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A CASE STUDY EXPLORING THE USE OF JOURNALS TO SUPPORT STUDENT ENGAGEMENT

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Abstract

This paper presents research related to improving student assessment and monitoring team engagement in capstone design courses through the use of design journals. It is proposed that design journals can be used to obtain a more detailed understanding of the progress of individual students in design learning that graded assignments, reports, and peer evaluations cannot provide. Several metrics have been developed and are discussed to better analyze journal content. Results are presented for one team of five students and include a look at individual cognitive activities, concept referencing, and concept propagation. Patterns pertaining to less-engaged students are witnessed and discussed. By utilizing design journals, instructors can become better equipped to make a dynamic examination of a student's understanding and engagement of design principles.

Keywords: Teamwork, Human behaviour in design, Evaluation

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1 INTRODUCTION

The best insight into a designer's thinking can be found in their concurrent design records. They can be used to understand critical steps taken during a particular design task, high impact decision points made during the process, mistakes the designer made, or something else entirely, there is a host of information awaiting to be unlocked. In the realm of engineering education, we can also examine design journals kept by engineering students to reveal how much they engaged in the consideration of concepts throughout a design process.

The standard design assessment practice in educational settings is typically to review the final product (the design) and any intermediate steps that are required assignements during the process, such as interim or final reports. Students are quite good at productng report information required in design reports but such assignments are generally written on behalf of a group, providing little insight on individual enlightenment about the design process or the methods used to generate designs (Grenier & Schmidt, 2007). It is also quite common in classroom settings that students may be given an assignment on generating options to a design task and the assessment of their performance is based on their output. Rarely is any information provided to the instructor that shows the steps students used to arrive at their ultimate design or any issues that they may have in using the method.

Another area which is currently inadequately assessed is the student's role in their team dynamic. Engineering capstone design courses are nearly always team based projects in keeping with ABET guidelines to inculcate a student's ability to successfully function as part of a team (ABET, 2014). Many such courses include some method of peer evaluation to aid instructors in understanding team member workloads. This has been shown to be a generally effective practice with great benefit in a team setting (Gransberg, 2010). Overly abundant generosity, fear of retribution, and collusion are a few common things which can skew such evaluations. While Gransberg's study found that these effects were typically minimal, other work has found that cultural influences can cause peer evaluation to become inadequate at individual assessment (Salma & Ahmed, 2011). In engineering design and education it is of paramount importance to have assessment methods capable of transcending the differences between the large varieties of cultures of the international community.

Even in the best of scenarios, standard peer evaluations have shortcomings that strikingly resemble design assignments – they show only the final determination of a student but not what brought them there. They provide only a static look at a student and not the more appropriate and complex look into the role they are fulfilling on the team as well as how they are interacting with other team members and their teammates' work. All of this should be viewed over the time of the project. This study does not propose the eradication of peer evaluations, but rather using it as one of many tools which together provide a more complete look at a student's performance.

The work presented here is a case study which explores the value of journaling in a capstone design team environment and indicates the opportunity in journal analysis to track more student project behaviors. Can design journals be used to accurately track concept propogation and development across members of a design team? Can design journal entries be used to reflect the level of design engagement for an individual during a team ideation process?

Data in this study was collected from one senior undergraduate team, comprised of five student in the mechanical engineering capstone course at University of Maryland, Engineering Product and Process Development (ENME 472). The research team collectively are the course manager and graduate teaching assistant for the course.

2 BACKGROUND

This section holds information on the topics of team concept generation and journaling studies, as sense of the research history on these subjects is critical to understanding the benefit of using journaling in engineering design.

2.1 Research on capstone design courses

Studies on maximizing the benefits of capstone design courses typically split into one of a few areas. A great deal of work has examined the impact of reflective practice as evidenced by student review of prior and on-going work (Schön, 1983; Valkenburg and Dorst, 1998). More recently, there has been a rise in research analysing the impact of online tools such as wikis on recording activities of the student design team (Walthall et al., 2011). Westmoreland and Schmidt (2010) previously explored the topic of hand journaling in a capstone design team which acts as the groundwork for topics explored here.

2.2 The importance of concept generation in the overall design process

Designers have the greatest freedom to exercise creativity and apply their experience during the initial stages of any design task. After understanding a design problem the first activity is ideation – the act of conceiving an idea. Ideation occurs at the beginning of conceptual design and is the activity that determines the breadth and novelty of the concepts that will be developed during the remainder of the conceptual design phase (Dieter & Schmidt, 2013). Conceptual design is worthy of study because up to 80% of a product's cost is determined during this phase (Yen et al., 1999). Work during conceptual design is error-prone because vast amounts of information are gathered from disparate sources, in a variety of formats and representations (Vargas-Hernandez and Shah, 2004; Summers et al., 2001). The use of an engineering design journal is one way to sort through and document this wide array of information (McMahon et al., 2004; Yilmaz & Seifert, 2011).

2.3 The benefit of journaling to the designer

Historically, designers used journaling as a means to capture, reflect upon and reuse design information. A few examples: Leonardo da Vinci, famous for his daily meticulous journaling practices, composed over 13,000 pages of notes in his lifetime that are now displayed in museums (da Vinci, 2005). Using notebooks or a journal used to be the norm for other creative thinkers and engineers; Thomas Edison wrote 3500 notebooks during his life (Michalko, 2001) and the currently successful entrepreneur Richard Branson keeps a small notebook with him for recording his thoughts (Fisk, 2011).

A design journal acts as a persistent witness, directly keeping track of the design activities that are written about, and indirectly capturing the designer's thinking. Research suggests that students use journals in capstone design to record: ideas, calculations, notes, questions to ask, analysis, sketches, meeting notes, to-do lists, project milestone issues, review of options not taken, etc. This requires the use of a medium – a journal – that can be easily accessed in any environment. Journals provide the time ordered documentation that can serve as a basis for reflection on earlier work (Sobek, 2002a and 2002b; Burrows et al., 2001; Zacharias, 1990), and as a way to communicate aspects of design behavior beyond design reports.

Journaling during any design activity uniquely enables real time drawing and sketching, two activities that have great value in engineering design. Schmidt, Vargas-Hernandez and Ruocco (2012) review research trends of sketching in engineering. Sketches are a good way to quickly communicate technical concepts (Van der Lugt, 2005; Kivett, 1998). Sketches relieve the sketcher of the mental load of remembering (Tversky et al., 2003) and allow the recall of sketches so that they can be reviewed at a later date or from a new perspective. This literal "re-view" of a sketched concept enables reinterpretation (Tversky and Suwa, 2009) and provides a focal point on which a designer may engage their cognitive processes (Bilda and Gero, 2008). To Schön (1983), sketching is the way a designer can have a conversation with themselves.

2.4 Journal entry coding schemes and metrics

Researchers have proposed different types of cognitive coding schemes relevant to a specific research agenda using data collected through journaling (Suwa et al., 1998; Westmoreland, 2012; Westmoreland et al., 2011; Visser, 2006; Hicks et al., 2005; Stempfle and Badke-Schaub, 2002; Ball et al., 1994; Adams, 2001; Adams and Atman, 1999). One of the most extensive journaling studies in a capstone design class was done by Sobek (2002a, 2002b) at Montana State University. The up-to-date design journals were coded multiple times a week to indicate which stage of the design process was associated with the journal entries.

Table 1. Cognitive classes and codes developed by Westmoreland and Schmidt (2010, 2012) to analyze design activity as recorded in journals.

Cognitive Class	**Cognitive Codes**
Class 1: Information Seeking and Noting	Search (1), References (5), Questioning (11), Price Quotes (26), and Definitions (36)
Class 2: Problem Understanding	Customer Requirements (2), Problem Statement Clarification (3), Criteria Lists (17), and Engineering Characteristics (37)
Class 3: Idea Generation	Project Ideas (4), Material Options (6), and Analogical Reasoning (8)
Class 4: Analysis	Estimates (7), Assumptions (9), Calculations (10), Testing Procedures (12), Variables (13), and Explanations (16)
Class 5: Decisions	Recommendations (14), Conclusions (15), and Design Changes (18)
Class 6: Project Management	To Do Lists (21), Meeting Notes (23), Task Assignment (24), Inventory (25), Task Completion (27), Project Milestones (28), and Field Trip Notes (29)
Class 7: Reflection	Personal Notes (19), Design Process Notes (20), Revelations (22), Mistakes (30), and Cross References (31)
Class 8: Other	Illegible Entries (33), Designer Signature (34), and No Code Identified (35)

Westmoreland and Schmidt (2010, 2012, 2013) proposed a cognitive coding scheme, partially generalized from the work of others, to categorize entries in design journals. Table 1 details the codes for the journal entries, which are broken down into classes relevant to engineering design project behaviour. An inter-coder reliability study was performed using the students design journals. The code developer, a beginning graduate student, and a sophomore undergraduate coded the same set of four design journals. Although there are thirty-six journal codes making a high Cohen's Kappa difficult to achieve, Coders 2 and 3 achieved scores of 0.63 and 0.655 on two student journals for code selection. These Cohen's Kappa values jumped to 0.805 and 0.865 when calculating agreement on cognitive classes. These values demonstrate the soundness of the coding protocol.

2.5 Team assessment metrics

Students in capstone design courses are tasked with developing the design of a new or improved artefact. The process first requires the generation of a number of alternatives for the artefact design. Each alternative design is called a concept. During journal coding, each entry's code includes a unique number identifying the concept to which the journal segment refers. This level of detail allows researchers to track concepts as they were adopted or adapted by multiple members of the same team. Table 2 holds a set of metrics developed for interpreting the journal writer's involvement in design team activities as measured by the concepts that are discussed in the journal. The metrics include two referencing ratios and an instancing ratio to measure the degree to which a student is involved in concept development on his or her team based upon their journaling records (Westmoreland, 2012).

Table 2. Ratios developed to analyse ideation and concept development team member behaviour involvement in concept generation (Westmoreland, 2012).

<table>
<tr><th colspan="4">Recorded Concept Referencing Metrics for Design Journals</th></tr>
<tr><td colspan="4">M = identification number for a design team from (1, 2…T), where T is the number of teams
m^M = number of members on design team M
j = identification number for each member of a design team M; j=1, 2…m^M
I^M = set of all concepts generated by members of team M
k_M^* = final design concept selected for team M
N_j = number of concepts that appear in journal j, N cardinality of I^M, or $|I^M|$
n_{jk} = number of times concept k appears as a referencing instance in journal j
$\mathcal{S}_j$ = total number of concept referencing instances appearing in journal j
c_{jkl}^M = k^{th} concept in journal j on team M; this concept is originated by member l; j=1,2…m^M and l=1,2…m^M
$\mathcal{C}_j^M = \{ c_{jkl}^M | \forall j \in M; \forall\, k\, , and\ \forall l\, \}$, set of all concepts appearing in journal j
$\mathcal{C}_{jl}^M$ = set of all concepts appearing in journal j originated by member l
A concept instance is any entry on a concept.</td></tr>
<tr><th colspan="2">Journaling Metric</th><th>Description</th><th>Relevance</th></tr>
<tr><td>Self Concept Referencing Ratio</td><td>$r_j^s = \frac{|\mathcal{C}_{jj}^M|}{|\mathcal{C}_j^M|}$</td><td>$r_j^s$ is the proportion of concepts referenced in member j's journal also created by member j. Others Concept Referencing Ratio, is $r_j^o = 1 - r_j^s$</td><td>Journaling engagement with concepts created by one's self.</td></tr>
<tr><td>Team Concept Referencing Ratio</td><td>$r_j^t = \frac{|\mathcal{C}_j^M|}{|I^M|}$</td><td>$r_j^t$ is the proportion of concepts created by Team M's design process that are referenced at all in member j's journal.</td><td>Journaling engagement with concepts the team members have proposed</td></tr>
<tr><td>Final Concept Instancing Ratio</td><td>$r_j^f = \frac{n_{jk_M^*}}{\mathcal{S}_j}$</td><td>$r_j^f$ is the proportion of the referencing instances of the final design concept of team M in member j's journal to the referencing instances of all team M's concepts.</td><td>Journaling engagement with team's selected concept</td></tr>
</table>

3 STUDY METHODOLOGY

This project's overarching goal was to explore the use of individual design journals to assess student performance and learning while enrolled in a capstone design course working as a member of a 5- or 6-person team. Additional investigation was performed pertaining to two team-centric areas of interest: propagation of concepts across team members and student engagement with their design team.

3.1 Student selection and course context for journaling

Students were drawn from University of Maryland's Mechanical Engineering Department's spring 2014 capstone design course (ENME 472) for which the research team are the course manager and graduate teaching assistant. This is a required course for all senior students in the undergraduate department with about 150 students enrolled per semester. Design journals are not currently required as part of the course requirements, so all students were asked to volunteer to participate with a particular interest in full teams willing to sign up. All participants signed a consent form approved by the University's Institutional Review Board. Participating student volunteers accepted the additional responsibility of journaling throughout their semester in exchange for small gift card payments every 5 weeks.

One full team's members were provided Livescribe pens, an electronic smartpen which automatically digitizes notes and uploads them to a cloud storage location (Livescribe, 2014). Students were told to use their journals throughout the semester as their project progressed through the stages of the design process and to use it as they would naturally. The smartpen team is the group that will be discussed in this study. The course allows students to come up with their own project topic and the group being examined here selected creating a solar dehydrator to dry microalgae for use as a biofuel.

3.2 Data collection and analysis

To assess a journal, each journal session (an entry made in one sitting) is divided into segments that are each labelled with a single cognitive code from Table 1. The coding process produces a design string for each segment. Figure 1 shows a pair of pages from a journal in the 2014 study. Both of these pages contain three segments each. The segments of the second page have been labelled A, B, and C to give a guided example of the coding system. Segment A's label 11.3.1.19.1.9 is interpreted as follows: 11 – 11th journal session; 3 – 3rd segment within the session; 1 - conceptual design phase; 19 - personal note; 1 – related to concept 1; and, 9 – includes no visual. Similarly, Segment B (11.4.1.4.1.1) and Segment C (11.5.1.4.1.1) are also both from the 11th journal session and identified as segments 4 and 5, respectively. These two segments also occurred during the conceptual design phase and are classified cognitive code 4 – project ideas. Both of these segments are in regards to concept 1 and contain a sketch.

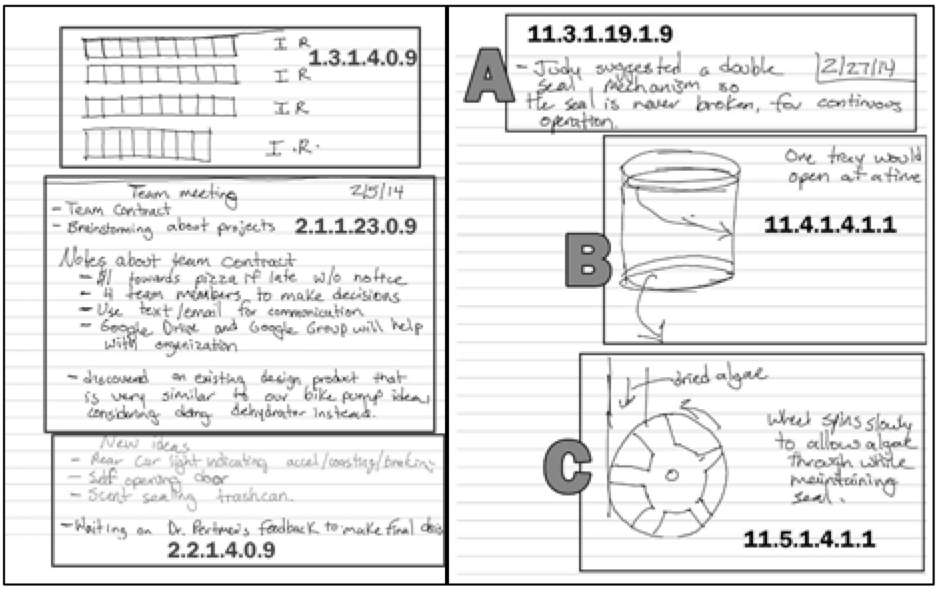

Figure 1. A pair of journal pages taken from the spring 2014 study

4 RESULTS

4.1 Individual recorded behaviour within the design process

The first research question of this study asked if journaling made it possible to better assess a student's engagement and understanding of the design process. The first evaluation which can be made on an individual level is to determine which recorded behaviours dominated a student's work. This provides insight into the role the individual served on their team which cannot be captured by team reports. Table 3 depicts the cognitive class behaviour frequency percentages calculated from the journals of the 2014 team.

Data for this table is percentage based, rather than based on a raw count, to better enable comparison between students. Bold numbers indicate the most frequent cognitive class for a given student. Student 2, for example, primarily focused on Idea Generation. This accounted for nearly 34% of Student 2's journal segments. This student's other leading areas of focus were Reflection (20.91%), Project Management (16.36%) and Analysis (14.55%). The remaining four cognitive areas collectively accounted for 14% of this journal's entries.

Table 3. Cognitive class frequency percentages for the 2014 team. Bold numbers indicate the most common cognitive class for a given journal.

Journal	Information Seeking	Problem Understanding	Idea Generation	Analysis	Decisions	Project Management	Reflection	Other
1	3.13%	0.00%	**40.63%**	9.38%	0.00%	15.63%	3.13%	28.13%
2	3.64%	7.27%	**33.64%**	14.55%	1.82%	16.36%	20.91%	1.82%
3	4.76%	16.67%	19.05%	16.67%	0.00%	4.76%	7.14%	**30.95%**
4	3.70%	14.81%	**44.44%**	3.70%	0.00%	14.81%	3.70%	14.81%
5	7.69%	1.92%	19.23%	**26.92%**	0.00%	21.15%	5.77%	17.31%
Avg	**5%**	**8%**	**30%**	**16%**	**1%**	**15%**	**12%**	**14%**

The numbers presented in Table 3 indicate some notable differences in the recorded behaviours of the team members. For example, members 1 and 4 display very little analysis work when compared to other team members. Also idea generation was the major activity for members 1, 2, and 4. Member 5 recorded more project management and analysis behaviour. It is good to see that the team shows a more balanced set of activities, as would be expected. It's also clear that students rarely record all the decisions made on the project in their journals. This could be because decisions were made verbally in a group setting. Category averages were included for anecdotal comparison.

It was previously discussed that peer evaluations do not always offer a particularly accurate image to use for determining a student's activity. Like many capstone courses, the one studied here required three peer evaluations throughout the semester. Team members rate their partners out of 100% for behaviour and also allocate contribution for all team members out of a total 100%. These scores are then combined to arrive at a final peer evaluation grade which accounts for 20% of their final grade. The values used here are the combined final peer evaluation scores. The team being examined here gave each other scores defining a very small range, from 96.5% to 100%. It should be noted that this range was on the high end of peer evaluations from other teams for the semester, though is not out completely of the ordinary for teams in the course. Regardless of the actual scores given to team members, one thing that peer evaluations like this accomplish is establishing an ordinal ranking of perceived team member effort. The actual grades are less important than the ranking they provide, which for the spring 2014 team turned out to be inversely proportional to the percentage of journal segments spent on cognitive functions in the "Other" class as shown in Figure 3. The vast majority of journal segments in this cognitive class are what most instructors would consider tangential to the design project. Notes less related to the design project—such as lecture notes—and list making with no objective or task associated with it are a few common example behaviours that fit this class.

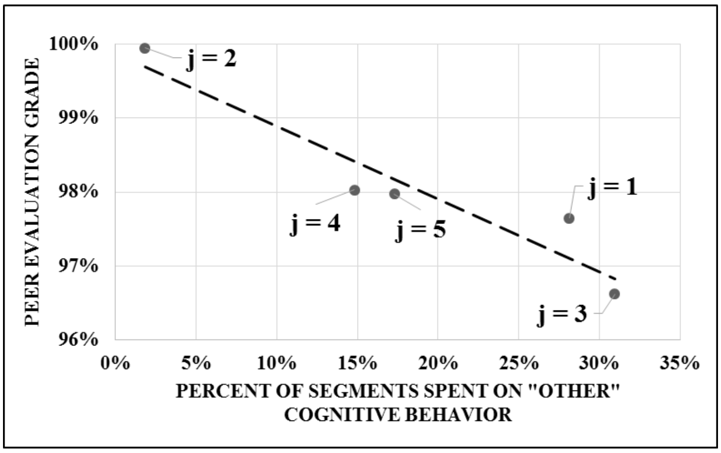

Figure 3. Peer evaluation performance versus percentage of journal segments spent on "Other" cognitive behaviour

Using journal record information, an instructor is much better equipped to evaluate the progress of individuals within a team that is performing well overall, as the team in the study was. While a peer evaluation may suggest that the team is perfectly splitting work and that all members are operating at 96-100% effectiveness, in reality two students on this team are consuming between a quarter and a third of their journals with entries that contribute little to no value towards their work. The team performed well on their project reports (earning a 97% final report grade), but there is much more to the story which is not captured by the report grade and peer evaluation forms as seen here.

4.2 Assessment of an individual within a capstone design team environment

Another measure for determining a student's activity within a capstone course can be determined using the concept referencing metrics which were defined in Table 2 and calculated below in Table 4. This table includes results from earlier teams (2010 and 2011) for the sake of comparison to the study team of 2014. Clearly a wide range exists between the tendencies of individual students to reference concepts generated by their teammates. For instance, Student 1 on the 2010 team recorded information on 79% of the concepts proposed by all members of the team but only 9% of this student's journal segments pertained to developing the team's final concept. Both Student 2 on the 2010 team and Student 5 in 2014 did not record any personal ideation activity, but rather only recorded information about concepts originated by other team members. It must be noted, however, that this does not mean Student 5 on the 2014 team was inadequately involved. Rather, Student 5 of the 2014 focused mainly on the final concept with 89% of his concept journal segments related to the final project and a heavy concentration on design analysis.

A student's number of references to the final concept, the one chosen for development, is tracked with the concept referencing metric, r_j^f, a relative measure of the percent of references to the final concept to the total references to all concepts in a student's journal. A low value for this metric (as in the case of team member 1 on team 1 on the fall 2010 study) indicates one of two behaviours: either the individual recorded on a larger number of concepts other than the final selection, or they were less engaged in recording activities related to the final concept.

Table 4. Applying concept reference metrics to three different capstone design teams

Concept Referencing on Three Capstone Design Teams									
	Fall 2010 Team; M = 1			Fall 2011 Team; M = 2			Spring 2014 Team; M=3		
Team Member (j)	r_j^s *Self*	r_j^t *Team*	r_j^f *Final*	r_j^s *Self*	r_j^t *Team*	r_j^f *Final*	r_j^s *Self*	r_j^t *Team*	r_j^f *Final*
1	27%	79%	9%	38%	46%	62%	40%	45%	67%
2	0%	7%	100%	100%	15%	79%	83%	55%	50%
3	60%	93%	23%	27%	15%	73%	40%	45%	33%
4	31%	21%	69%	30%	54%	67%	67%	27%	70%
5	16%	71%	42%				0%	18%	89%
Avg.	27%	54%	49%	49%	33%	70%	46%	38%	62%
Stand. Dev.	22%	38%	36%	34%	20%	7%	32%	15%	21%

The data also allows one to gauge the frequency of final design references made by an individual as a part of their team. The 2014 team had a combined total of 39 journal references to the final design. Four of the five team members each made between 7 and 11 final design references (or 18 to 28%). Student 3, again, fell drastically short of their peers by only providing 3 (or 8%) of the references to the final design. Figure 4 depicts this breakdown against peer evaluation scores as a ranking of peer perceived effort. Again we find that Student 3's performance as a member of the team is again reflected in their level of attempted contribution. Within this case study team, the number of journal entries related to the final design correlates to performance of the best and worst students.

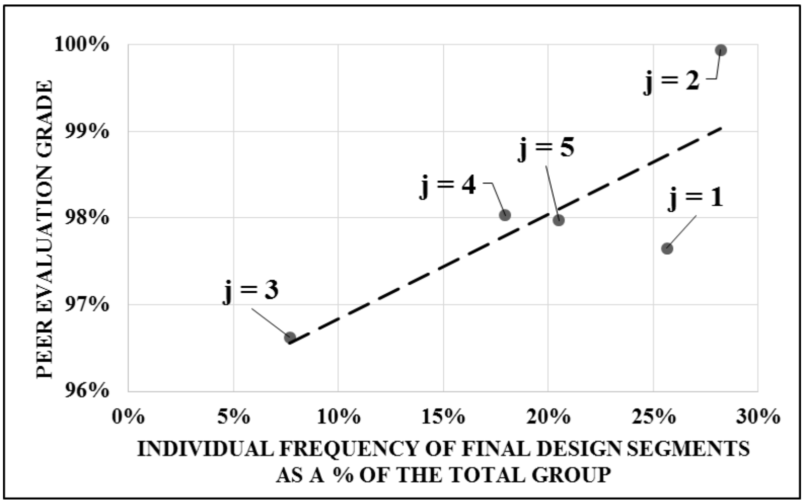

Figure 4. Peer evaluation performance versus contribution towards the final design

4.3 Concept life span

By tracking the dates of concept references in the journals, it is possible to construct a timeline of the project's progression in selecting concepts for development. Relatively low journal coding time is needed since it only concepts are followed rather than using the full coding scheme. Figure 5 depicts the 2014 team's concept timeline. The first concept which was introduced (thermal) persisted through the conceptual design phase, ultimately overtaken by the final design (cylinder drum). The final design and its main alternative persisted through much of the design process. Many other options lasted just a few iterations.

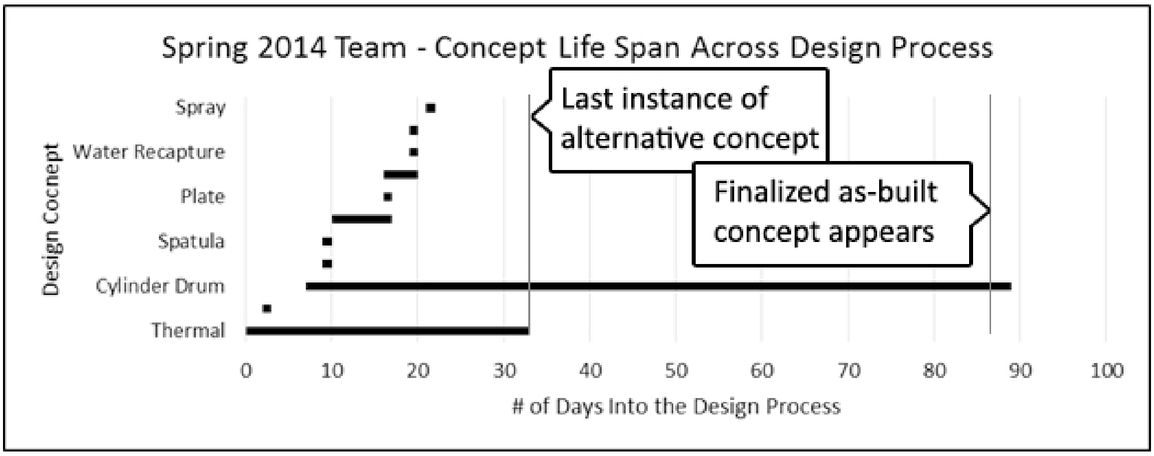

Figure 5. Concept timeline for the one of the journal study teams

4.4 Concept propagation across a capstone design team

Perhaps most interesting to analyse is the propagation timeline which combines several of the previous metrics discussed. Again using journal session dates and concept numbers it is possible to track the movement of a concept across a team, as shown in Figure 6. Several interesting takeaways can be determined from this chart. Note that Student 4 only referenced the selected concept once after the decision was made to develop it, even though Student 4 is credited with originating the idea. Meanwhile Student 1 only referenced the cylinder drum once before the concept selection decision but multiple times after. As was previously noted, Student 3 contributed very little to the final design which is evidenced by the fact that they only reference the design once before and once after concept selection. This is particularly powerful because it very quickly offers a strong look at project engagement for each member of the team.

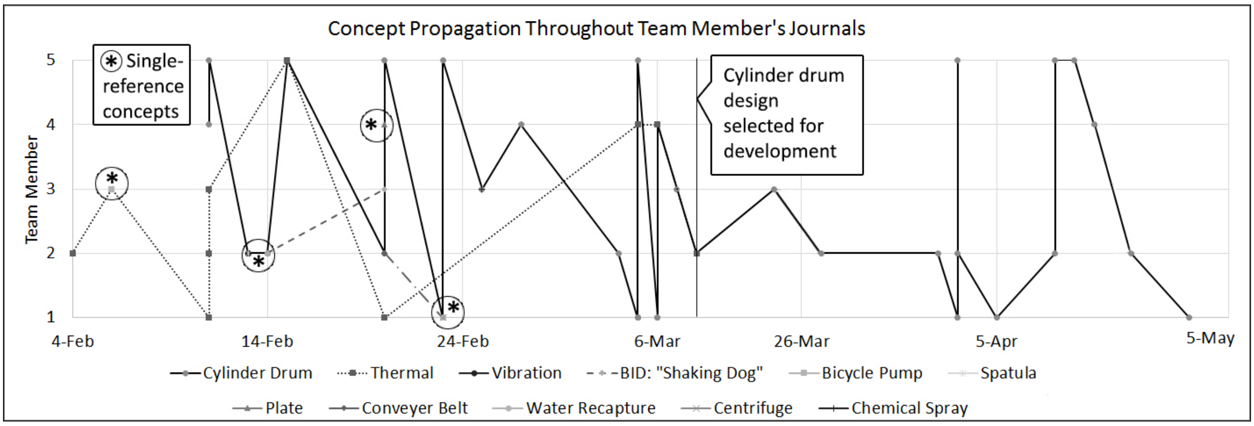

Figure 6. Concept propagation across the 2014 capstone design team.

5 CONCLUSION

Results from this small case study indicate that design journal engagement with the team project correlates to student peer evaluation performance, but while providing a more detailed view on how individuals within a team are functioning. Unlike peer evaluations, journal activity is impartial to team politics, cultural differences, assessment personalities, and group collusion. Moreover, utilizing journals for assessment better enables an instructor to decipher more expressive data regarding student progression than team reports or peer evaluations could ever offer. Just like assessing only a final design, these options only provide a static look at the individual student and not the path they took to get there. This dynamic examination of a student's understanding and engagement of design principles is critical for advancing engineering education.

While fully decoding journals has benefits, it is also time consuming and difficult to expect of instructors. However, by simply tracking journal dates it is very easy to obtain information such as the timelines shown in Figure 5 and Figure 6. Such data offers a quicker look at project engagement as well as individual engagement, serving as a proxy measure for an individual student's involvement with their project and their team. Using even just this highest level of design journal data allows an instructor to draw comparisons between team members and better assess the unbiased performance of each student. From this case study the benefits of utilizing design journals, both for the student and the instructor, seem strong. Determining techniques to reintegrate journals as a natural part of design will help prepare the next wave of engineering professionals to face the innovation challenges of tomorrow.

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