is useful to first extract domain terms from both the transcript and from the visual content of the video image frames. This process utilizes two existing services SceneDetection and PhraseHinter, that are briefly described below. The interested reader may refer to the cited ASEE publications for more information.

4.2 SceneDetection

SceneDetection is a video analytics service that was introduced in [3] and implemented in ClassTranscribe. It can extract all of the visual text presented during the video. A typical one hour video, recorded at 60 frames/second, consists of 216,000 images, with most images being similar to a previous image. Using multiple similarity metrics and a trained support vector machine classifier, the SceneDetection service can efficiently reduce a video to a smaller set of unique, representative images, which still represent the equivalent visual information of the original video. For a traditional lecture presentation, each presentation slide will be represented by one image. As part of this processing, text in each scene image is extracted using automated Optical Character Recognition (OCR), a technique that transcribes text embedded in images into a machine-readable format. The representative video start and end timestamps of each image is also saved; i.e., the output of the SceneDetection service efficiently describes what text is displayed and when.

4.3 PhraseHinter

PhraseHinter is a text analytics service that was discussed in [12] and adopted into ClassTranscribe. Based on the SceneDetection results, a video-specific corpus can be constructed from the OCR-transcribed text of all scenes. PhraseHinter extracts domain-specific words and phrases for a lecture video by comparing the term frequency of each term in the video-specific corpus to that in a general English language corpus using the TF-IDF metric[20]. Domain-specific phrases are extracted using a Sequential Pattern Mining algorithm[1]. Each extracted domain term is assigned with a timestamp according to the timestamp of its corresponding scene.

These extracted domain-specific terms serve as the source input i.e., candidate set of glossary items for the explanation extraction workflow, which is discussed in section 5.1.

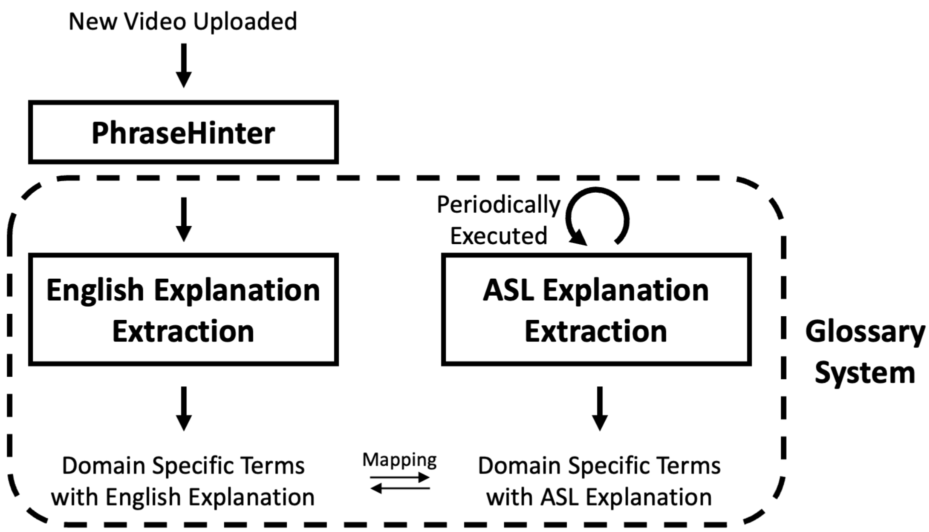


Figure 1: Overview of the explanation extraction workflow. A set of potential domain terms (the set of candidate Glossary items) is provided externally by the PhraseHinter. The Glossary system searches for both English and ASL explanations.

As of this writing, the most recent version of the Glossary further expands the candidate set of glossary terms by adding domain terms extracted from the caption data using the same TF-IDF and Sequential Pattern Mining approach.

4.4 I·Note

In addition to the traditional video-based modality, ClassTranscribe also creates an inclusive accessible lecture delivery in a text-based modality, "I·Note", a digital book that contains the equivalent information of the original lecture. I·Note was introduced with a goal to help DHH students to better learn lecture content [13]. Each lecture video has a corresponding I·Note, which consists of screenshots of the scenes and the audio transcription. Instructors and students are also given user interfaces to separate the I·Note into chapters and sub-chapters or provide supplementary materials via text or images. Multiple formats of I·Note, including EPUB, PDF, JPG images of the screenshots, and LaTeX resources are available for download.

5 Explanation Extraction Workflow and Considerations

The explanation extraction workflow in the Glossary system is summarized in Figure 1.

5.1 English-Based Explanation Extraction and Indexing

An automated workflow was designed and implemented to extract English-based explanations of glossary terms. The workflow is as follows. A list of potential glossary items is created from the domain terms extracted by the PhraseHinter service. Then, for each candidate glossary item, its explanations in English text are curated from online encyclopedia and dictionary sources including Wikipedia and WordNet. The ASL-based videos of the

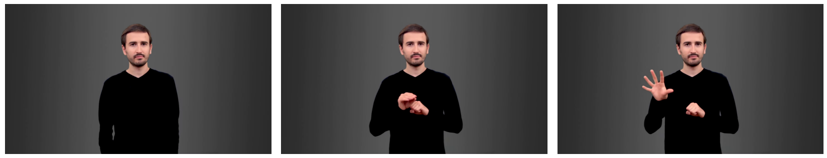


Figure 2: Sample image frames from the 4-second video for the electromagnetic "Emit" sign. Video published by the Quantum ASL project.

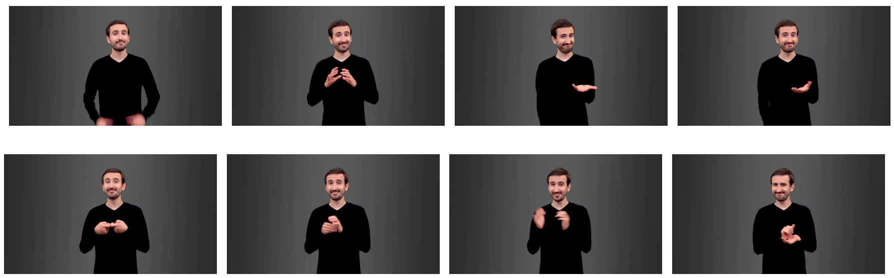


Figure 3: Sample image frames from the 12-second video for the electromagnetic "Emit" definition, "Energy release in the form of electromagnetic radiation." Video published by the Quantum ASL project.

term are mapped to the English-based explanation in the database if the ASL videos have already been downloaded.

In our initial design, it is assumed that one glossary term has the same meaning across the same course. However, instructors among different engineering courses might have different interpretations for the same term. For example, although the term "field" may refer to one kind of algebraic structure in a Mathematics course, it also means a part or a portion of a data entry in the database from a Computer Science course. Therefore, the affiliated course information was also saved for each glossary term with its explanation in the database so that instructors were able to access and edit the glossary terms of their own courses. Furthermore, for each glossary term, both a one-sentence explanation and a one-paragraph explanation were saved to adapt to the different interest levels and needs of students. For example, for students who desired a brief review of technical terms in the course, a simple but essential definition may be preferable. On the other hand, for students who require more detail or context, a more detailed explanation and optional hyperlink would be appropriate. Both of these needs can be satisfied provided we extracted both shorter and longer explanations for each glossary term.

As mentioned in section 3.2.1, some technical terms have multiple meanings. For this category of terms, online sources such as Wikipedia may provide explanations in different domains. To extract explanations that were helpful for lecture learning, a list of STEM disciplines and topics was prepared in our workflow, which served as a filter to remove non-technical explanations and retain the most relevant STEM-related explanation for a technical term.

ASL Category	English Equivalent
Isolated Sign	“Density.”
Sentence Definition	“The amount of mass contained by a volume.”
Example Usage	“The density of water is 1000 kilograms per cubic meter.”

Table 2: The 3 categories of ASL-based explanations for the glossary term “density.”

5.2 ASL-Based Explanation Extraction and Indexing

The ASL-based explanation extraction workflow collected a set of STEM-related terms with their ASL explanation videos downloaded from online vocabulary resources including ASLCore, Quantum ASL, and DeafTEC, which offered professional and accurate ASL-based explanations. An example of ASL sign and definition videos are illustrated in Figures 2 and 3. In our design, each ASL explanation video downloaded was indexed with an unique identifier. The workflow was executed periodically to update saved explanations and download new ASL explanation videos. Meanwhile, as new ASL explanation videos for a term were downloaded, the system checked if the term existed in any of the courses and mapped its English-based explanations to the ASL-based explanations in the database to provide updated ASL-based explanations for course-specific glossary terms.

To provide DHH students with comprehensive access to the ASL glossary terms, 3 categories of ASL-based video explanations were provided in our design. These were 1) Isolated sign, 2) Sentence definition, and 3) Example usage. For example, given the glossary term “density”, the English equivalent of the ASL-based explanations were summarized in the Table 2.

6 Evaluation

As discussed in 3.2.1, the explanation quality and processing time were important design concerns in the explanation extraction workflow of the system. In this section, we discuss empirical experiments that evaluated the system performance.

6.1 Dataset

The evaluation dataset consisted of (N = 300) candidate domain-specific terms from 8 video lectures of multiple engineering disciplines offered at University of Illinois Urbana-Champaign. The candidate domain-specific terms were identified by the PhraseHinter service that was discussed in section 4.3. The total duration of the lecture videos was 4 hours and 58 minutes.

6.2 Quality of English Glossary Items

Out of 300 candidate domain-specific terms inside the evaluation dataset 241 English explanations were curated, i.e., Extraction efficiency of 80.3%. Each of the 59 terms without explanation available for download was manually reviewed by the researchers. As presented in Table 3, the terms were divided into 3 categories with different reasons for the missing explanation. For the first category of terms, the system was unable to match the term to the

Reason	Count	Example
Mismatch	19	“Recall”, “Causation”
Term has ambiguous meaning; System cannot disambiguate	11	“Limit”, “Expectation”
Not a domain term	29	“Limitation”, “Partial”

Table 3: The 3 categories of terms with different reasons for the missing explanation.

Score	Evaluation Criteria	Comments
1	Explanation is correct and corresponds to the course context	Explanation is of high quality and is helpful
0	Explanation is either unrelated, misleading, incomplete, or involves unrecognizable characters	Explanation is of low quality and is not helpful

Table 4: Rubric evaluating quality of the extracted English-based explanation for a domain-specific term.

exact entry in the online resource that provided the explanation. For the second category of terms, the online resources provided multiple explanations for the term with respect to different domains, but the system was unable to disambiguate and locate the STEM-related explanation. For the third category of terms, the system could not find a specific explanation from the online resources because the term was overly general and was not affiliated to a specific domain.

Missing explanations for terms in the third category is acceptable because explanations for non-technical terms are not helpful for the purpose of engineering education. However, the system ideally should be able to match terms in the first two categories to the STEM-related explanations offered by the online sources because explanations of those terms are important for learning course-related concepts.

For the terms with explanations extracted, the rubric in Table 4 was used to evaluate the quality of an explanation. In our experiment, each explanation was scored by two researchers with experience in related engineering disciplines. Each explanation received a final score which was the average of the two scores from the researchers. A score of 1 meant that the explanation is of higher quality and is likely to be helpful for students. To measure the inter-rater reliability, the Cohen's Kappa coefficient[8] was calculated based on the scores given by the researchers. The coefficient value in our experiment was 0.73, which indicated that there was substantial and sufficient (but not perfect) agreement between raters assessing the extracted explanations and marked the robustness and correctness of the score given to each term[18].

Recall and Precision were selected to measure the utility of the system. Recall is the ratio of the sum of scores to the number of candidate domain-specific terms inside the dataset, and Precision is the ratio of the sum of scores to the number of explanations that were extracted by the Glossary system. The Extraction efficiency, Recall, and Precision are reported in Table 5.

Extraction efficiency	Precision	Recall
80.3%	82.0%	65.8%

Table 5: Quality evaluation results for 300 candidate domain-specific terms in the evaluation dataset. The astute reader may notice Recall is the multiplicative product of Extraction efficiency and Precision.

Isolated Sign	Sentence Definition	Example Usage	All 3 Categories
15.3%	13.0%	10.7%	6.7%

Table 6: Extraction efficiency of ASL explanation video of different categories.

Recall measured that, for all candidate domain-specific terms inside the dataset, what percentage of them have explanations accurately extracted. Of the items with a definition available, Precision measured how many were accurate and of high quality. Precision is an important measure because we desire the explanations provided to students to be correct, relevant, and helpful. Both Recall and Precision metrics are important considerations if the Glossary is to be an effective learning aid.

As indicated in Table 5, the Precision was slightly higher than 80%, the original subjective goal of 4 correct items out of 5. In a real course use, the remaining incorrect explanations could be either 1) corrected by the course instructor or, 2) ignored by students based on the number of Like votes, which will be introduced in section 7.3.

6.3 Quality of ASL Glossary Items

The extraction efficiency of ASL-based explanation from 3 online vocabulary resources is summarized in Table 6. Each field in the table represents the Extraction efficiency for a particular category of ASL explanation video. Out of the 300 candidate domain-specific terms, the workflow curated an ASL video of an isolated sign for 46 terms (15.3%), ASL video of a sentence definition for 39 terms (13.0%), and ASL video of an example usage for 32 terms (10.7%). Among them, only 20 terms (6.7%) were provided with all 3 categories of ASL explanation videos. The Venn diagram of candidate domain-specific terms with available ASL videos is presented in Figure 4. The Extraction efficiency of ASL-based explanation is lower than that of the English-based extraction due to the limited amount of available ASL videos for STEM-related topics. These results highlight the need for greater set of publicly available ASL-based technical content.

Full Corpus Processing Time (seconds)	Single Lecture Processing Time (seconds)
236.9	39.8

Table 7: Processing time of the English-based explanation extraction workflow for all 8 videos in the dataset and one 50-minute lecture.

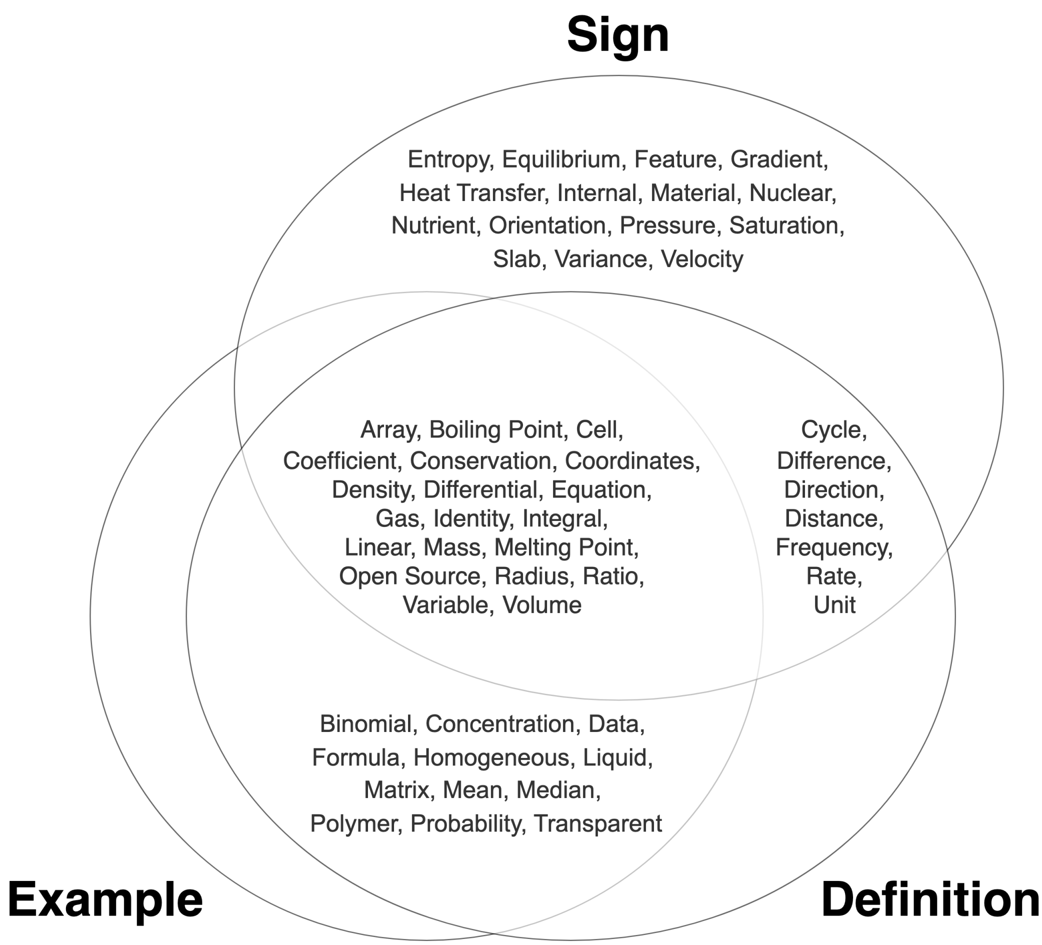


Figure 4: The Venn diagram of candidate domain-specific terms with available ASL videos.

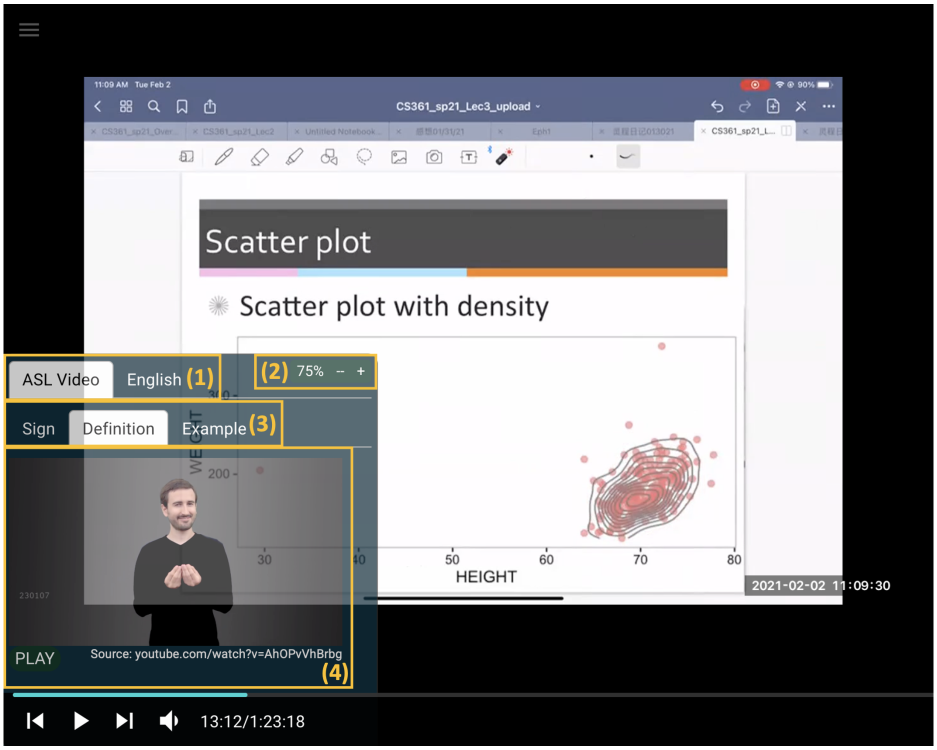


Figure 5: Web page popup explaining the glossary term "density" in ASL.

6.4 Time Requirement

The evaluation was conducted on a laptop with Generation-6 (2015) 4-Core Intel i7 CPU. The processing time for the English-based explanation extraction workflow is summarized in Table 7. As indicated in the table, it required less than 1 minute for the workflow to complete extracting glossary explanations for a normal 50-minute lecture, which is satisfactory performance to allow inclusion into ClassTranscribe,a video-based learning production platform.

7 Web-Based Applications and Implementations

The Glossary system has been deployed into ClassTranscribe with 3 different user interfaces designed and implemented for students with different needs and preferences.

7.1 Web Page Popups

The Glossary system was embedded in the traditional video-based modality as a web page popup, which provided in-text explanation in both English and ASL for glossary terms that appeared in either the video screen or the audio transcription. To realize this interface, the occurrence timestamp of each glossary term was first retrieved from the results of the SceneDetection service and automatic speech recognition. Depending on the current timestamp the student is watching, the popups display the explanation of the nearest glossary term that is being discussed by the instructor.

Figures 5 and 6 show an example of the popup explaining the glossary term "density"

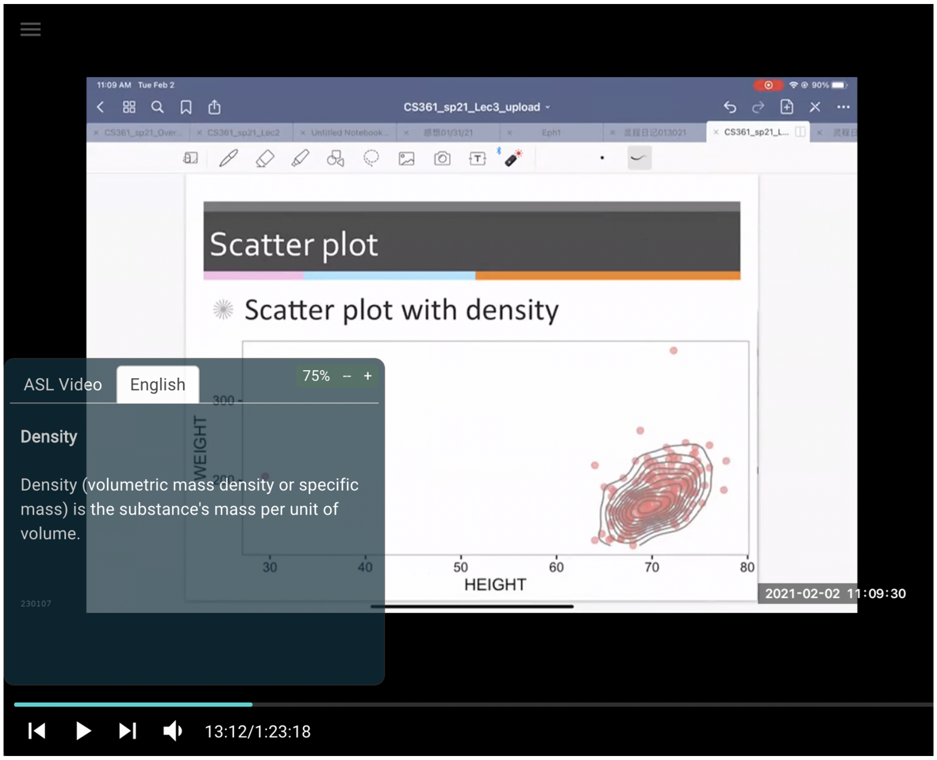
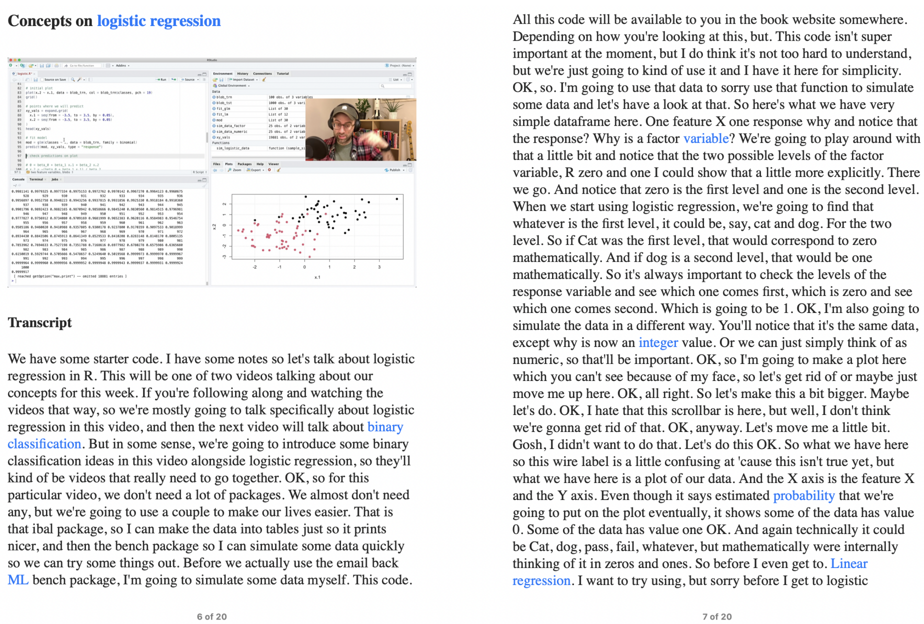


Figure 6: Web page popup explaining the glossary term "density" in English.

in ASL and English respectively. This term appeared in the video screen of a lecture from an Applied Statistics course. Multiple interfaces were offered for students with different learning needs. Specifically, as indicated in Figure 5, students would be able to switch between English explanation and ASL explanation in workspace (1). One of the goals of the web popups is to provide students a smooth experience in a learning glossary that does not interfere with viewing the lecture video. As a result, students would be able to set the transparency of the popup in workspace (2) so the popup does not completely obscure the lecture video. A future version of the player may allow students to move the glossary window to a different position. Students can choose a specific category of ASL explanations in workspace (3). In workspace (4), students can watch or pause the ASL video.

7.2 Glossary Appendix

For the I·Note interface, where students use a text-based digital book interface, a glossary appendix was added after the end of the main content, and hyperlinks were added to the main text where domain-specific terms appeared. Figures 7 and 8 illustrate an example of the glossary appendix page of an I·Note document generated in a Statistical Learning course. As indicated in Figure 7, all glossary terms that appeared in the main text (which is created from the lecture transcription) within a chapter or a sub-chapter were highlighted using a different color from the rest of the text. A hyperlink was attached to each glossary term in the main text, which redirected to an appendix page at the end of each chapter and sub-chapter. The appendix page (Figure 8) listed all the within-chapter glossary terms with



Concepts on logistic regression

Transcript

We have some starter code. I have some notes so let's talk about logistic regression in R. This will be one of two videos talking about our concepts for this week. If you're following along and watching the videos that way, so we're mostly going to talk specifically about logistic regression in this video, and then the next video will talk about binary classification. But in some sense, we're going to introduce some binary classification ideas in this video alongside logistic regression, so they'll kind of be videos that really need to go together. OK, so for this particular video, we don't need a lot of packages. We almost don't need any, but we're going to use a couple to make our lives easier. That is that ibal package, so I can make the data into tables just so it prints nicer, and then the bench package so I can simulate some data quickly so we can try some things out. Before we actually use the email back ML bench package, I'm going to simulate some data myself. This code.

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All this code will be available to you in the book website somewhere. Depending on how you're looking at this, but. This code isn't super important at the moment, but I do think it's not too hard to understand, but we're just going to kind of use it and I have it here for simplicity. OK, so. I'm going to use that data to sorry use that function to simulate some data and let's have a look at that. So here's what we have very simple dataframe here. One feature X one response why and notice that the response? Why is a factor variable? We're going to play around with that a little bit and notice that the two possible levels of the factor variable, R zero and one I could show that a little more explicitly. There we go. And notice that zero is the first level and one is the second level. When we start using logistic regression, we're going to find that whatever is the first level, it could be, say, cat and dog. For the two level. So if Cat was the first level, that would correspond to zero mathematically. And if dog is a second level, that would be one mathematically. So it's always important to check the levels of the response variable and see which one comes first, which is zero and see which one comes second. Which is going to be 1. OK, I'm also going to simulate the data in a different way. You'll notice that it's the same data, except why is now an integer value. Or we can just simply think of as numeric, so that'll be important. OK, so I'm going to make a plot here which you can't see because of my face, so let's get rid of or maybe just move me up here. OK, all right. So let's make this a bit bigger. Maybe let's do. OK, I hate that this scrollbar is here, but well, I don't think we're gonna get rid of that. OK, anyway. Let's move me a little bit. Gosh, I didn't want to do that. Let's do this OK. So what we have here so this wire label is a little confusing at 'cause this isn't true yet, but what we have here is a plot of our data. And the X axis is the feature X and the Y axis. Even though it says estimated probability that we're going to put on the plot eventually, it shows some of the data has value 0. Some of the data has value one OK. And again technically it could be Cat, dog, pass, fail, whatever, but mathematically were internally thinking of it in zeros and ones. So before I even get to. Linear regression. I want to try using, but sorry before I get to logistic

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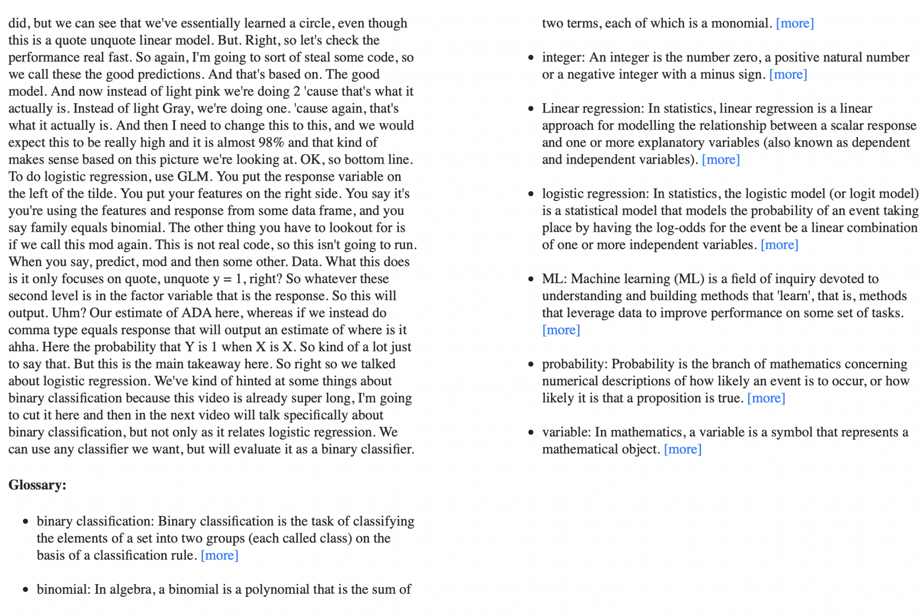
Figure 7: An I·Note document with glossary terms highlighted and attached with hyperlinks to the relevant glossary entry.



did, but we can see that we've essentially learned a circle, even though this is a quote unquote linear model. But. Right, so let's check the performance real fast. So again, I'm going to sort of steal some code, so we call these the good predictions. And that's based on. The good model. And now instead of light pink we're doing 2 'cause that's what it actually is. Instead of light Gray, we're doing one. 'cause again, that's what it actually is. And then I need to change this to this, and we would expect this to be really high and it is almost 98% and that kind of makes sense based on this picture we're looking at. OK, so bottom line. To do logistic regression, use GLM. You put the response variable on the left of the tilde. You put your features on the right side. You say it's you're using the features and response from some data frame, and you say family equals binomial. The other thing you have to lookout for is if we call this mod again. This is not real code, so this isn't going to run. When you say, predict, mod and then some other. Data. What this does is it only focuses on quote, unquote y = 1, right? So whatever these second level is in the factor variable that is the response. So this will output. Uhm? Our estimate of ADA here, whereas if we instead do comma type equals response that will output an estimate of where is it ahha. Here the probability that Y is 1 when X is X. So kind of a lot just to say that. But this is the main takeaway here. So right so we talked about logistic regression. We've kind of hinted at some things about binary classification because this video is already super long, I'm going to cut it here and then in the next video will talk specifically about binary classification, but not only as it relates logistic regression. We can use any classifier we want, but will evaluate it as a binary classifier.

Glossary:

- binary classification: Binary classification is the task of classifying the elements of a set into two groups (each called class) on the basis of a classification rule. [more]
- binomial: In algebra, a binomial is a polynomial that is the sum of two terms, each of which is a monomial. [more]
- integer: An integer is the number zero, a positive natural number or a negative integer with a minus sign. [more]
- Linear regression: In statistics, linear regression is a linear approach for modelling the relationship between a scalar response and one or more explanatory variables (also known as dependent and independent variables). [more]
- logistic regression: In statistics, the logistic model (or logit model) is a statistical model that models the probability of an event taking place by having the log-odds for the event be a linear combination of one or more independent variables. [more]
- ML: Machine learning (ML) is a field of inquiry devoted to understanding and building methods that 'learn', that is, methods that leverage data to improve performance on some set of tasks. [more]
- probability: Probability is the branch of mathematics concerning numerical descriptions of how likely an event is to occur, or how likely it is that a proposition is true. [more]
- variable: In mathematics, a variable is a symbol that represents a mathematical object. [more]

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Figure 8: Glossary Appendix page in the I·Note with within-chapter glossary terms and their one-sentence explanations.

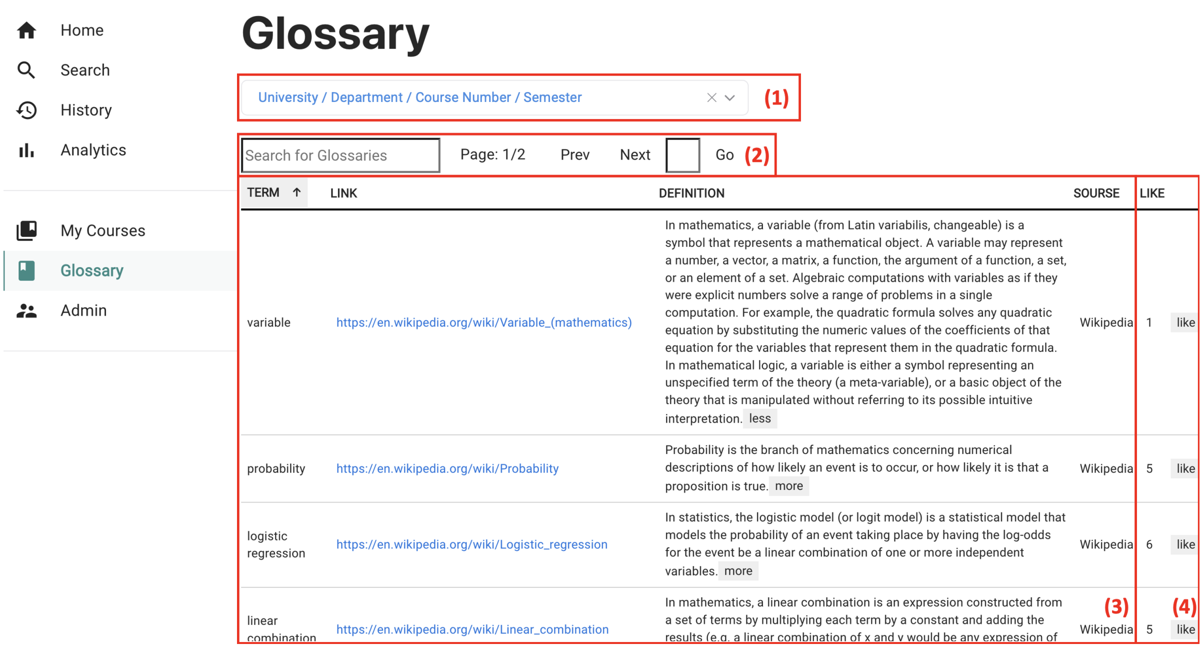


Figure 9: An English-based gallery page for a Statistical Learning course with different workspaces identified.

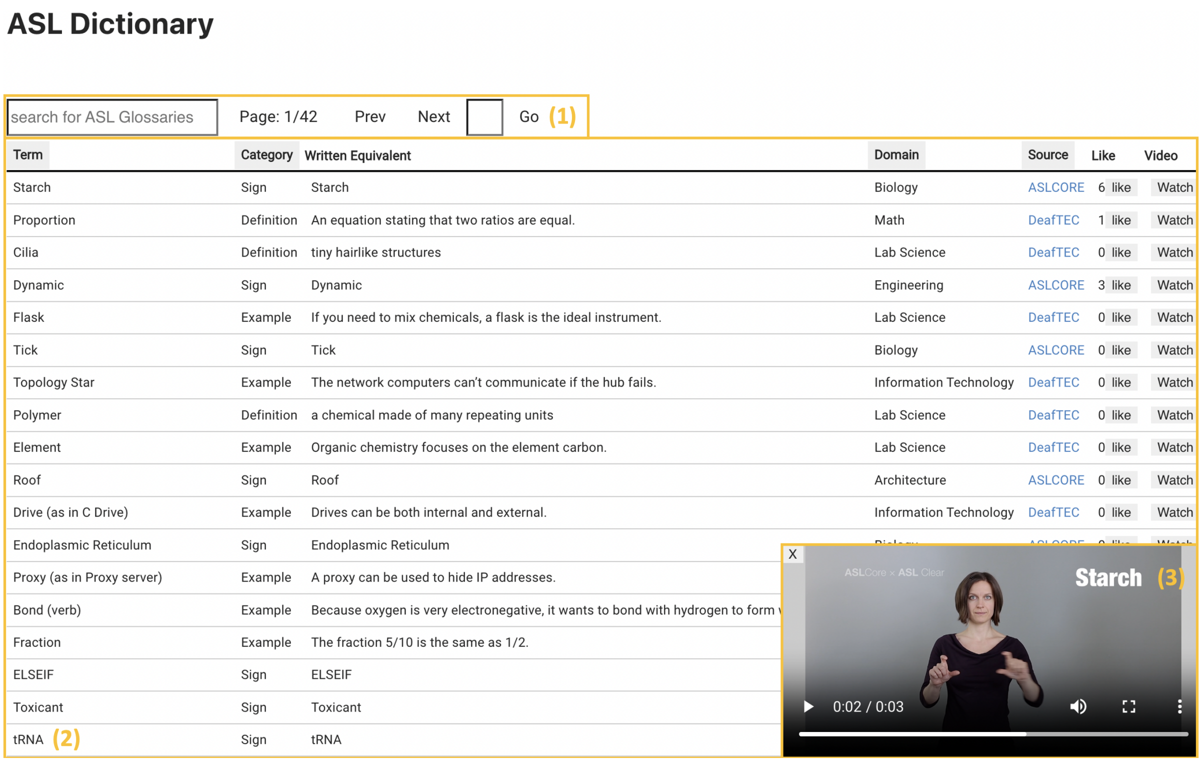
one-sentence explanations for reference. If students still cannot understand the meaning or want to know more about a term, a button opened external web document where students could obtain more information.

Full access to the glossary appendix was granted to instructors and students to create their own I·Notes with different demands. For each I·Note created, instructors and students were allowed to add, remove, and edit glossary term information. By default, to reduce visual clutter, it is assumed that highlighting only the first occurrence for each glossary term in the main text is sufficient for most students. However a configuration option was provided to highlight all occurrences of each glossary term in the main text.

7.3 Online Gallery Page

We also offered online gallery review pages that list all glossary terms with their explanations. The gallery page was designed for multiple purposes. First, students could search and learn about the technical terms which they missed or were confused about during the lecture time, which helped them fill in the potential knowledge-gaps. In addition, the gallery page may serve as a review list for students to check their understanding on glossary terms. Additionally, for students who want to learn more technical vocabulary, they can browse through the dictionary for advanced terms or terms that were only briefly mentioned in the lecture.

Two categories of gallery pages are provided including the English-based gallery page and the ASL-based gallery page. Pagination, search, and filtering functions are supported in both categories.



ASL Dictionary

search for ASL Glossaries | Page: 1/42 | Prev | Next | Go (1)

Term	Category	Written Equivalent	Domain	Source	Like	Video
Starch	Sign	Starch	Biology	ASLCORE	6 like	Watch
Proportion	Definition	An equation stating that two ratios are equal.	Math	DeafTEC	1 like	Watch
Cilia	Definition	tiny hairlike structures	Lab Science	DeafTEC	0 like	Watch
Dynamic	Sign	Dynamic	Engineering	ASLCORE	3 like	Watch
Flask	Example	If you need to mix chemicals, a flask is the ideal instrument.	Lab Science	DeafTEC	0 like	Watch
Tick	Sign	Tick	Biology	ASLCORE	0 like	Watch
Topology Star	Example	The network computers can't communicate if the hub fails.	Information Technology	DeafTEC	0 like	Watch
Polymer	Definition	a chemical made of many repeating units	Lab Science	DeafTEC	0 like	Watch
Element	Example	Organic chemistry focuses on the element carbon.	Lab Science	DeafTEC	0 like	Watch
Roof	Sign	Roof	Architecture	ASLCORE	0 like	Watch
Drive (as in C Drive)	Example	Drives can be both internal and external.	Information Technology	DeafTEC	0 like	Watch
Endoplasmic Reticulum	Sign	Endoplasmic Reticulum				
Proxy (as in Proxy server)	Example	A proxy can be used to hide IP addresses.				
Bond (verb)	Example	Because oxygen is very electronegative, it wants to bond with hydrogen to form				
Fraction	Example	The fraction 5/10 is the same as 1/2.				
ELSEIF	Sign	ELSEIF				
Toxicant	Sign	Toxicant				
tRNA (2)	Sign	tRNA				

Figure 10: The general ASL-based gallery page with different workspaces identified.

English-based gallery pages are offered on a course-by-course basis, each serving as a shared course-specific dictionary and presenting all glossary terms with their English explanations for a user-specified course. Figure 9 is an example of the English-based gallery page for a Statistical Learning course. Specifically, area (1) presents a filter for students to locate a specific course from which they want to access the dictionary. Other than viewing all the glossary terms, students can directly search for specific terms through the search bar provided in area (2). In area (2), students can also view or change their current page. Area (3) displays all the glossary terms with explanations, external links, and original sources, which supports sorting in alphabetical order. A button is provided at the end of each glossary explanation to allow students to switch between viewing one-sentence explanations or one-paragraph explanations. As indicated in Figure 9, a one-paragraph explanation was presented for the term "variable" and one-sentence explanations were presented for the other terms. Students could also access the original online source for more information through the provided hyperlink. In area (4), students can upvote a specific term to indicate their preference for a particular explanation. In general, the number of Like votes may act as an indicator that a particular explanation is helpful or not. This will be the subject of future research. In addition to viewing the English-based glossary content, instructors and students are also allowed to add new glossary terms, delete or modify the automatically generated glossary content.

We also offered a general gallery page for all glossary terms with ASL explanations available, as indicated in Figure 10. Similar to the English-based gallery page, students can search for a specific term and view or change the current page in area (1). Area (2) presents all glossary terms with category, English equivalent, domain, original source, and number of Like votes of their ASL explanation videos. Area (3) contains a scalable and movable video player in which students can view the ASL explanation video.

8 Student Feedback

A preliminary user study was conducted on (N = 14) engineering students who have utilized the Glossary interfaces for lecture learning. Among them, 3 students (22%) were native English speakers, 1 student (7%) was a native ASL speaker, and 10 students (71%) had other first languages. The following questions were asked in an anonymous feedback form sent to each participant.

- (Likert Scale) Agree or Disagree? The 3 glossary interfaces will be useful when I need to review technical terms used in the lecture.
- (Likert Scale) Agree or Disagree? In a difficult course, the 3 glossary interfaces will help me understand the background concepts that I need to succeed in the course.
- (Multiple Choice) When will the glossary interfaces be most useful?
- (Multiple Choice) Which interface is most useful i.e., would you like to see it be available first?
- (Free Response) How can we improve the Glossary interfaces?
- (Free Response) Any others comments on the Glossary interfaces?

Most of the students (13 out of 14, 93%) expressed a positive opinion (Strongly Agree or Agree) on the first question and believed that the glossary interfaces will help them review technical terms. Most of the students (12 out of 14, 86%) expressed a positive opinion on the second question and believed that the glossary interfaces will help them better understand the background concepts. For the third question, a majority of the students (11 out of 14, 79%) stated that the glossary interfaces are most useful when they are learning the lecture content for the first time. The native ASL speaker believed that the glossary interfaces are most useful for native ASL speakers to practice communicating technical content in ASL. The other 2 students (14%) most preferred to use the glossary interfaces for exam preparation. For the fourth question, 64% of the students (9 out of 14) preferred the Web Page Popups interface while the other 36% of the students (5 out of 14) preferred the Glossary Appendix interface, suggesting both interfaces have significant pedagogical value.

Their informal suggestions for improvements included, "Multilingual explanations are also expected ... Include pronunciation of the term. This could be particularly useful for students whose native language is not English ... Add visual explanation via videos and figures ... Glossary Appendix can be generated in a different font size or style to be visually different from the main text content ... Present the glossary terms based on users' familiarity ... Embed the term explanations inside the transcriptions." Their informal comments also included, "It will be of great help when learning professional college-level courses … The interfaces can help beginners to learn faster … It saves time when we are searching for meanings of technical terms, which improves learning efficiency." These comments and suggestions will help inform future versions of the Glossary interfaces.

Though the feedback by students is a limited and initial evaluation, it is still valuable and is sufficient for the authors to continue improving the Glossary interfaces.

9 Conclusion and Future Work

In this paper, we described how small knowledge-gaps among students may act as barriers and inhibit them from learning and using technical terms. We emphasized the importance and multiple benefits of additionally providing glossary explanations in American Sign Language for Deaf and Hard of Hearing students, including reducing cognitive load for students whose first language is ASL and providing exposure to communicating university-level technical content in ASL. We also noted the importance of introducing engineering students to interfaces that are inclusive, accessible and have universal design elements. We presented a new embedded Glossary system, which automatically curated glossary explanations in English and ASL from online sources and directly satisfies a Universal Design for Learning goal to provide supporting information when the student needs it. Evaluation results based on a dataset of 300 candidate domain-specific terms indicated that the Glossary system was able to collect accurate glossary explanations within the performance constraints desired of a production system. We demonstrated the implementation of the Glossary system in 3 different user interfaces deployed to ClassTranscribe, including 1) Web page popups, 2) Glossary appendix pages and hyperlinked text, and 3) A gallery page for glossary term searching, review, editing, and voting.

Of the 300 candidate glossary terms, 13.0% of the terms had an ASL video of a sentence definition available, and only 6.7% had all three categories (sign, sentence definition, and example use) available. While it is exciting that we were able to find a non-zero number of ASL videos to embed in an engineering content, these small fractions highlight a *compelling need for a greater set of publicly available ASL-based technical dictionary content for engineers and university students who use ASL.*

Our work also opens new topics for future research in inclusive and accessible engineering education. For example, 1) Educational studies on the effect of the Glossary system on learning outcomes, motivation, and retention improvement with transfer students, students at risk of leaving the major, and students with impoverished educational backgrounds, 2) Effect, engagement and use of ASL resources by signing and non-signing students, 3) Approaches to enhance learning outcomes on understanding technical terms for students with low vision, 4) Crowd sourcing English glossary terms and identification of preferred entries when multiple variations are available, and 5) Ensuring the text aspects of the Glossary interface work intuitively for students who use a Screen Reader and web pages are rendered in Braille and audio using text to speech.

The Glossary system is available for the engineering education community for use in their courses and is open source (github.com/classtranscribe). Please contact the authors for more information. We invite other researchers, software developers, and educators to supplement our efforts in a vision that combines open source development, scholastic research, and adoptable practices of inclusive, accessible engineering education.

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