AC 2012-5470: TRACKING DESIGN KNOWLEDGE IN ENGINEERING STUDENT PROJECTS AROUND COURSE MILESTONES

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Abstract

Project-based courses challenge students by presenting them with real-world situations in which they have to constantly balance their time and efforts between formulating the problem, exploring and adapting concepts to their problem domain, and documenting their progress to present to clients and instructors. Although it is widely accepted that project-based courses benefit students, the explicit role of project milestones in the progress of the project is not well understood. This paper addresses the effect of milestones by examining the vocabulary used in an inter-disciplinary project-based course in online discussions as well as design documentation. Noun phrases, which are surrogates for design concepts, vary throughout the three phases in the class. The data is then divided into editing/presentation and design categories and the noun phrases used in the two categories are compared. Students must allocate their time between designing and documenting and we observe that their design activities often peak just after the documentation deadlines. The paper concludes that instructors need to be aware of the role played by explicit project deadlines in project based courses. A delicate balance between externalization and active student collaboration is required for effective student learning experience.

1. Introduction

Many engineering design project courses challenge students with real-world problems that require teams to integrate their knowledge and to think creatively. When faced with conflicting constraints, students must break their classroom thinking patterns. The externalization of the knowledge of individual students and the development of a shared understanding by the team does not happen by itself. External stimuli, such as explicit project milestones, client presentations and class meetings, force the students to share and integrate their design ideas.

Since most of the knowledge creation by students occurs without the instructor present, instructors are often unaware when students deviate from the project’s objective. Instructors intend to assess student learning outcomes and assist them when they observe a teachable moment. However, students consider product outcomes as the primary goal of project-based courses and are reluctant to share the problems they face with the instructors. Given this constraint, the intermediate and final grades are often based on the quality of the product and on self-reported functioning of the team. Even when the evidence of student collaboration is accessible through discussion forums and e-mail threads, making sense of this data is difficult due to a lack of practical tools to synthesize the information. This paper addresses the problem of information management in project courses by examining the documents students create and reference throughout the course and the online discussions with their peers.

Prior research has shown that noun phrases can be used as surrogates for design concepts. Since the goal of this research is to assist instructors in analyzing students’ progress towards the project goal, we track the noun phrases used by the students throughout the semester. The analysis shows that the number of noun phrases peaks at the end of each of the three phases in the class.
The peaks represent the number of distinct noun phrases used in the documents and discussions in the week before the project deadlines. We divide the data into editing/presentation and design categories and compare the noun phrases used in the two categories. In other words, the knowledge created because of individual group deadlines (intermediate phase milestones) is compared to that in the overall class presentation deadlines (end-of-phase milestones). We find that some phase milestones require more coordination among groups and thus show higher peaks than the intermediate products. The paper presents sample individual concepts (noun phrases) used by the student teams and tracks how they are modified at the end of each phase or dropped because of design choices. This paper analyzes the role played by explicit project deadlines in project based design courses and shows the role of externalization in design project realization.

1.1 Research Testbed

An interdisciplinary project course taught at Carnegie Mellon university is the focus of this study. This course gives students a real-world experience in multi-disciplinary design problems by requiring them to design, build and deliver a prototype physical system for a real client. The course can be taken by undergraduate and graduate students across multiple departments, including Electrical and Computer Engineering, Mechanical Engineering, Computer Science, Industrial Design and Human-Computer Interaction. The course uses a typical product development cycle, starting from the requirements of clients to the final demo and delivery of a prototype system. The students experience real-world constraints, such as firm deadlines, limited budget and a client. The course is divided into three phases with the students submitting documentation and making formal presentations at the end of each phase.

The students use a light-weight collaboration tool for student project team collaboration called the Kiva3. This tool provides a thread-based discussion environment in which students can form groups, participate in discussions and upload files. All posts are visible to everyone in the class, and students are encouraged to read not just their own group’s posts, but also the ones made in other groups. The tool captures team conversations, discussions, slide presentations, class documents, weekly plans, work-logs, meeting minutes, intermediate update reports, references (including URLs) and project files that students would have otherwise shared through e-mail or chat, within their teams or with other teams. Such detailed information allows this study to explore various aspects of design in depth. In addition, because the course is multi-disciplinary, students need to be explicit in their arguments and decisions.

Examining the data shows that the student posts on the online discussion forums ranged in size from 10-500 words and the number of noun phrases contained in them was negligible compared to the formal documents posted by the students. For example, the Phase 1 report had about 16,000 words and the final project report had about 25,000 words. Table 1 shows the number and types of files that were posted in the Spring 2008 class. The zipped folders usually contained the programming files that students were working on and were unzipped before the analysis.

1.2 Organization of Class

The course is organized into three phases: Phase 1 involves requirements exploration and definition, benchmarking, and a rough conceptual prototype; Phase 2 involves the creation of a functional prototype that satisfies most of the feasibility constraints; and Phase 3 involves system
integration and more design iterations to make final refinements. Throughout the project course, clients are actively involved with the teams, providing relevant expertise, project advice and any needed clarifications. The role of team leaders is filled by students, not by instructors or teaching assistants. At the end of each phase, each team is required to document its design choice, the criteria used for design selection and present the project to the clients. Students are encouraged to document the intermediate design iterations and rationale behind important design decisions; however, compliance varies across teams and from one class to another. By the end of the semester, all teams have a functional product/detailed design specifications and an extensive report to submit to the client. The teams receive feedback and grades for their project reviews after each phase. These are tabulated at the end of the semester for individual student grades.

The data used for this research was taken from a class of 25 students taught by two instructors and one teaching assistant in Spring 2008. The teams worked for a semester on the preliminary design of a virtual coach called Guru for new power wheelchair users. The aim was to monitor whether wheelchair users were following the clinician’s prescription properly, or if the prescription was causing pressure sores and other ailments and needed to be changed. The major teams in the class were: Chair, Clinician, Infrastructure and Sensors.

- The Chair Team was responsible for defining the interface for sensors communication, developing the GUI, Avatar, and the coding menu layout, menu tabs, displaying data and basic algorithm for storing/accessing data.
- The Clinician Team was responsible for the server side database, database access through stored procedures, data visualization and design of the website to review and modify data.
- The Sensors Team was responsible for the assembling and calibration of the tilt, pressure and IR sensors on the wheel chair, and for writing the software to convert the raw values into real data and providing the functions for accessing the real data.
- The Infrastructure Team was responsible for designing and building a mounting system to house the touch screen, computer, and battery on the chair, for calculating power estimates and measuring power consumption of actual equipment, and for Skype integration through Bluetooth connectivity for phone access.

Figure 1 shows the system architecture of the Guru system, pattern-coded by group responsibility.

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<thead>
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<th>File-types</th>
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</tr>
</thead>
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<tr>
<td>Text files</td>
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Table 1: Number and types of files included in the analysis
Figure 1: The Guru System Architecture diagram pattern-coded by group responsibility
1.3 Timeline of Class

The Guru project was divided into three phases, each lasting approximately five weeks. During Phase 1, the instructors gave the students the system architecture diagrams and intermediate and final project reports from prior years’ projects so the students could benchmark the expected level of detail in each phase report. The students were required to create a system architecture diagram for the Guru system, the software and hardware architecture diagrams, and visionary scenarios. They were also expected to situate their contribution in the research landscape. Based on the system architecture diagram, similar tasks and responsibilities were aggregated, and the major teams were formed to examine the different steps required to accomplish the assigned tasks. This was done at a high level so students could do a breadth-first overview of the existing research literature and have a basic idea of the required tasks. During each phase, new sub-teams were created to address tasks that arose in that stage of the project. In the second and third phases, the details of the project were more refined as the students acquired domain expertise in the tasks assigned to them.

Noun Phrases as Indicators of Design Performance

Past work in information retrieval has shown that noun phrases are a good approximation of concepts. The term ‘concept’ is not well-defined in the literature and subjective considerations are involved in classifying a phrase as a design concept. Nevertheless, we use noun phrases as surrogates for the major design concepts used by students.

The n-dim group made observations about the relation between design vocabulary and successful design teams. They stated that teams, in which the designers communicate frequently with each other, stabilize the design terminology much earlier than teams in which the communication breaks down or is non-existent. They extrapolated their reasoning to suggest that the late reconciliation of group design vocabulary is an indication of poor team coordination and can lead to complete project failure or significant delays in the completion.

Mabogunje followed up on this work by examining the relationship between design questions and performance in real-time design. He performed endogenous indexing of the questions captured over the course of projects, focusing on requirements documents that were produced as the project progressed. The results showed correlations between the design questions and the endogenous indices, most of which were composed of noun phrases. His research question was subsequently transformed to use noun phrases as a predictor of design performance.

The advantage of using noun phrases is due to their role as an objective design document metric for predicting design process performance. The pattern of distinct noun phrases at every stage of a design artifact can reveal insights about the state of the project. Mabogunje’s study examined the intermediate and final project reports submitted by a project class and discovered that for successful design teams the number of distinct noun phrases expanded at the initial stages of the project and contracted as the project progressed. He deduced from these findings that the expansion was because student teams were exploring (brainstorming) a variety of design options in the research literature. The contraction, on the other hand, happened as the teams refined the structure of the artifact and the approaches needed to formalize them, and started using shared
vocabulary. According to his study, if the number of distinct noun phrases used by teams contracts as the project progresses, it reflects that the project is being executed successfully.

**Approach**

The project archive of discussion posts and attachments of the class were converted to text. The noun phrases were extracted using the Stanford part-of-speech tagger\(^8\) and the number of distinct noun phrases was counted for each group. The collaboration tool allows students to cross-post and to post to teams in which they are not members, so attributing noun phrases to an individual team is difficult, since a thread might include contributions from members of other teams or the instructors. An additional concern is that the many versions of the same document may be posted by students during different phases of the project.

To resolve these problems, three analyses were done. The first analysis includes only the documentation posted to the four main teams in the project. The second analysis includes only the documentation made by members of the teams regardless of the thread in which it was posted. The third analysis compares the time-based trends of noun phrases in the editing/presentation and design categories within the documentation.

**2. Results**

This section discusses the findings of the analysis of noun phrases done from the student documentation. Week 9 was mid-semester break for students.

2.1 First Analysis

The first analysis extracts noun phrases only from the documentation posted to the four main teams in the project. The results of the analysis are shown in Figure 2. The noun phrases during the first week show an unusual peak because of the large volume of course documents and sample project reports (from prior projects) that the instructors posted. These reports provide illustrations of the deliverables to be given to the client, including the intermediate and final reports. A number of posts were also made by students in Week 1, but the volume is small compared to the reference material posted by the instructors.

A local maximum occurs at Week 3 when the students start posting material to be included in their respective sections of the Phase 1 report. The Phase 1 report is due at Week 6, but the noun phrases for the four major teams do not show a peak then since a separate sub-team was constituted for the task of writing the Phase 1 report. This sub-team included representatives from all four major teams who went over multiple versions of the Phase 1 report. However, since these were not posted in the major teams’ threads, they have not been included in this analysis.

The Phase 2 report was due at Week 12. However, unlike Phases 1 and 3, each teams worked internally to finalize their section in the Phase 2 report without requiring an editing sub-team. A local maximum can be observed at Week 12. Note that this local maximum is about half the size of the one at Week 3, showing that student design vocabulary is contracting in the number of noun phrases being used. The Phase 3 report was due at Week 17 and a new sub-team was constituted to create the final draft. A local maximum can again be seen around Week 15 when the teams posted their sections to their own teams. These were subsequently taken over by the
The maximum is again slightly smaller than the one for Week 12, thus confirming the trend toward contraction as the project progressed.

The distinct noun phrases are shown in Figure 2.b and closely correspond to the peaks for the total number of noun phrases in Figure 2.a. The local maxima are smaller for the distinct noun phrases since this graph discards the frequency of occurrence of the noun phrases. This is necessary to ensure that multiple versions of documents do not inflate the total number of noun phrases. Some limitations can be observed in this approach: First, the design contributions made by the individual teams are not adequately reflected in their vocabulary, since their corresponding project report sections and presentation sections have not been included in the analysis. So no maxima are observed for the Weeks 6 and 17. Second, this approach has a strong bias in favor of the documentation from prior projects posted by the instructors that is not relevant to the class in terms of its contents.
Note that no significant correlation was found between the noun phrase counts and the student grades. This is due partly to the way the class is structured: the student teams are graded collectively and the instructors subsequently look at the individual work-logs to estimate each student’s individual contribution.

2.2 Second Analysis

In order to address the issues with the first analysis, a second analysis was done: in this, the activities of the team members were tracked throughout the semester, instead of analyzing only the material posted in the teams’ threads. This process attributes only the noun phrases used by members of a team to the team’s knowledge. This approach discards all posts and files posted by the instructors, including class documents, sample project reports of prior completed projects and any external references, since they do not reflect student thinking at different project milestones.

Figure 3.a presents the total number of noun phrases observed in the student documentation and discussions throughout the semester. The contributions made by different teams to the intermediate project reports and presentations are included in the analysis: both Figures 3.a and 3.b show that Weeks 6, 12 and 17 have local maxima, corresponding to the increased student activity at each of these milestones. The direct correlation between the maxima in Figures 3.a and 3.b also shows not just the frequency of certain select noun phrases in the design vocabulary, but also their diversity causes variations in the number of noun phrases.

The noun phrases for each of the is low at Week 1 because the first week typically has students orienting themselves, getting introduced to each other, going over the project’s problem description, learning the collaboration tool, starting new groups and discussion threads based on their interests and suggestions provided by the instructors. The level of deliberations, and consequently the number of noun phrases, in use rises continuously up to Week 3 when the students are expected to present the first draft of the artifact’s system architecture diagram: owing to the explicit deadline in Week 3, all the teams also post the first drafts of their respective sections for the Phase 1 presentation and Phase 1 report. The Phase 1 report and Phase 1 presentation are submitted at Week 6. The noun phrases used by the Clinician team have a large peak in Week 6 because of the level of detail in Phase 1 report and not necessarily the contribution of the Clinician team alone. Peaks can also be observed at Weeks 12 and 17 corresponding to the submission of deliverables by the class to the instructors and client.

From Figure 3, one can observe the heights of the maxima decrease progressively. This agrees with the findings made by Mabogunje about the design vocabulary expanding in the initial phases of design projects and continuously contracting as the designers narrow down the design solution space. This also shows that explicit deadlines set in the class have a significant effect in motivating students to externalize their knowledge. Nevertheless, it must be noted that not all intermediate deadlines are set by the instructor: some are also decided by the structure of the class. For example, the large number of noun phrases used by the Clinician team in Phase 1 is partly because of the role played by one of their members as the Editor-in-Chief, i.e., he was exchanging draft versions of the intermediate reports more often than the rest of the class.
Similarly the prominent role played by a given team in the overall implementation also sometimes gives them a disproportionate share of the credit, e.g., the Sensors team was responsible for selecting and testing the various types of sensors and so was observed to be the most prolific user of noun phrases at the end of Phase 2.

Instructors cannot always predict which team will be most actively searching the solution space for a suitable design alternative, although the timing of the peaks in noun phrases can be anticipated based on when the students are supposed to turn in their intermediate reports and presentations. However, in order to contrast between tasks done by students explicitly for meeting deadlines in class projects versus those where they are making progress on the project, regardless of when they are expected to present their findings, a third analysis was done.
2.3 Third Analysis

The editing/presentation and design activities usually happen simultaneously for the project course in this study, given the relatively short duration of the individual phases (six weeks each). To understand the externalization done by the students around project milestones, we need to distinguish between these two types of activities or compare the vocabulary of the editing/presentation documents vis-à-vis the design documents. In the third analysis, different versions of project reports and presentation files have been analyzed along with the project documentation for the other design activities that students engaged in, i.e., the files posted by students were segregated into the editing/presentation and design categories. This was done based on whether the files related to particular versions of the project report or included slides for the intermediate/final presentation to clients. For example, if student members of the Sensors team engage in a meeting to select the types of tilt sensors for the wheelchair, the meeting minutes and any reference material used during the meeting would be considered as documentation of the design activity; while the review of different draft versions of the section on tilt sensors in the intermediate and final report would be considered under editing tasks. Note that the most common design activity is verbal interaction among the students and with the client/instructors. The lack of audio data in this research limits how many design activities can be used for analysis.

Like the previous analyses, noun phrases were extracted from these documents and their trends with time are shown in Figures 4 and 5. The total number of noun phrases and the distinct noun phrases are again correlated in Figures 4 and 5 respectively, each of which also shows the design and editing activities separately.

As Figure 4 shows, the student design activities do not necessarily follow the class deadlines, unlike those including editing of the project reports or presentations. For example, after students have presented a first draft of the system architecture and their expected responsibilities for the project in week 3, they continue to explore the existing alternatives for the project incrementally until week 7 beyond the class deadline for the phase 1 presentation. This is in contrast to the sudden lull in editing activities the week after phase 1 report is submitted. Figure 5 shows that this is true not just for the volume of noun phrases, but also for the variety of noun phrases. The only time that the design and editing activities are in sync in terms of student participation is during the Spring Break in week 9 when everything stops, as expected. As students return in week 10, they continue to experiment with rapid prototyping of their individual parts of the wheelchair, leading to a continued burst of activity between weeks 10 and 13. When the students start documenting for the project report, they stop working on the design activities, as seen by the peaks in week 14 and 15 (the final client presentation was in week 16).

This discussion shows that by instructors can infer much about student activity if they observe the noun phrases used by students in real time: the finer resolution of what types of activities are generating the noun phrases can reveal further insights about the performance of the class, as observed in the third analysis. However, the next sub-section describes how tracking of individual concepts can also reflect the project’s progress and how the abstract ideas about the artifact’s structure get more refined and specific over time.
4.a: Noun phrase counts in design activities by week

4.b: Noun phrase counts in editing tasks by week

Figure 4: Noun phrase counts in design and editing activities by week
2.4 Transformation of Design Concepts across Phases

Some design concepts are introduced by teams in project-based courses but wane with time, i.e., they are either abandoned or transformed into a related concept in the final design. For example, the Sensors team introduced the term *tilt sensors* in Phase 1 when it was planning to measure the *tilting angle* of each panel on the wheelchair. However, in Phase 2 when the team members were searching for alternatives between the kinds of *tilt sensors*, they decided to use an *accelerometer* to measure the *tilt angle* to provide the added functionality of being able to determine the acceleration of the chair at any given time. The tilt sensors were to be placed on the back, the seat, and the leg rest of the wheelchair. The team members also had to account for the *tilt recommendation* by the clinician since that was the activity recommended by the clinician for the user to follow over periodic intervals of time. The software module also had to check that there were no obstacles in the *tilt range* before it alerted the user to follow the clinician’s *tilt*
recommendation. So the basic idea of having a tilt sensor was introduced in the team in Phase 1 and then expanded in the subsequent phases. Table 2 summarizes the vocabulary used by Sensors team while referring to the tilt of the chair. These noun phrases were extracted automatically by aggregating all instances, where the word tilt and its different forms occurred in noun phrases in the project corpus, by using regular expression syntax. The evolution of vocabulary as shown in Table 2 can indicate to the instructor the extent to which teams are exploring alternatives and whether they are going into sufficient depth to implement the chosen design alternative.

Table 2: Noun phrases used by the Sensors Team to refer to the tilt of the wheelchair

<table>
<thead>
<tr>
<th>Teams</th>
<th>Phase 1</th>
<th>Phase 2</th>
<th>Phase 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensors</td>
<td>different tilt sensors, tilting angle</td>
<td>accelerometer, general tilt, tilt measurements, tilt range, tilt recline feet elevation, tilt recommendation, tilt sensors, tilt, wheelchair tilting angle</td>
<td>accelerometer, nac tilt recline, pressure tilt, tilt data, tilt measurements, tilt position, tilt range, tilt recommendation, tilt sensors, wheelchair tilting angle</td>
</tr>
</tbody>
</table>

Note: The term “accelerometer” was added manually to the list, since it could not be detected automatically. This simulates the real-world in which the instructor needs to review the vocabulary from time to time.

Conclusions & Future Work

This paper has presented insights about a project-based course that instructors can have access to by observing the noun phrases used by students from different perspectives. The paradigm of using noun phrases from student documentation to assess design team progress has been accepted in design research literature for the past two decades. However, this research takes the paradigm forward and shows how noun phrases in a design project can help to measure design team communication at various project milestones. The counts of noun phrases have been analyzed to show how the class has performed from the perspective of prior research models of expansion and contraction of vocabulary for successful projects. The paper also shows what activities the students are engaged in and how they are dividing their time between documentation versus actual implementation of the artifact prototype. Through a number of examples, this paper has discussed how the changes in design vocabulary reflect the introduction and omission of design concepts with time and across teams. When the instructors have access to such information in real-time, they can actively monitor the progress being made by the teams and focus their attention on any concepts that seem out of place, or appear to be only tangentially related to the project focus. This can also help them assess if teams are collaborating with each other effectively, and if the vocabulary used by them becomes consistent over time. They can also intervene in a timely manner in case they detect a potential teachable moment.

Future research can examine how different deadlines for courses with similar class structure affect the project outcomes. In other words, it still needs to be determined whether project
milestones affect the final artifact structure based on how much time the students need to spend on externalizing what they are learning.

Acknowledgments

This research was supported in part by National Science Foundation grants EEC 0648487 and EEC 0935127

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