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Tracing Stories across the Design Process: A Study of Engineering Students' Engagement with Storytelling in an Undergraduate Human-Centered Design Course*

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Stories help design teams develop shared understanding and vocabulary throughout the process of developing solutions and prototypes. While stories are widely acknowledged to be essential to the design process, their use by novice designers in university settings remains relatively unstudied. In this work, we examine the story practices of undergraduate engineering students enrolled in a one-semester human-centered design project-based course. We develop a coding framework grounded in narrative theory to quantitatively describe the presence of story and its constituent elements in student work. We also integrate three simple interventions in the course to facilitate students' use of stories. After examining assignments ($n = 162$) spanning six iterations of the human-centered design process, we find that students show marked increases in their use of stories in the context of their prototypes. We also find limited improvement, or in many cases, a decline, in students' use of stories in the observational and frameworks stages of the process. These findings suggest a relationship between design project iteration and novice designers' use of story, building on previous research relating professional designers' differing use of story across design phase. This work invites several opportunities for design educators to incorporate facilitation of storytelling practices into their design courses.

Keywords: storytelling; design education; human-centered design; design process

1. Introduction

Creating, inventing, and making are recognized as crucial to the development of future engineers [1]. To realize these outcomes for students, design education through project-based learning [2] has been widely adopted and often leverages innovation processes from academia and practice [3–6]. These processes, while different, share foundational activities that broadly aim to guide students to "begin with abstraction and end with useful novelty" [7], and include user research, problem definition, idea generation, and prototyping.

Stories, defined here as time-based narratives of events (see Section 2.1), are widely acknowledged to be essential to effective design and innovation practice [8]. The reasons for stories' value to the design process are manifold. A widely-accepted explanation is that stories help design teams develop a 'shared vocabulary' and shared understanding of their work, through the process of what Lloyd calls 'sensemaking' in his study of professional design engineers [8]. This sensemaking power of story also helps teams surface and navigate 'value tensions' that emerge through differing perspectives and interpretations of design [9]. These behaviors are crucial to the success of design teams, especially in early stage design. Further studies expanded on how stories bring abstract value to the design team, ranging from developing empathy to establishing memorability [10]. A study by Adams et al. of engineering design meetings suggested that cross-disciplinary engagements have an emergent 'storyteller' role to help facilitate exchange in the design process [11]. The wide-ranging value of story was identified even in globally-distributed, remotely-collaborating design teams [12].

Literature's accepted value of story in the design process, but its focus on professional practice, inspires our two research questions: first, how do novice engineering design students engage with story and its constituent parts in the design process? Second, how does this engagement change across iterations of the design process, as students develop increasing understanding of their problem space and correspondingly high-resolution solutions and prototypes?

To explore these questions, we develop a methodology to evaluate the presence of story and its key constituent elements of character, time, and setting (Section 2.1). We use this method to code 162 assignments that span the distinct observation,

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framework, and prototype phases of the design process across six iterations in an undergraduate engineering design course (Section 2.2 and Section 3.2), quantifying the presence of story and story elements. We also introduce three simple interventions that were anticipated to increase students' use of story and examine their effects.

Our findings indicate that novice designers' use of story in the sensemaking phases of the design process stays consistent or declines with subsequent iterations. This decline appears to be unaffected by simple interventions to inspire student use of time and character elements. We also find that student use of story in the prototype phase of the design process appears to increase with subsequent iterations, and appears sensitive to interventions to inspire use of character and time elements. The main contributions of this paper are, in summary:

- Exploring novice engineering design students' use of story in a project-based human-centered design course.
- Developing a methodology to quantify students' use of story based on design process assignments and artifacts.
- Tracing the evolution of students' engagement with story across several design process iterations.

2. Related Work

2.1 Professional Designers' Use of Story

The value of stories has been described as evolving through the design process. Beckman and Barry traced the efforts of a corporate innovation team developing a new category of diapers and distinguished two roles for stories in the team's work. In the research and problem definition phases of design, they argued that stories *informed* the team's understanding of users, leading to their identification of an unmet customer need. Later, in ideation and prototyping phases, stories *inspired* the design team, helping designers produce new stories envisioning the future. This led to the launch of a highly successful product and the transformation of the organization's innovation culture [13]. In Enningna's ethnographic study of a corporate design team developing a new alcoholic beverage dispenser for a global brand, a similar distinction was identified. Enningna describes the first role of stories as 'storytelling,' communicating and sharing information among the team, and the second as 'storymaking,' producing narratives that bridged differing viewpoints. Together, these dual roles of story helped the team develop a successful design outcome [14].

2.2 Undergraduate Engineering Students' Engagement with Story

Research on storytelling in design education suggest that some of storytelling education in project courses focuses on traditional public speaking presentation approaches. Such approaches were described to be potentially counterproductive to students in a course on engineering start-ups [15]. Expanding on traditional communication curricula, Karanian proposed a 'Storytelling-Based Learning' model in which students *tell* (speak, listen, and narratively write), *make* (create a new story), and *engage* (connect with audiences) throughout the entrepreneurship or design process. Such an approach was shown to enhance audience engagement through more effective storytelling [16, 17]. Karanian's recent work leverages a unique model of a Tell/Make/Engage storytelling course, which allows significant instructor and student focus on storytelling exercises. Karanian's work speaks to the influence of story on *outputs* of project-based learning, but does not address stories' role in the *process* of design.

3. Background on Frameworks of Story and Innovation

Many frameworks exist to understand the definition of stories, narrative, and innovation. In this section, we ground our work in definitions of story and a single framework to describe innovation that also governed the examined course's structure.

3.1 Foundations of Story and Narrative

The prominence of stories in human communications have inspired reflection on the nature of narrative, its principal elements, and strategies for effective composition as far back as Aristotle's Poetics [18]. The contemporary field of narratology encompasses contributions from diverse disciplines including literary theory, communications studies, linguistics, and cognitive science [19]. In particular, our understanding of story and its fundamental components draws from Chatman's extensive synthesis, critique, and systematization of work in narrative theory [20]. Chatman distinguishes story, the conceptual content of a narrative, from the discourse that expresses it. Further, stories consist of events (actions and happenings) and existents (characters and settings) linked in specific ways. Events in a story will be linked by relationships of sequence and causality, and, potentially, by hierarchical relationships differentiating major events ("kernels") from minor events ("satellites"). By contrast, existents – characters and settings – constitute the "story-space" within which events occur.

Characters may be the subjects of traits, personalities, and motivations. Settings, environments and their objects, form the background against which characters and events are figured. Chatman contends that discursive forms (including text, speech, cinema, and other expressive modes) become narrative forms to the degree that they index and relate these conceptual components of story.

Based on Chatman's model, we define stories as texts that index instances of three principal conceptual components: (1) characters as bearers of traits and motivations; (2) places and environments with physical details; and (3) a progression of time marked by a sequence of discrete events with causal and, potentially, hierarchical relationships. It is useful to note that a story's coherence is a function of appropriate relationships among the instances of these components, that is, that their co-presence appears as necessary and reasonable with respect to the constraints of a given physical and/or social reality.

3.2 Foundations of Innovation Frameworks

Numerous examples of design and innovation processes exist, but share significant overlap in content and philosophy. In the course examined in this work, we adopt the widely-cited 'innovation as a learning process' framework for design and innovation [21]. This framework analogizes the innovation process to the learning process, a simultaneous toggling between analytic and synthetic modes of questioning and understanding, and between abstract and concrete modes of knowledge creation. The intersection of these modes produces four quadrants (Fig. 1) defining observations, frameworks, concepts, and prototypes as four phases of the design process. Design teams iterate through this process towards a solution, and in practice, prototypes produced at the 'end' of a first iteration are used to gather observational feedback to start the second iteration.

4. Methods

4.1 Course Background

4.1.1 Participants

This study was performed at a major public research university in the United States. Participants were exchange students, all of international origin and all fluent in English. A total of 20 undergraduate students were enrolled in the course. Five participants were female and 15 participants were male.

The course syllabus described three learning objectives to the students: to master the iterative human-centered design process, to gain in-depth skill training in 2D, 3D, and user experience design and prototyping tools, and to combine prototyping and storytelling tools to articulate clear, compelling design solution hypotheses.

Prompted by five project descriptions (Table 1), a key goal of the course was for the students to develop a portfolio-ready prototype contextualized by a compelling story grounded in user needs. A representative example of a final prototype, from Team B, consisted of three parts. First, the team developed a mobile application interface mockup, developed using Figma, illustrating the workflow of their solution. Second, the team developed a func-

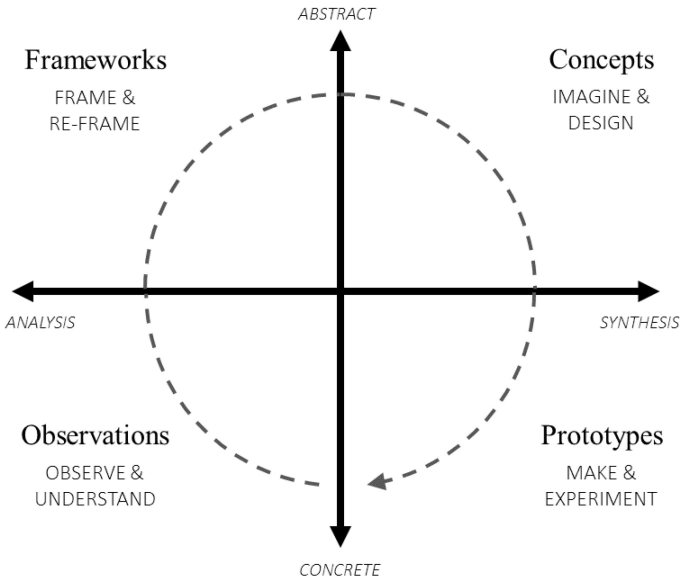

Fig. 1. The innovation as a learning process model portrays the design process in four iterative phases – Observations, Frameworks, Concepts, and Prototypes, describing the outputs of each phase; subtitles describe the key activities of a design team in that phase [21].

Table 1. Team Project Descriptions show areas chose to explore in the broad problem space of mobility

Team Identifier	Brief description of problem area and problem space
A	Improving the experience arriving in a new country
B	Reimagining the process of attending professional networking events
C	Improving the experience of commuting via public transportation
D	Reimagining the experience of shopping for goods from home
E	Improving the experience of transporting and moving supplies

tional 3D-printed wristband that activated an interaction on a phone via near-field-communication (NFC). Finally, the team developed a short video describing the user's experience working with their prototype.

4.1.2 Iterating through the Human-centered Design Process

In total, students completed six full iterations of the human-centered design process (Fig. 2). This course structure was developed to emphasize learning through iteration of the design process. The course structure also leveraged a 1-week pre-semester intensive, followed by weekly lecture-studio hybrids for a total of 30 hours of in-class instruction. Such a model is of interest to programs with capacity constraints in traditional semester course schedules.

4.2 Analyzed Assignments and Interventions

Three types of assignments were studied for this research: user observations, journey map frameworks, and prototypes (Table 2) across six iterations.

We study all six user observation exercises, individual assignments. After in-class exercises on industry best practices on ethnographic approaches

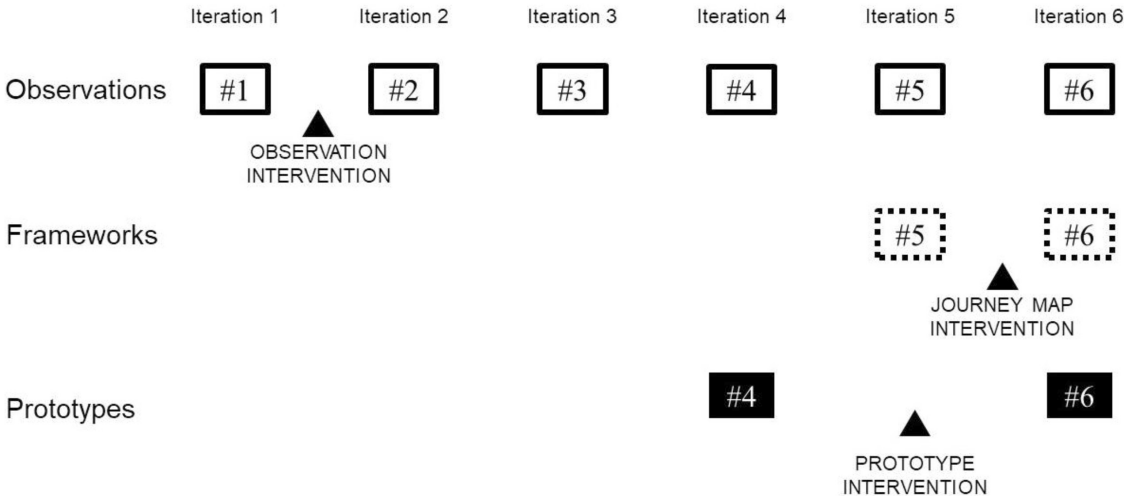

Fig. 2. Course structure diagram that emphasizes the placement of assignments that correspond to distinct phases of the human-centered design process: observations, frameworks, and prototypes. Coded assignments are shown, as is the placement of an intervention in each phase.

Table 2. Summary of assignments and corresponding interventions studied in this research

Assignment	Phase	Individual or Team Assignment?	# of Assignments Coded per Student/Team	Total Coded	Base case requirement	Intervention requirement
User Observation	Observations	Individual	6	116	To record at least five findings from the research	To record at least five observational stories with 'a beginning, middle, and end'
Journey Map	Frameworks	Individual	2	36	To construct a journey map with an arbitrary 'positive/negative' y-axis	To organize the journey map's vertical axis by a character-specific emotion or desire.
Prototypes	Prototypes	Team	2	10	To present a compelling instantiation of the students' concept	As base case, plus to represent the envisioned experience for the key user

to need-finding [22], students were asked to identify users or stakeholders relevant to their problem area, interview them, and record at least five distinct findings from their interview. After the first observation, we intervened in the assignment description to explicitly ask students to record these findings as stories, with 'a beginning, middle, and end,' with minimal further guidance on story. Observations are inherently grounded in character, and we anticipated our intervention to increase student engagement with story, particular the time element. The recorded findings were coded for the presence of story elements. 116 observations were coded, approximately six per student.

We study two frameworks exercises, in which we had students individually construct journey maps, a widely employed pattern-finding framework in design research, for a single stakeholder [23]. Students visually represented the journey map with at least five distinct steps, organized both chronologically (x-axis) and spatially on a y-axis representing positive/negative user experience. Students wrote a short paragraph explaining the map. For the second journey map assignment, we intervened on the previous assignment, requiring students to identify a key character's emotion or condition in defining the 'y-axis' of the journey map. By having students frame an explicit emotional state for the examined stakeholder, we anticipated an increased engagement with the character element of story. Students' short paragraphs explaining their journey map were coded for the presence of story elements, and a total 36 journey maps were coded, approximately two per student.

We study two prototype assignments, those created for team mid-term and final design reviews. In both prototypes, teams were asked to create a compelling instantiation of their concept, and submissions ranged from detailed storyboards (mid-term) to, as described previously, an NFC-enabled 3D-printed wristband, supported by a video of a specific use case (final). The intervention was to require students to explicitly represent the experience their solution creates. With this intervention, we anticipated seeing increased engagement with the character element of story. For prototype exercises, students' artifacts – videos, storyboards, and presented explanations physical prototypes – were coded for the presence of story elements. A total of ten team prototypes were coded, two per team.

Concepts were not examined for the presence of story in this study, because of the difficulty in applying the story coding framework to often-indeterminate early-stage design ideas.

4.3 Coding Methodology

No previous example of rubrics to describe story in engineering design education could be found. However, rubrics for evaluating story and narrative have been widely used in the field of creative writing [24]. Rodriguez, in evaluating undergraduate fiction writing assignments, proposed a 50-point rubric grounded in Chatman's narrative theory separated into ten categories scored at five points each. These categories included format, grammar, plot, time, setting, and character, among others [25].

Building on Chatman's narrative theory and Rodriguez's work we develop a rubric for story in engineering design education (Table 3), focusing on character, time, and setting as the foundational

Table 3. Story evaluation rubric. Drawing on three core elements of story, with eight subcategories, we are able to qualitatively code student work for a comparison in terms of the presence of story elements

Story Element	**Description**	**Score**
Character	*Who* A clear characterization of *who* the story is about	1
	Feeling Description of the individual's feeling, emotion, or motivation.	2
	Personal Context Description of the individual's personal context – where are they coming from, where are they going?	2
Time	*Beginning/middle/end* Distinction of a 'beginning, middle, and end' of the individual's experience in this story	3
	Sequencing A sequencing of events with a chronologically causal relationship	2
Setting	*Place* A clear definition of where, or in what context, the story is taking place	1
	Physical Detail Some character-independent description of the physical details of the setting	2
	Social/Environmental Detail Some character-independent description of how this setting includes/engages people and/or environment	2

elements of stories used by design teams. Each element was scored on a five-point scale for a total evaluation of 15 points. The rubric evaluates the presence of story and its constituent elements, and we do not relate rubric score and design outcome.

Anonymized assignments were double-coded by two course instructors and averaged. We calculated Intra-class Correlation (ICC) statistics for total story evaluation scores using $n = 152$ observations. We select a two-way mixed effects model with $k = 2$ raters and consistency of data. This model is chosen for three reasons: (1) we have the same, specific set of raters for all observations; (2) we average the result of rater scores to be the benchmark measurement; and (3) we are interested in consistency between raters inclusive error, rather than absolute agreement. ICC was determined to be 0.82, indicating that for this study, the rubric achieves reasonable interrater reliability [26]. We acknowledge that were the tool to be scaled up to a larger pool of raters, or were an absolute benchmark score of story elements developed, other ICC models would apply and reliability could decrease.

5. Results

5.1 Mean Course Story Evaluations

Averages of course-wide story evaluations are shown in Fig. 3. Each phase of the design process reveals different engagement with story over time. Observation-phase stories (Fig. 3a) show an increase between the first iteration (Mean (M) = 4.9, Standard Deviation (SD) = 2.0) and the second iteration (M = 6.1, SD = 2.6). A paired-samples t-test showed that this increase was statistically significant ($t(18) = 2.31$, $p < 0.05$). We notice that the increase is driven by story elements of setting and character. We suspect that the increase in the overall story evaluation was not due to the intervention, which stipulated students use a 'beginning/middle/end' framework. This correlates strongly to the time element of story, which exhibited a decline between iterations one and two. Character and setting increased instead. Little change was observed between the second iteration and the sixth iteration (M = 6.1, SD = 1.5), and a paired-samples t-test showed that the difference between these two iterations was statistically insignificant. We note that the proportion of story elements between the second and sixth iterations remain relatively similar. Iterations three through five are not shown, as their average story evaluation scores did not deviate demonstrably from iterations two and six.

Frameworks (Fig. 3b) show a marked decrease in total story evaluation between the fifth iteration, before the intervention (M = 7.6, SD = 3.37), and sixth iteration, after the intervention (M = 6.4, SD = 3.04). A paired-samples t-test indicated that this decrease was statistically significant ($t(16) = 3.98$, $p < 0.005$). The change in total story evaluation was driven by a reduction in time and setting elements, but an increase in character. While an increase in character was to be expected, given an intervention centered on identifying user emotions, this increase was outweighed by declines in time and setting. The decrease in the time element was unexpected, as journey maps inherently help designers organize insights chronologically.

Prototypes (Fig. 3c) show a substantial increase in total story evaluation between the mid-term and final prototypes, iterations four (M = 5.8, SD = 2.2) and six (M = 11.2, SD = 0.8). A paired-samples t-test indicated that this increase was statistically significant ($t(4) = 6.30$, $p < 0.005$). Marked gains were

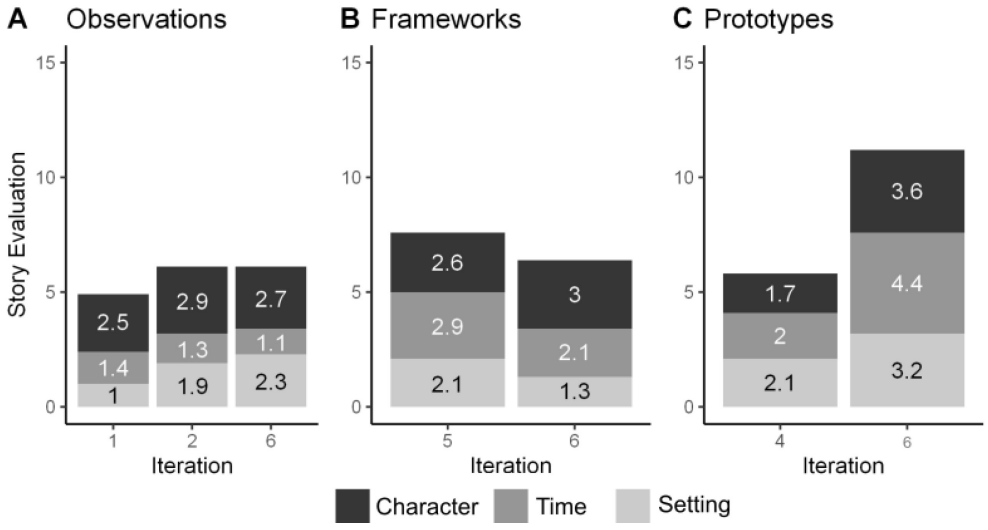

Fig. 3. Mean course-wide story evaluation.

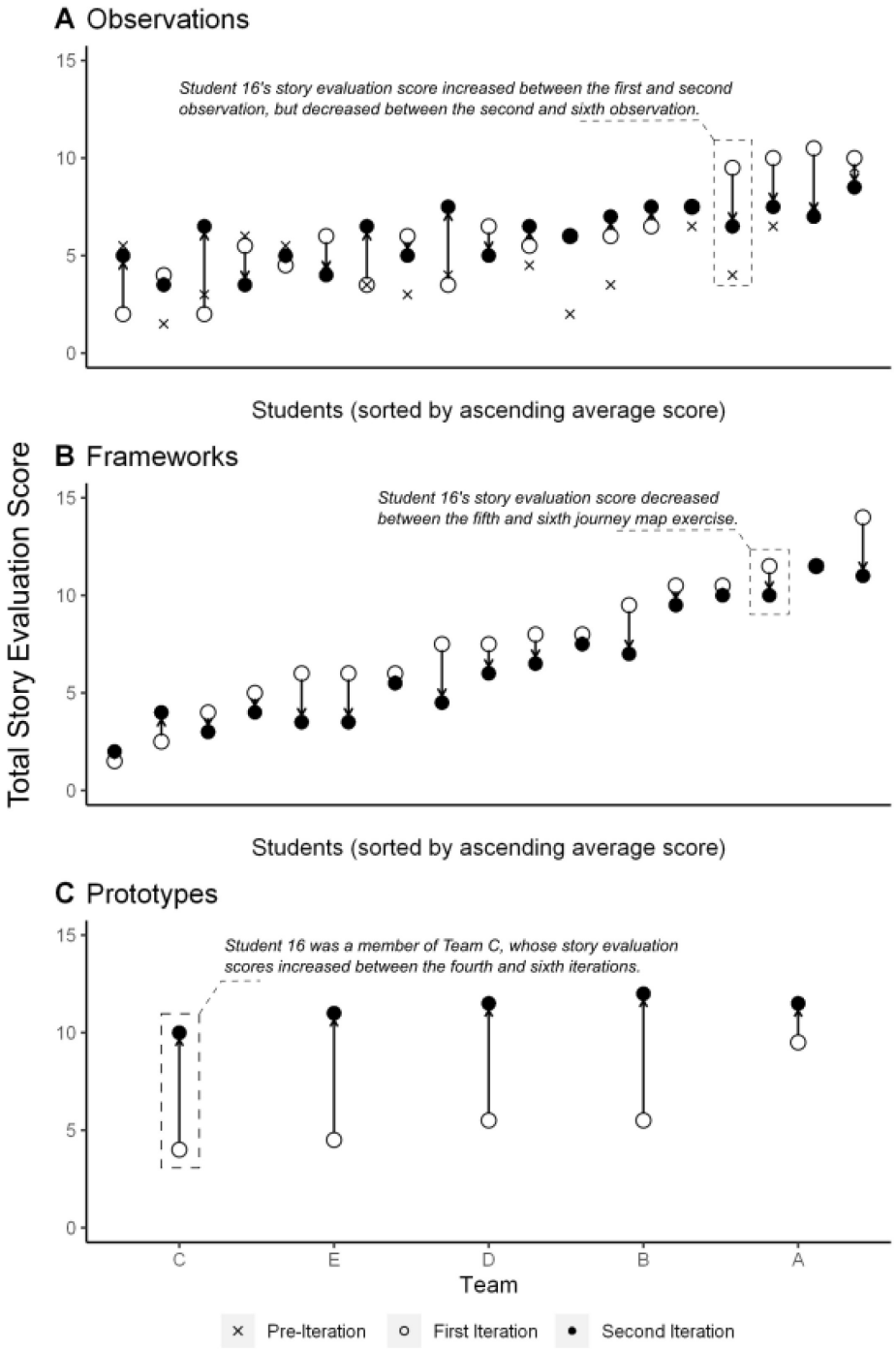

Fig. 4. Story evaluation by student or team for (a) observations, (b) frameworks, and (c) prototypes. An empty circle represents the first coded assignment, e.g., Iteration 4 for frameworks, while the filled circle indicates the last, e.g., Iteration 6 for frameworks. For (a), an x indicates the first coded assignment (Iteration 1), the empty circle the second (Iteration 2), and the filled circle, the last (Iteration 6). Prototypes were completed as a team assignment, and are thus organized by ascending order of the team's average score.

observed across all elements of story, most saliently in character. An increase in character was anticipated based on the focus on envisioning a new user experience. The increase in the character element (1.9) was less than the increase in time (2.4), suggesting that time-based narrative is of paramount importance to students' articulation of new experiences.

5.2 Individual Student and Team Total Story Evaluations

The individual student – and team-based data show the heterogeneity of students' experiences with story (Fig. 4). Observations demonstrate a substantial number – ten out of seventeen total observations – of students declining or staying constant in their

engagement with story between iteration two and six (Fig. 4a). In the frameworks phase (Fig. 4b), students showed a near-categorical decrease in story evaluation between the journey maps prepared during iterations five and six. Every team exhibited an increase in story evaluation in the prototypes phase (Fig. 4c).

5.3 Team Average Story Element Evaluations

Team-level trends in story engagement appear diverse. Observational stories (Fig. 5, top) show two teams (A and D) engaging significantly with setting in iteration six, a main driver of their overall storytelling evaluation increase. Both teams converged on highly place- specific final prototypes – a public transit directions kiosk (Team A) and a virtual-reality environment for shopping (Team D). This suggests that different project topics encourage different elements of story.

In both observation and frameworks (Fig. 5, middle) phases, the time element of story shows a decline in 80% of cases; the two cases that are exceptions, teams C and D in the observation phase, show no change and a very slight increase in their time element evaluation, respectively.

In the prototypes phase (Fig. 5, bottom), all teams showed increases in story evaluation, but arrived at this increase in differing patterns. Teams B, D, and E, showed significant growth in two or more areas, while team A increased insignificantly. Team C, however, had a substantial increase in their time element evaluation, which almost entirely drove the increase of their total story evaluation. Team C's final prototype, of a rental service for public transit comfort devices, was a video and interface demonstrating the steps in using the service, a prototype grounded in chronological causality.

6. Discussion

6.1 Evolution of Story Practice over Time in the Design Process

We observe several examples of engineering students' changing engagement with stories over time in the design process. Through subsequent iterations, teams in 'stories that inform' phases – observations and frameworks – engage at best equally with story, or in the case of frameworks, less. In contrast, the 'stories that inspire' phase, prototyping, exhibits a sharp increase in story evaluation over iterations. One possible explanation follows from Lloyd: while story is valuable to students in their first iterations through the design process, students perceive less value of story in the 'stories that inform' phases during later iterations, as teams have already developed a shared vocabulary and shared understanding. Anecdotally, this is further supported by a marked shift in the focus of stories students found important from their interviewees over time. In later iterations, observational stories

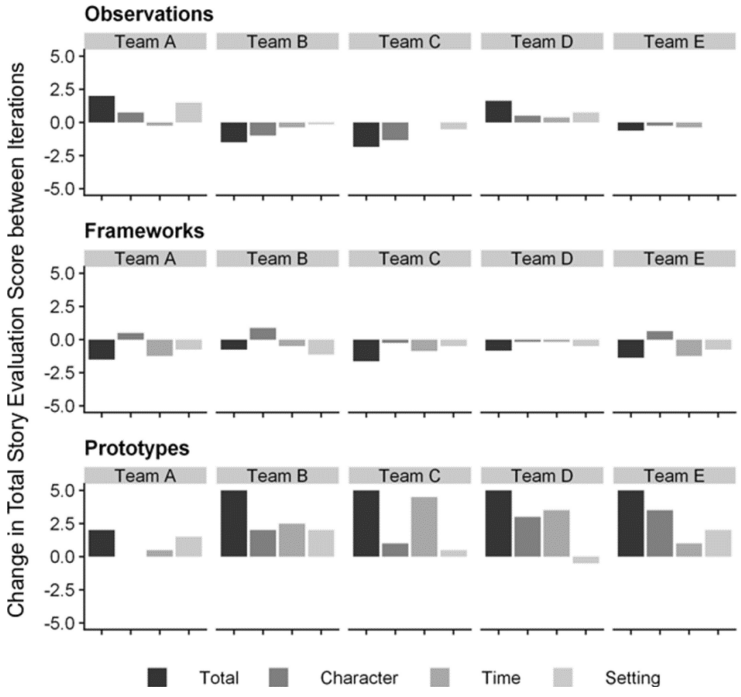

Fig. 5. Change in team average story evaluation by element. Plotted are the changes in average story evaluation by element, in points, separated by Teams A-E (see Table 1) for observations (top), frameworks (middle), and prototypes (bottom). For observations, the plotted change is between iteration two and six. Teams showed different patterns of change in their story evaluation by element.

were focused far more on validation of concepts and features, rather than broad understanding of the user's experience evident in earlier observations.

Meanwhile, it appears that story plays an increasing role in shaping, articulating, and defining prototypes with subsequent iterations. This is evident from Fig. 3c, Fig. 4c, and Fig.5. As student design work becomes more resolved and more sophisticated, student prototypes evolve accordingly. Story becomes a powerful prototyping tool in this process.

This finding extends Beckman and Barry's and Enningna's separate descriptions of a two-phase engagement of stories that inform vs. stories that inspire and storytelling vs. storymaking by introducing the longitudinal effect of iterations into designers' engagement with story. With subsequent iterations, once shared understanding and language have been established, the utility of stories as informative devices is likely less relevant; meanwhile, the demands of more sophisticated prototypes make story increasingly important for inspiration.

6.2 Engagement of Story Elements in Project Types

The stories that designers tell and perceive about their work appear to follow the topic and stage of the project. From Fig. 5, different types of products, services, or other solutions could be correlated to how story, and story elements, are used in support of prototypes. Anecdotally from this cohort's work, it appears that service-based solutions engage heavily with time-based story elements. Meanwhile, more tangible solutions appear to engage more readily with character and setting.

More interesting than a specific correlation between story elements and types of projects is to use story elements as a way to highlight what design teams have yet to emphasize in their activities, whether during the research or the prototype stage. Taking the example of Team C (Fig. 5), there remained significant opportunity for the team to engage with character and setting to realize a more effective final prototype.

6.3 The Challenge of Decision-Making and Frameworks

Building a shared understanding in design can yield what Lloyd describes as "a design vocabulary . . . defined as much by common disagreement as by common agreement." [8]. Nowhere is this more evident than in the frameworks phase, where teams build consensus about the meaning of stories uncovered during observations. Story evaluation scores for frameworks, which decline significantly between iterations five and six, suggest that students view story elements as less effective in this consensus-building process in later iterations. These dilemmas, identified in professional designers' practice, appear to be just as present and challenging in the students' experiences with design projects, and could have significant effects on student outcomes if not managed accordingly.

6.4 Implications for Design Education

From these key findings, several implications for design education emerge. First, from Section 6.1, there is an opportunity for design educators to challenge students' reduced engagement with of stories in frameworks and observations phases of later design iterations. Instructors could encourage students to bring open-mindedness and an eye for story to their user research, even when a key goal is validation of concepts. Such encouragement could take many forms, but would help students engage with their problem and concepts broadly, balancing a tendency to frame later-stage interviews around the features and details of their proposed solution.

Second, as implied in Section 6.2, educators can facilitate student engagement with particular elements of story even if their project or prototype lends itself more immediately to other elements. This would support students' thinking towards a more complete narrative, that could potentially more effectively inspire the design team and their audience.

Third, extending from Section 6.3, there is a need for the design education community to consider how to help students best establish consensus through stories in the classroom. Lloyd suggests that design teams that do not converge on a shared understanding or shared language have less optimal outcomes. Intentionally educating students and teams to navigate this issue could lead to more effective student outcomes and design practices.

Finally, this study offers a cautionary note about intervening to facilitate student story activities. None of the simple interventions proposed in this work yielded the intended effect. For example, an intervention asking students to use a 'beginning / middle / end' framework to report their observations yielded a *decrease* in the use of the time element of story. This suggests that student engagement with story, especially at the story element level, is shaped by broader dynamics (Section 6.1) and that interventions regarding story should be designed around these behaviors.

7. Limitations & Future Work

This study has several limitations. The course involved a small sample size of students, $n = 20$, with various assignments having as low as $n = 17$ submissions, which limits the robustness of its findings. The storytelling rubric is also subjective, and will require rigorous calibration and training

before it can be deployed beyond highly specialized contexts.

An important limitation is that all students in the studied course were of international origin. The majority of these students spoke English as a second language (ESL) fluently. Noting the strong cultural basis of learning styles [27], the authors acknowledge that the findings in this study may not be generalizable beyond ESL storytelling and design contexts.

Significant limitations stem from the nature of the class and assignments. First, while we saw indications of longitudinal effects on storytelling over design process iterations, the progressively iterative nature of the class and students' limited experience with design make it impossible to control for students' development as designers and the advancement of their projects through the course. Some portion, or perhaps even a significant portion, of effects observed in this study are attributable to this development.

Second, the stories examined in this course were written and submitted as assignments, or in the case of video or storyboard prototypes, were recorded or drawn. The majority of storytelling in design activities, however, happens orally. Written work is an important representation of designers' thinking, but it is not a comprehensive rendering of designers' story practices.

Third, interventions were embedded in assignments in the course, stipulating that students engage with storytelling behavior in prescribed ways. The storytelling behaviors observed after interventions are thus not necessarily natural storytelling behaviors, and may be difficult to replicate in settings without interventions. It is the authors' intent, however, to explore and share directions for encouraging students' engagement with storytelling in the design process, which the observed responses to storytelling suggest.

Several future research directions stem from our findings and our study's limitations. Controlled studies to further examine the evolution of story across iterations of the process, rather than just the phase of the process, could be a direct extension from this work. Similarly, larger scale studies, supported with interviews and recordings like several published ethnographic studies of story practices in design teams, could further develop some of the early insights presented in this paper. Further work would include reconciling the literature on professional designers' story practices with those of novice designers by interviewing both categories of designer and following them through the life cycle of real projects. Emerging approaches in natural language processing (NLP) could support a larger-scale and more repeatable quantification of story in student design work, both written and oral.

8. Conclusions

This work explored novice engineering design students' use of story in the human-centered design process. The key research goals were to (1) understand how novice engineering design students engage with story and its constituent parts in the design process, and (2) explore how this engagement changes across iterations of the design process. To address these questions, a storytelling rubric to evaluate the presence of story elements, grounded in Chatman's work on narrative theory, was developed and applied to 162 assignments across six design iterations of the in a project-based engineering undergraduate course.

Our findings indicate that student's use of story in the observation and frameworks phases of the design process, when designers typically use 'stories to inform' their process, as described by Beckman and Barry, decline with subsequent iterations of the process. Furthermore, simple interventions intended to inspire further use of story in these phases appear to be unsuccessful to counter the broader decline in story usage. Meanwhile, students' engagement with story in the prototype phase of story, when designers typically use 'stories to inspire' their process, appears to increase with subsequent iterations of the process, and is enhanced by simple interventions to facilitate use of story. Story use also appears to be shaped by the type of student project, and reveals challenges in developing a shared understanding and what Lloyd describes as a 'shared vocabulary.' These findings point to several opportunities for design educators to engage explicitly with storytelling.

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