Capstone Design CONFERENCE 2026
JUNE 1–3, 2026 ▶ COLLEGE STATION, TX

Capturing Design Progress in an Engineering Capstone Course: Development of an LLM Tool

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This paper describes the development of a Large Language Model (LLM) tool to assist design teams and instructors in understanding and visualizing their design process. Through weekly progress reports, students identified the design processes they engaged in. By mapping which design processes the teams engage in as the project advances, a visual representation of the overall design process can be created—notably, a design signature. However, the accuracy of the design signature depends solely on the knowledge and understanding of the design team. With this limit in place, we created an LLM tool with three fundamental goals: create a design signature based on a teams' self-reported design processes, analyze evidence provided by the team in terms of activities related to the reported design processes, and, finally, evaluate the teams' processes. Through the use of this tool, a clearer understanding of the teams' knowledge of the design taxonomy can be established, allowing for better feedback and assistance in the design framework.

Keywords: human-centered design, design project reports, LLM

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Introduction

Capstone courses with design projects possess many student challenges as student teams are often unprepared to manage projects and teamwork, and they may struggle to translate open-ended project goals into concrete, week-to-week progress.[1] At the same time, instructors and teaching assistants encounter difficulties in (i) monitoring and evaluating progress consistently and (ii) providing timely, targeted formative feedback.[2,3] One common way to track group work is tasking teams to submit weekly progress reports to document and reflect on their project development. Nevertheless, these documents become administrative unless they are used to support the groups' performance and instructors' feedback. To address this, this paper describes the development of a web-based LLM tool that analyzes PDF progress reports and generates a design signature that groups and instructors can use to concretely support the groups' performance. These progress reports task teams to reflect on the human-centered design processes that the team engaged in during the previous week.

The LLM tool was developed for use in a materials science and engineering capstone course; however, it is not discipline specific, as it focuses on the design processes. In this course, the human-centered design (HCD) taxonomy described in Lawrence et al. is used as the design model that can guide the students' design journey.[4] The taxonomy is composed of five non-linear design spaces (Understand, Synthesize, Ideate, Prototype, and Implement). Each space is composed of four design processes that students can implement during a design project. Here, we describe the tool's prototyping approach and validation plan. We also outline a reliability study comparing tool-generated signatures with human ratings of the same report sets. Finally, we present how the tool will be implemented to support student reflection, enable more efficient instructional feedback, and examine how signature trajectories relate to final project outcomes.

The role of design projects in undergraduate engineering capstone courses

Design projects play a critical role in undergraduate engineering capstone courses. They provide students with an experiential, collaborative learning opportunity where students can apply cumulative engineering knowledge to practice engineering design.[1,2] These projects are usually hands-on, authentic challenges that are very similar to what engineers experience in the workplace.[1] Studies show that engaging students in these projects is consistently associated with gains in their conceptual understanding, problem solving, and development of soft skills such as collaboration and communication.[5] Nevertheless, evidence from these studies suggests that the effectiveness of capstone design projects depends on how the experience is structured.[3] For example, emphasizing teamwork by embedding activities that foster team collaboration, and encouraging the use of a design methodology by suggesting a specific design model, can help students make concrete and observable progress on the project.[1] In turn, utilizing a shared design methodology can enable the course instructor and teaching assistants to provide more specific and actionable feedback for students.[1]

Capturing students' progress on engineering design projects

The teaching team's ability to provide real-time feedback to students can benefit significantly from the use of tools such as progress reports, project schedules, and rubrics, as these tools capture students' progress on the project and play a dual role in scaffolding the students' experience and informing instructors about the students' project status. By tasking students to regularly reflect on and report their progress, instructors can synthesize students' design timelines or the ways in which they engage in different design processes over time.[6] This information is critical for scaffolding students' engagement in a complete design process.[4] One such tool that has emerged from investigating students' design timelines is Atman et al. 's design signature, which visualizes and categorizes students' progress on a design project.[6] The design signature provides an overview of students' progress and process at a glance, allowing for instructors to provide actionable feedback in real time while also serving as a basis for students' self-reflection. Currently, design signatures can be generated via the app,[7] which provides select design activities to choose from, or manually, allowing users to tailor the signature's activities to their content. In either case, creating the signatures requires time from users. Furthermore, the current form of design signatures does not provide any evaluation of user inputs, meaning that instructors do not know the extent to which students' self-reported progress or activities are accurate without further investigation. Thus, there is a need to evolve the design signatures process so that signatures can be generated and evaluated in minimal time, allowing instructors to inspect both students' perceived progress and their understanding and provide informative feedback that can better scaffold students' experiences during the design process.

Capstone Course Structure

The tool was created for a materials science and engineering capstone course at a large R1 university, with the capstone enrollment of approximately 60 students. The capstone course is a sequence consisting of a fall, 1-credit course followed by a 2-credit spring course. In the fall, students learn the design principles and taxonomy of human-centered design, receiving their capstone projects at approximately the midpoint of the fall semester. The remainder of the fall semester and spring semester emphasizes the design principles and students' progress on their team projects. The capstone projects are worked in teams of 4-6 students. The major capstone project deliverables for the fall semester are a literature review and a work plan presentation. In the spring semester, the major deliverables are a midterm progress presentation, a final poster presentation, and a final portfolio. To track the teams' progress, weekly progress reports are submitted to the instructional team and discussed in weekly meetings between the student teams and instructors. These weekly meetings provide opportunities for the students to receive detailed feedback on their overall performance.

Progress report template

A progress report template was provided to the student teams; each week, the teams are to submit this report as a PDF prior to their weekly meeting with the instructors. Among other prompts, the template asks the teams to list their activities during the previous week, a description of said activity, the HCD space, and the HCD process.

In reviewing the progress reports and manually creating the design signatures, it was found that capstone teams were incorrectly identifying or misinterpreting some HCD spaces and processes. It is believed that automating the creation of the design signature and evaluating the evidence provided for each space and process would benefit the students' learning by allowing the instructors to provide concrete, tailored feedback specific to each team.

Tool Development:

An LLM tool was created to automate the creation and analysis of the design signatures. The main goal of this tool is to (i) generate a design signature, (ii) accurately label the design processes based on the evidence provided, and (iii) evaluate the labels against the students' submission, allowing richer, personalized feedback from the instructor to the student teams.

The data flow is shown in Figure 1 with the language and frameworks of the tool shown in Table 1. The current iteration has users upload a PDF to a created website. The PDF is then preprocessed via a parser, using the fitz library to extract page text into LLM-friendly markdown text. The extracted text is then sent to LLM for formatting into a schema-constrained structure and normalized. Normalization includes text cleaning, typo correction, and enforcement with only the given spaces and processes. Utilizing the data from a PDF allows seamless integration into the course infrastructure.

The LLM labels each activity for the HCD process, then compares the labels to the students' submission, as generated by the normalization process. The LLM determines if the students' submitted label is correct based on the evidence provided by the students and comparing the definition to the LLM pre-trained data. The LLM finalizes the results to Correct, No Evidence, and Incorrect (+1, 0, -1) and outputs the data in JSON format. The API renders the JSON into a table viewable on the website. Currently, no database, LMS, or storage bucket is involved; as such, after the results are returned via Restful API, the classifier will lose all its progress reports data.

Currently, the tool uses a Zero-Shot strategy; the structured output was enforced via Pydantic model for LLM generated output. The output is compared to the pre-trained data of the LLM itself, with the tool prompts encoding rubric, scoring framework and output constraints.

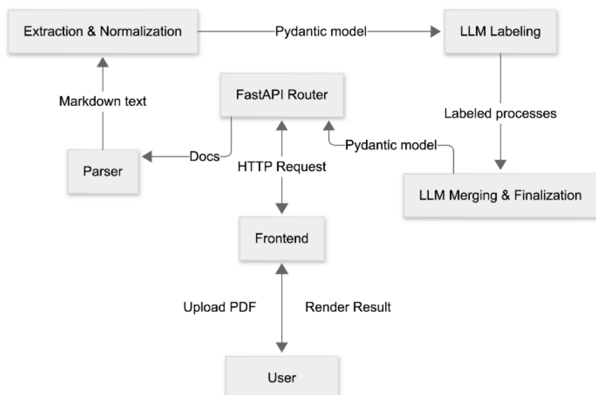

Figure 1. Data flow of the LLM tool to analyze HCD processes and create a Design Signature

Table 1. Language and Frameworks of LLM Tool

Language	Python (backend), NextJS (frontend)
API Server	FastAPI
ASGI Server	Uvicorn
PDF Parsing	Fitz
LLM Integration	Langchain
LLM API Provider	GPT 4.1 on OpenAI API
Schema Validation	Pydantic
Containerization	Docker
Deployment	Google Cloud Run (backend), Vercel (Frontend)

Performance and Scalability

A performance analysis was conducted (Google Cloud Run, 1vCPU, 512MB RAM, US-Central-1 Region, No Cold Start) and the total time to analyze a progress report was 6.88 seconds. The current implementation uses async for all LLM calls and asyncio.gather to make batch LLM calls. This significantly reduces the latency of the labeling, merging, and finalizing stages, which involve processing multiple rows concurrently. Currently, the latency is roughly equal to the sum of maximum time for each individual task.

The majority of the time (3.17 seconds) is spent in the preprocessing stage, specifically in the extraction module. This is due to using an LLM to extract tables as a Pydantic model, requiring the need to send the entire progress report, adding latency. Merging and finalizing took 2.79 seconds due to calling the LLM to evaluate the final results for all activities and labels. Using lighter models for simple tasks like extraction and changing the API provider to one with higher inference speed could decrease overall time.

The current implementation can handle high rates of requests and is cloud-native and scalable: the backend is deployed on a stateless Google Cloud Run Serverless container with auto-scaling capabilities and the frontend is deployed on Vercel, which is also serverless and built on an auto-scaling infrastructure. The frontend was delivered worldwide using Vercel's CDN.

Prototyping plans

The current version of the tool allows users to upload either a single PDF file or a series of PDF files that the tool can use to generate a design signature that summarizes patterns in the team's design journey. An example output of the design signature is shown in Figure 2. Our prototyping plans will begin with training the tool and validating its outputs using multiple sources: students' progress reports from previous semesters, progress reports that are created by the researchers, and research papers that the tool can refer to when evaluating the signatures. Moreover, the tool's reliability will be established by comparing its outputs with human ratings of the same progress report set and quantifying agreement between the two. Currently, using a zero-shot strategy and test design activities, the tool is at 65% precision at evaluating the design activities to their corresponding HCD space and process.

Broader impacts and future directions

The ability to generate and evaluate design signatures in real time is a significant resource for engineering design education. Capstone teaching teams often face a major teaching load and large volume of students with disparate projects combined with limited time and bandwidth. Having the support to provide customized, accurate feedback to students without a significant time investment is impactful for any capstone course.

To improve the scoring of the processes and spaces, the first attempt will be via Few-Shot Learning; this uses an in-context training on a small dataset to, hopefully, significantly improve accuracy. For further refinement, or if the Few-Shot Learning does not improve the accuracy to the desired level, a Supervised Fine-Tuning (SFT) method will be employed. The SFT incorporates heavier training on model weights, requiring a much larger and higher quality training dataset.

Classification Results

Multi-week Process classification (Green = 1, Yellow = 0, Red = -1)

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Process	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14	Week 15
Explore	0		1												
Observe															
Empathize	0	-1													
Reflect	0	-1													
Debrief	0	-1													
Organize			1	0											
Interpret															
Define															
Brainstorm	0	-1		-1											
Propose	0	-1	0		1	-1	-1								
Plan	1		0	0	-1	1	-1	-1							
Narrow Concepts			1	0	1	1	-1	-1		-1					
Create					1	1	1	1	0	1	1	0	1	1	
Engage					0		0				0	-1	-1	-1	
Evaluate						0		-1	0		-1	-1		-1	-1
Iterate						0			0						
Support															0
Sustain															
Evolve												-1	-1		
Execute															

Figure 2. Design Signature created by the current LLM tool. Green indicates correct evidence is provided for that design process, red indicates incorrect evidence is provided, and yellow indicates no evidence is provided for the labeled process. Data is taken from a capstone design group in academic year 2025-26.

Following the training and validation, the tool will be implemented in a Materials Science capstone course. It will be used to support students' reflections on their design journey through recurring signature feedback. It will also be used to enable instructors and teaching assistants to monitor design progress more effectively and provide targeted formative feedback. Researchers can collect the groups' signatures to examine their relationship with the design projects scores and outcomes.

Future development of the tool can be separated into usability and accuracy. For improved usability, an integrated upload into the Learning Management System (currently using Canvas) and output into a csv or similar file format would be ideal. Furthermore, long-term efforts can use feedback from instructors and observational data from implementation to fine-tune the characteristics of its design signature generation and evaluation to better suit instructors' and students' needs.

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