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Lean Capstone Writing: Adopting LEAN A3 Thinking Summaries over Reports

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Abstract

Capstone experiences in Architectural Engineering (AE) programs most commonly meet ABET-defined culminating design experiences that typically require a substantial written report and one or more presentations be generated and delivered by students. In fact, some capstone reports commonly exceed 100 pages, and students often prioritize the technical work over succinct summaries. Some capstones further have embedded writing requirements that satisfy general education requirements. Prior work similarly notes that students struggle to write concisely and lack skills to leverage images, charts, and figures to convey results quickly and clearly. In addition, many AE programs rely on multidisciplinary team-based capstones with multiple iterations of design that are not always effectively compared and contrasted in final deliverables. While page limits do exist in capstone-type student competitions, like the Architectural Engineering Institute (AEI) student design competition, which drives conciseness; those formats do not consistently align with documentation practices used by the architectural, engineering, and construction (AEC) industry.

In a newly revamped AE capstone course, the authors piloted the Lean Construction Institute's (LCI) practice of Lean Thinking by implementing the A3 Problem Solving approach. Here, student teams are required to summarize key technical decisions, studies, and alternative designs on concise A3 (11x17) sheets (ideally one sheet per topic), emphasizing visual information and only the most important results. Appendices were allowed for technical justifications, assumptions, and sample work, but students were explicitly told not to format the documents into traditional written reports. Results indicate A3 writing adoption showed positive impacts on writing quality and technical summarization, alongside initial barriers related to learning the A3 format and identifying essential result-based information. This paper describes the adopted A3 approach, shares takeaways from student work, and provides recommendations for integrating this writing technique into future design courses and capstones.

Introduction

Across ABET [1] and relevant engineering-education literature, a consistently emphasized outcome is the development of students' communication skills—written, verbal, and graphical [2]. The goal for this communication is for students to convey processes and results in formats that are easy to understand for a variety of stakeholders [3]. The ASCE Body of Knowledge (BoK) and the National Academy of Engineering (NAE) [4-5] places communication in "soft skills" or "professional skills" that also include teamwork and ethics [4]. Beginning with the 2019–2020 cycle, ABET better specified an ability to apply written, oral, and graphical communication for a broad audience. Multiple studies [6-7] document the importance of teaching communication that students can expect to participate in, in industry are critical competencies [1,4]. Abbas et al. [6] and Leyden [8] found that in professional practice, writing skills often comprise 20%-40% of an engineer's workday or more (up to 70% for upper management-focused roles).

Although students generally take one or more writing courses through liberal arts programs (i.e., English), capstones typically offer the most substantive opportunity for discipline-specific writing practice [9]. While researchers such as Adams and Manion [10] and Fu et al. [11] have tried to make department (or college wide) specific technical writing courses; they remain uncommon. Alley et al. [12] provides a slightly different strategy, supply reference materials that can be adopted across the entire college for any instructor. Conrad et al. [13] summarized these solutions do not consistently address how to best leverage images and succinct bulleting instead of lengthy paragraph writing [13,14].

Capstone reports frequently play a significant role in the final assessment, allowing students/teams an opportunity to practice communication development [15]. Here, students attempt to communicate complex technical ideas and iterate over time [16]. In practice, however, capstone generated reports tend to be long narratives (100+ pages from the author's experience), with students devoting more effort to technical analysis than concise summarization. Other studies [9,17] echo that students often underutilize or fail to "best" leverage images, charts, and figures to tell the story efficiently. In multidisciplinary team-based AE capstones, integrated designs and/or multiple iterations are being performed, yet comparisons are not always clearly presented [18].

Responding to these documented limitations and ABET's emphasis on communication, a newly revamped capstone with LEAN Problem Solving and Thinking [19] was piloted, particularly with a focus on A3 writing [20]. This paper documents how the capstone writing was formulated around A3s, how assignments were delivered and assessed, and the resulting trends observed through student perception surveys, faculty observations, and rubric scores from two representative A3 assignments.

Challenges in Teaching and Evaluating Technical Writing

Recent engineering education papers emphasize 21st century competencies that need instilled in UG students [21-22]. The most reported have been critical thinking and problem solving; creativity; communication (oral, written, and visual); and collaboration (e.g. teamwork and discipline integration) [21]. Conrad et al. [13] found civil engineering programs are generally responsive to practitioners' concerns for technical skill expectations (e.g., following ASCE BoK guidance) [23], but programs less consistently respond directly to practitioner concerns about writing. There exhibit similar mindsets and approaches to AE communication tend to be more visual (e.g., architecture, rendering, and working drawings), with less emphasis on concise technical style [24,25].

By necessity, engineering communication blends written and visual modes [26] to convey complex solutions. From a capstone perspective, Goldberg [9] found that students devote considerable time and effort on design and development but are less motivated to refine writing, leading to final reports problems with organization, clarity, and effectiveness. Furthermore, there is often an imbalance in leveraging high-quality visual data [27-29]. Retherford and Mobley [30] found that with project-based, and open-ended courses, lengthy reports and time constraints can limit opportunities for instructors to provide vital feedback for students to iterate revisions.

Compared to more generalized writing that students do in courses, industry writing is often more technical and concise [8]. One example of industry writing is LEED narratives that demand both technical precision and effective summaries [17]. If instructors in design intensive courses (such as capstone) can afford a simplistic format that does not constrain technical depth, while reducing grading burden, it is likely to benefit both students and instructors [30]. Conrad's [13] study on industry writing can provide guidance on how to work with students to write more effectively. Here it was found that practitioners:

- Used simpler sentences where they focused their writing on facilitating fast reading for clients.
- Expressed connections between ideas that were important for engineering content.
- Used images, tables and figures to tell stories with limited words.
- Focused on accurate engineering content with an appropriate level of precision, to meet clients' needs, and to manage liability.

Lean Thinking and A3 Problem Solving: A Solution?

Lean Thinking is a philosophy under Lean Production [21,31] that is rooted in innovative practices deployed at the Toyota Corporation [32] to reduce “muda” (Japanese for waste) to compete with the Ford assembly line. In the conception of the lean philosophy, it was important that investigators analyze every step of the production process to develop solutions for any wasteful task(s). Lean thinking grew throughout the building industry in the 1990’s as a response to stagnant construction production rates, compared to the manufacturing industry. The Lean Construction Institute (LCI) was established in 1997 to reform production management and has expanded and grown lean theory and concepts for the building industry [19] since its inception. The goal of leveraging leaning thinking is to maximize information and problem solving in a way that is collaborative and waste reduced by using only important facts for an effective and efficient review and finally decision [33]. A3 thinking can be applied in areas such as design problem solving, idea generation, knowledge communication, lessons learned, visualization and knowledge re-use for future projects [34]. More specifically, A3 Thinking is Toyota’s way of using A3 reports as a standard form of communication that every “issue” is approached and summarized with proposals, problem-solving, status updates, and solution recommendations that are all communicated on one sheet of paper [21]. According to Saad et al. [35], A3 writing provides a knowledge environment to support designers and engineers to make decisions surrounded by only the important or most needed facts.

Conceptually, an A3 is a series of summaries that tell the story [20]. Because of this, A3 reports are often called A3 story boards [36] that fit on an A3 formatted page. The name A3 comes from a metric sized sheet of paper used but commonly in the United States, an 11”x17” sheet of paper is leveraged. According to Handlinger and Landwehr [37] and Shook [38] that good A3 report follows a format with seven main sections: 1) Background, 2) Current conditions; 3) Goal; 4) Analysis; 5) Proposal; 6) Implementation plan; and 7) Follow up.

The conciseness and applicability of A3 in capstone can be correlated in that students generate new designs or alternative designs for “clients” [36]. Here students can summarize their most important work onto A3 sheets that provide the key information only [20]. This has the possibility to eliminate wasted time writing and long explanations that are not needed (and often observed in students' reports). This study will adopt these notions but adjust the scope to some degree given the academic nature of a multi-disciplinary capstone course.

Research Study Design

At the onset of this study, the intent in adopting A3s was to: improve students’ summary writing (processes and key findings), reduce the utilization of AI for written reports, reduce grading burden, increase student feedback, and align student technical writing with lean AEC industry trends. As a result, this yearlong AE Capstone adopted A3 style writing for many (but not all) generated documents by individuals, from discipline subgroups, and even full multi-disciplinary teams. The overarching aim was to better prepare students for professional practice while also speeding up the faculty grading process that allowed for better opportunities regarding constructive feedback. Embedded communication objectives for the new A3 format are:

- Demonstrate the ability to write concisely by focusing on results.
- Demonstrate the ability to execute conventions of grammar, usage, and mechanics.
- Demonstrate the ability to produce and leverage meaningful images, charts, figures and tables that properly showcase results in quick to grasp mechanisms.
- Encourage students to write earlier throughout the semester as a way of getting feedback.
- Utilize these A3s to make team and discipline decisions.

Course Composition and Administration

In the Architectural Engineering (AE) Department at The Pennsylvania State University, capstone is a year-long (two semester) two course cumulating design experience that all students take in their 5th and final year of the program that makes up 25% of the total credits for that year [39]. Each course provides students with 6 hours of in-class meeting time per week with the expectation of approximately 6 hours per week out of class (as a minimum) resulting in the university recommended 180 hours minimum for the semester. During class, time is largely application-focused where students work on assignments with advisor mentoring rather than lecturing. When done, lecturing is typically given only on common reoccurring topics with many questions or for specific project types where specialized system(s) solution topics need to be introduced (leveraging just-in-time learning).

The capstone experience has historically been delivered in two formats that ran concurrently: 1) a multi-disciplinary team approach that utilized a design competition (for 13 years from 2012 to 2024) and 2) an individual student discipline approach with real building projects (since the 1960s up to 2024). Starting in Fall of 2024, the AE Dept revitalized the capstone experience to be exclusively team based, similar to the competition delivery but with attributes of individual technical student studies [40]. As part of this new integrated design team capstone, a balance of integrated studies and discipline specific studies were coordinated that push students through key aspects of the design process. During the first year, many ad hoc adjustments were made as the course went along, including A3 writing being adopted.

In administering the capstone, the department is involved through a two-tiered management process [39]. The overall course coordinator(s) manages general requirements, establishes main guest industry speakers, and oversees the overall structure of the program. The second level is the integration advisor and the discipline specific advisors who mentor their respected set of discipline students. All advisors provide technical support (mentoring) during class as well as execute the main technical grading. A student to faculty ratio is set around 12-14:1 or 6 teams is maintained (whichever is more).

From a project perspective, the course coordinator finds and selects unique existing real world building projects to study (with consensus agreement from the other advisors). In most cases, no projects are repeated from year to year. From a team-to-team perspective, 2-3 teams use the same building project. All projects are either fully designed and either under construction or have been fully built within 3 years of the academic year of interest. Setting this completion level aligns with having easier access to project data such as boring logs, structural loads, enclosure tests, construction schedules, etc. In year two, a site relocation requirement was added to force new climatic and natural disaster considerations that the existing building didn't have. This was in attempt to require new engineering systems to be redesigned.

Student Work

In the fall semester, students start by examining the existing building's functionality and attributes of its technical performance from their discipline perspective (Table 1, Assign #2). From there, a series of integrated and discipline alterative systems and building performance benchmarking studies are done at varying levels of simplified to more thorough investigations (Table 1, Assign #3). After a student understands the current performance, the real designers' reasonings behind their project, and some early alternative possibilities for systems (Table 1, Assign #4 and #5), then students execute alternative design optimization in the spring semester (Table 1, Assign #6). These optimizations span integration and discipline depths from the perspective of both "what make sense for the project" along with "what interests' students have in self-learning".

In terms of integrating writing into capstone, the course holistically has relied on larger technical reports (3-5 in the fall semester and 1 large one in the spring semester). Historically, these reports (with appendices of calculations) regularly exceeded 30-50 pages in the fall (for each assign.) and over 100+ pages in the spring. Resulting in lengthy reports were often difficult to quickly read where students spent too much time writing unnecessary information that was not key to their results. Additionally, students often could have spent time trimming much of the text and conveyed their ideas more simplistically with better figures.

In the new delivery, one item of interest to this paper was the switch from larger page count 8.5"x11" reports to A3 format writing during the spring semester of the first year of the new delivery format. Based on the first spring offering, A3s were adopted in more assignments in year two (Fa25-Sp26). Table 1 provides a summary of key assignments in the fall including the deliverable, and time spent on that scope. For spring, students were tasked with creating a final set of A3 sheets as a single "report" that summarizes their executed work. Along the way in the spring, students submit draft A3s and do intermediate presentations as a way to track progress and gain feedback from advisors. A3s were selected as they are becoming more popular in the design and construction industry to summarize key decisions and systems when presenting work to clients and at multi-disciplinary meetings. Getting students ready for this type of concise writing was considered more important over long technical report writing.

One difference between Toyota's and LCI's A3 vision [36-37] to that of this capstone, is that for many studies, multiple A3 sheets were permitted. This sheet count expansion was given to allow students to expand on their analysis with additional detail regarding building systems and design alternatives or to add other supporting evidence and better documentation of solutions (since the capstone doesn't generate working drawings). However, the concise nature of the A3 documentation was stressed and graded accordingly. Regardless, reports commonly shrunk from 30+ pages per discipline to 5-8 A3 sheets with far more visuals (in general). Students were still permitted (or required) to submit representative appendices of calculations and output from simulations to justify their A3 sheets, these appendices were considered supplementary though.

Table 1: Major Fall Assignments that Require Writing

Assignment	Key Scope	Integration or Depth*	Student Work Format^	% of Grade and Time to complete
#1: Team Agreement	Team contract and workload responsibilities	Integration (M)	Flyers Report (8.5x11)	5% of Total 1 Weeks
#2: Existing Building Performance	Students describe the existing systems of the building and conduct a code review.	Integration (m) Discipline (M)	Flyers Report (8.5x11)	15% of Total 3 Weeks
#3: Baseline Building	Students move the project to the new site/location and baseline the building for systems performance benchmarking.	Integration (m) Discipline (M)	A3s (I:11, D:4)	15% of Total 3 Week
#4: Integration Exploration	Teams develop 3 integrative alternatives that respond to faculty's prescribed challenges.	Integration (M) Discipline (m)	Presentation A3s (I:5@3, D:3)	25% of Total 5 Weeks
#5: Alternative System Exploration	Disciplines refine and narrow options for systems and explore their designs at a conceptual/schematic level.	Discipline (M)	A3s (D:1 per alternative+ 1 comparison)	15% of Total 3 Weeks
#6: Spring Scope of Work (SoW)	Students propose what they want to individually study as well as coordinate with the rest of the team.	Integration (m) Discipline (M)	Presentation Report (8.5x11)	10% of Total 1.5 Weeks

^D:# is number of discipline technical A3 sheets permitted per discipline.
^I:# is number of integrated A3 sheets permitted per team.
**M: Major effort spent; m = minor effort spent (compared to one another).*

Study Data Collection

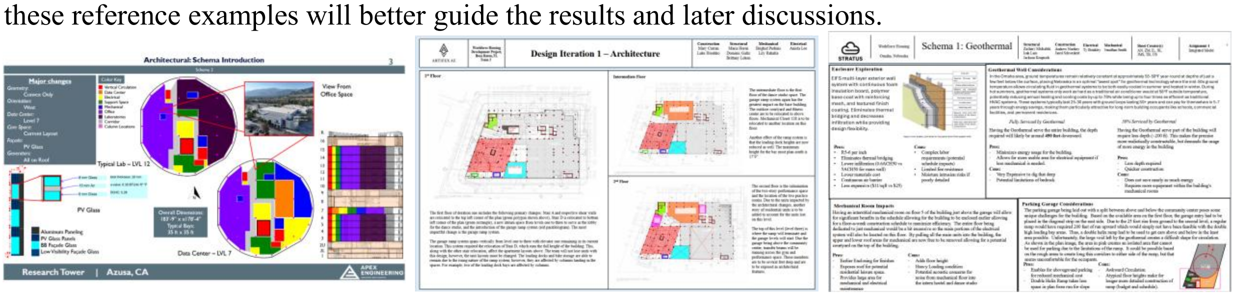
To evaluate the impact of adopting a largely A3 thinking mindset towards capstone writing, data was collected for this study from various sources, of which there were three primary methods: 1) writing rubric scores for A3 sheets, 2) faculty observations, and 3) an end of fall semester student perception survey. As a result, the data encompasses 12 teams (n=94 students) in year two of the capstone revamp during the fall semester (Fall 2025). Within the 12 teams, the discipline breakdown was: Construction (Constr.) (n=25, 26.6%), Lighting/Electrical (L/E) (n=15, 15.9%), Mechanical (Mech.) (n=16, 17%), and Structural (Str.) (n=38, 40.4%). For the optional survey data, the response rate was 90.4% (n=85) with only one Constr., two L/E, one Mech. and five Str. students opted not to do the survey. Since students were able to skip any question, variable respondent counts did exist.

All students writing submissions for Assign. #4 and Assign. #5 were used in the rubric data. Assign. #4 was selected as it predominantly centered on integrated work (heavy multi-disciplinary studies) and Assign. #5 was the alternative discipline development (technical discipline studies at a broader level). As a result, A3 reports for Assign #4 had full team writing and limited discipline specific sheets while Assign. #5 was just discipline writing (with multiple students on the same team internally dividing the work).

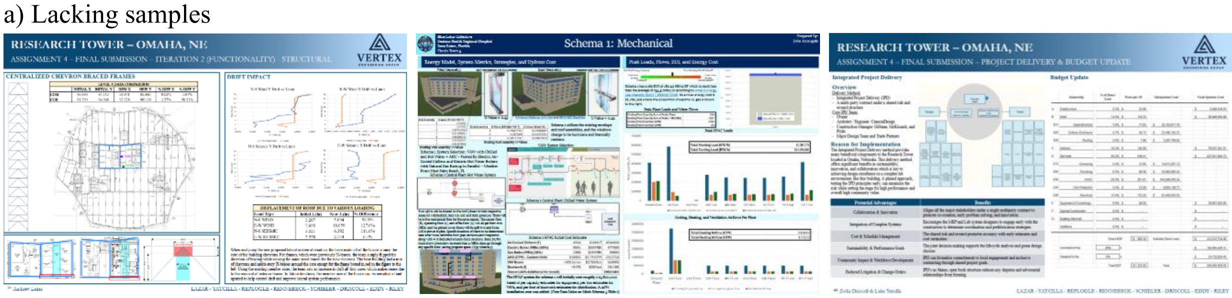
A3 Adoption Results

From the data sources mentioned above, this section of the report will summarize our findings. To best follow the results, results are organized around student performance (rubric scores), student perceptions (survey), and faculty observations.

Before getting into the data results, and to better understand the generated student work, Fig. 1 and 2 highlight representative A3 work from the Fall 2025 semester. Both Fig. 1 and Fig. 2 are organized by student deliverable quality that is either “effective” or “lacking”. A common trend in the “effective” samples is the proper balance of technical results in figures, images, charts, etc. that are with limited text (short, bulleted findings). “Lacking” samples regularly exhibit an overreliance on too much text, images that don’t convey results or poor formatting with no explanations for the visual information given. Having these reference examples will better guide the results and later discussions.

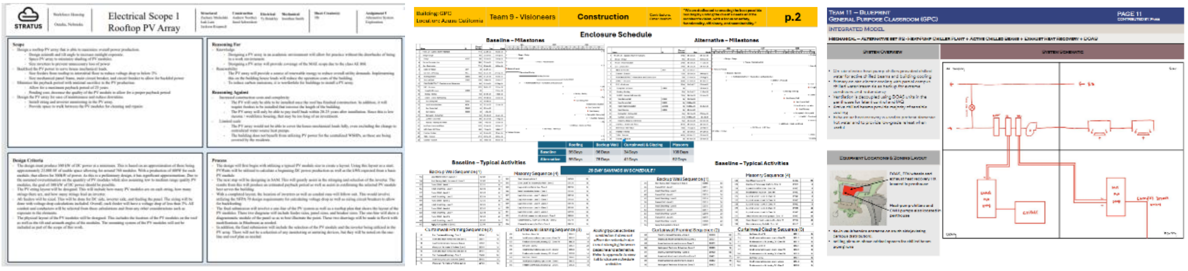


a) Lacking samples

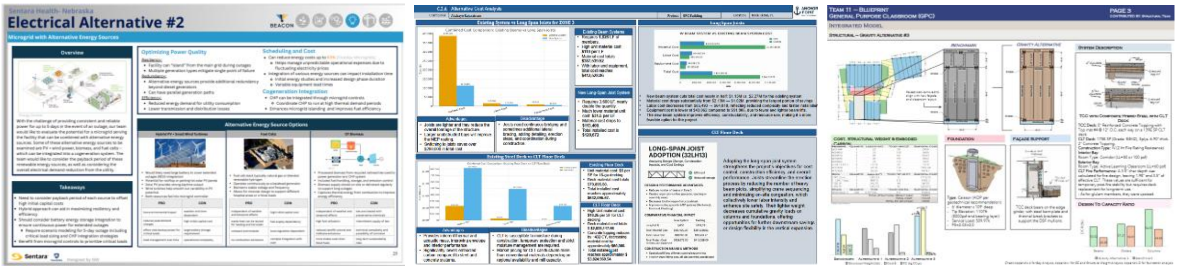


b) Effective samples

Figure 1: Assign. #4 A3 samples.



a) Lacking samples



b) Effective samples

Figure 2: Assign. #5 A3 samples.

Student Performance in Technical A3 Writing

As mentioned earlier, the key to understanding the impact of A3 thinking was student performance in their actual A3 writing. Given the "new" concept of A3s, the developed writing rubric used in this study looked at seven metrics (listed below). These metrics can be paralleled to traditional report writing with the key difference being conciseness of facts. Of note is that the results presented from the rubrics do not look at the technical correctness of the studies. For each metric, up to 10 points were given with the following scale being used (same scale as technical work): Comprehensive (C): 9.5-10, Sufficient (S): 8.5-9.4, Adequate (A): 7.5-8.4, Marginal (M): 6.1-7.4, and Unacceptable (U): 0-6. In most cases, graded scores are presented as average or the percentage of students in each grade scale.

- Quality of grammar.
- Quality of images, tables, charts, and figures.
- Ability to concisely write about more important (key) results.
- Ability to pull out the most important information from studies to make decisions.
- Correctly putting what was asked for on the A3s (from the assignment descriptions.
- Organization of A3 sheet (readability).
- Appropriateness of appendices (to support A3s as needed).

While Assign. #4 was mostly an integration exploration of big ideas, there was time (faculty suggested 1 week) to look at discipline content. This was to get students to think about disciplines while doing integrated "design" work. As such, discipline sheets were graded separately from integration sheets. Fig. 3 provides each rubric metric as a numerical average of all 12 teams. Only averages were used as each team was graded collectively.

Most important to Assign. #4, was to examine the integration writing. Overall writing performance earned an 84.4% (B) average with the different metrics ranged from 74.2% (appendices) to 92.1% (grammar). The ability to extract and summarize the most important information, scored second lowest (81%). Within the assignment, students needed to compare three integrated model solutions. Only 7 of 12 teams provided the necessary comparison summary A3 sheet with a final recommendation. This was a surprise omission as it was critically explained and documented. When asked, students "felt" their other sheets data and the presentation was "good enough". Negatives that pushed the grades lower were a lack of support calculations to justify results and not being able to extract the most meaningful data. Many integrated A3 sheets used multiple graphics that conveyed only surface level information or lacked good visuals in terms of mixing: 3D images, plans, charts, tables and section cuts, making navigation difficult.

Construction A3 trends had an overall metric average of 90.2% (A-), while the scores ranged from 88.5% (appendices) to 92.2 for grammar and 90.9% for A3 organization. Although these metric averages are higher than other disciplines, Assign. #4 focused on developing a detailed schedule with support from a 4D model (combining model elements with a timescale). The addition of the 4D model increased the visual appeal of the A3 submissions and allowed the students to focus their written content on areas of interest and concern. The construction advisors were pleased with these results and commended the construction students on their ability to organize their A3, increase their image quality, and convey appropriate information per the assignment. All three of these advanced areas were present in numerical scoring trends, highlighted in Figure 3. The largest area of improvement for Assignment 4 was the appendix organization and connection from the appendix to the A3 material. The construction faculty were pleased with Assign. #4 results and looked to improve the appendix value for Assign. #5.

Lighting/electrical students scored similarly with each metric spanning between 82.7% to 84.5% that had an 83.1% (B) overall average (excluding the metric on appendices since no electrical assignments included a substantial appendix that needed graded). The most notable struggle was the ability to pull out the most important information to make decisions. In addition, the ability to convey correct information for the assignment was less than ideal, but the concise nature of the grammar and narrative was good.

For mechanical students, they numerically performed consistently across the metrics except for "appropriate use of appendices" (only 4 teams did this). Metric averages ranged from 80.8% to 84.1% with an 82.1% (B-) overall average. Of those that did appendices, those scored an 81.2%. Positives included leveraging of monthly energy performance plots (bar or line) and graphs showing original vs relocation energy consumption. Negatives, an overall lack of critical thinking in how to tell the results. Other factors impacting the scores included, more paragraph writing the didn't convey conciseness (excessive text) or a lack of connection between unexplained (and unlabeled graphics) vs the selected text.

Structurally, students had metric averages between 82.9% to 91.3% with an overall average of 85.6% (B). Picking the right data and summarizing it with as few words as possible was the weakest. These students placed less than ideal formats (e.g.: tables rather than charts) or had generic low-quality images (e.x. missing grids overlapping with arch). Other writing aspects were too much text or the poor selection of key results that did not support integration.

Based on work from Assign. #4, students advanced their top ranked integrated solution (or hybrid attribute combination) and generated a new integration model to build discipline systems from. As a result, Assign. #5 explored multiple discipline alternatives (faculty required 3-4 alternatives). This was to get students to think about alternative systems (in a broad sense) to integrate with their new designs. It was expected at the start of Assign. #5 that this writing should be better than Assign. #4 as students were more comfortable writing about their own "expertise" [41]. In Assign. #5's description, disciplines were given a recommended format to summarize their results; particularly in comparing the alternatives to be able to evaluate and rank them. Fig. 4 provides rubric metrics as a numerical average for all 12 teams. Only averages were used as each team was graded collectively (by discipline).

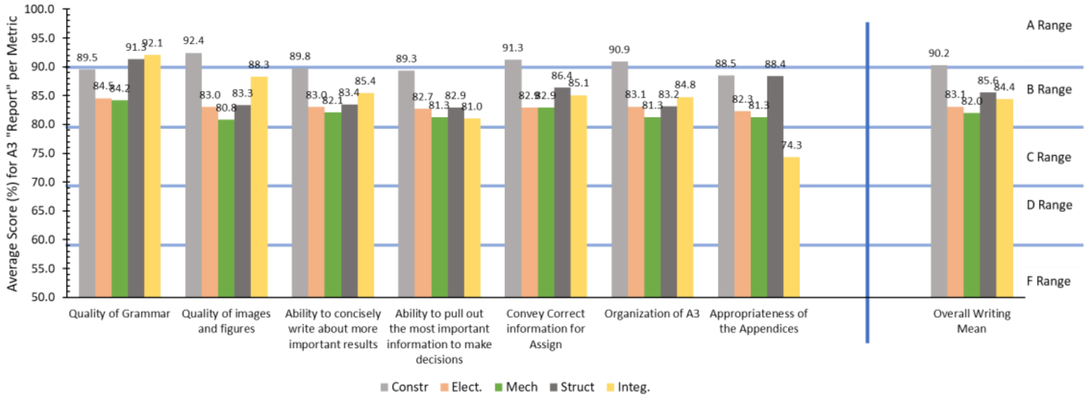


Figure 3: Numerical score trends for Assign. #4 by discipline.

Construction students performed slightly better or maintained their performance from Assign. 4 in nearly all cases. Here, the averages were 88.1% to 93.8% with an overall average of 90.3% (A-). Although the construction students did well on Assign. #5, there was little to no improvement on the appendix quality (88.1%), and the result-focused approach (89.3%) also declined slightly. The construction faculty were surprised by the lack of improvement on the appendices in Assign. #5. However, the A3 process still has a learning curve to tell a story with your results while providing appropriate back-up for your calculations.

Electrically, students did well in most metrics ranging from 86.3% to 87.7%, with an overall average of 84.8% (B). Exceptions included the ability to pull out the most important information (79.5%) and the quality of images and figures (80.7%). These scores were marginally better than Assign. #4. Most of the struggle was related to the students' ability to concisely present their alternative using limited text with appropriate graphics. Ideas and concepts were technically solid, but the presentation was lacking.

For mechanical students, they performed comparable to other disciplines with metrics ranging from 81.5 to 85% with an 83.2% (B) overall. Similar to Assign #4, only 3 Mech. teams chose to leverage appendices. Interestingly, one team chose to write their work as a report and not in A3 (without approval). This data was removed as there was no reason for the change (it was graded as if it was wrong from a writing perspective).

Structurally, students did well with metric spanning 86.0% to 91.6% that had an 88.2% (B+) overall average. This was between 1.3% to 3.1% better than Assign. #4. Students were better at summarizing data and organizing the sheets; yet multiple teams (n=7, 58.3%) chose not to compare alternatives as required / described in the assignment. There remained a struggle to pick the right data, but it was less than Assign. #4. Leveraging to images remained consistent from Assign. #4 to #5 as the structural students chose bullets (or at times paragraphs) giving descriptions instead of good, annotated images. There was an increase in charts and figures, but they were often missing descriptions, labels, or short annotations to give meaningful context.

Knowing the numerical scores, the categorical distributions (%) were also calculated. This was done to see where students fell in a broader writing context. Figs. 5 and 6 provide comparisons between the seven-rubric metrics. Broadly, comprehensive writing (9.5-10) was limited yet, Construction had several metrics over 40% (in both Assign. #4 and #5). From the sufficient writing category (8.5-9.4), 65% of Assign. #4 and 64% of Assign. #5's metrics had this grouping as the largest. This is considered good as students who are positioned here write well but have occasional mistakes, less than ideal composition, or missing minor items to tell the full story.

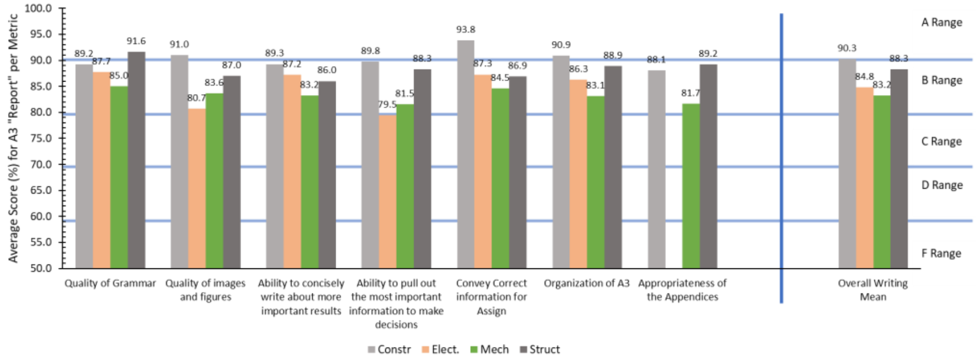


Figure 4: Numerical score trends for Assign. #5 by discipline.

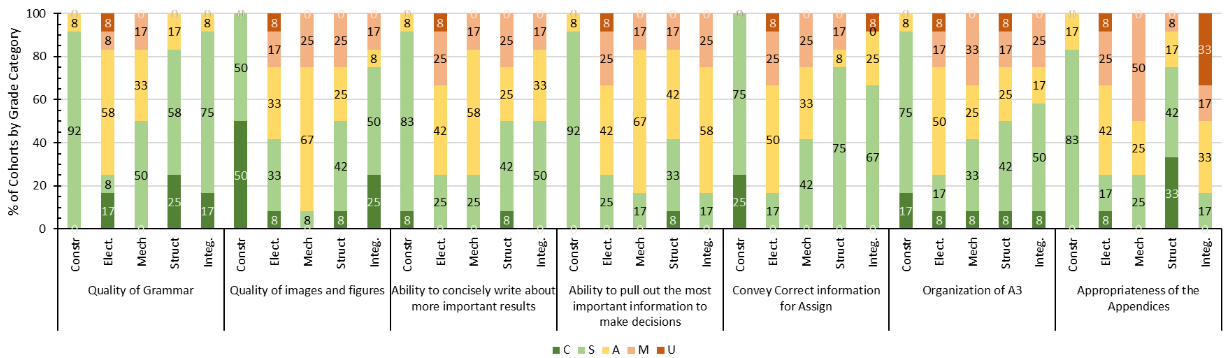


Figure 5: Writing rubric metric category trends for Assign. #4.

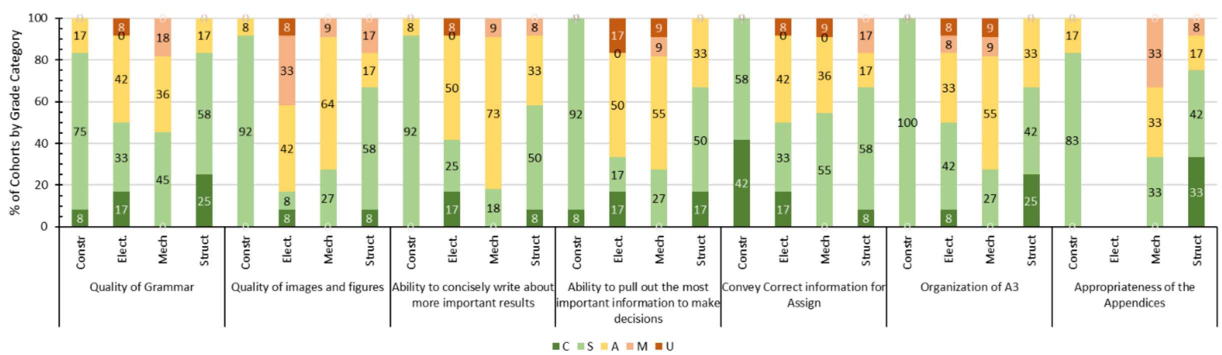


Figure 6: Writing rubric metric category trends for Assign. #5.

Acceptable writing (7.5-8.4) had the second largest (%) grouping. These acceptable students in Fig. 5 and 6 make sense for each category based on more errors being made and lesser writing refinement or a lack of care to tell the story through the A3s. Marginal writing (6.1-7.4) and Unacceptable writing (0-6) had low scores: M ≤25% in #4 and ≤20% in #5 nearly all cases; while for U, it was similar with less than ≤10% in #4 and ≤17% in #5. Integration had the exception for U (33% for organization) and mechanical had an exception for M (50% for appendices). Collectively the Comprehensive group stayed about the same from Assign. #4 to #5. That said, the Sufficient group did grow in some disciplines for some metrics (shows a slow long-term improvement). Lastly, the negatively performing (M and U) writers exhibited limited change in all but a few areas. A small jump was observed in negative performance that shows that while iterative writing can help, it may be necessary to introduce this earlier in the curriculum.

Student Perceptions on A3 Writing

Students were asked to meta-cognitively reflect on their writing ability and their experiences in A3 format writing in the fall capstone semester. Three multi-scale questions were asked. These focused on: 1) the quality students approaching A3 writing, 2) A3 writing preparing students for their careers, and 3) perceptions on their own technical writing skills.

To understand how students thought their approach to A3 writing went, 9 metrics were used (Fig. 7) that leveraged a 5-point Likert Scale anchored with Strongly Agree (SA): 5 to Strongly Disagree (SD): 1 to rate their level of agreement. Across the 9 metrics, an overwhelming student majority strongly agreed on A3 writing mechanics being beneficial. In 7 of the 9 metrics, Constr. students scored the strongest while L/E and Mech. students had the most disagreement (but <15%). Mech. and Str. students had weak agreement on how easy it was to write in an A3 format. This can lead to students thinking they need to summarize their complex systems on a single sheet. While L/E and Mech. Students' designs are very different, visual representations are often similar (line schematics). As such, both disciplines consistently scored higher in visual metrics below. Across the board, integration summarization skills could be improved as it had some of the lowest SA and A agreements (Fig. 7, second in on the right).

Beyond classroom writing perceptions, students were surveyed on their opinions towards the A3 writing regarding how they see it in their future careers. These insights were captured across 4 metrics (Fig. 8) using a 5-point Likert Scale of Strongly Agree (SA): 5 to Strongly Disagree (SD): 1. Similar to the other perceptions, students generally strongly agreed (18-54%) with the exception of L/Es who felt their skill level was only agreeable in meeting industry expectations (0% for SA but 69.2% for A). Limited disagreement and neutral perspectives were a good sign where <38% (the max of any discipline and category). This indicates that connections are being made to the importance of A3 writing and conveying results concisely.

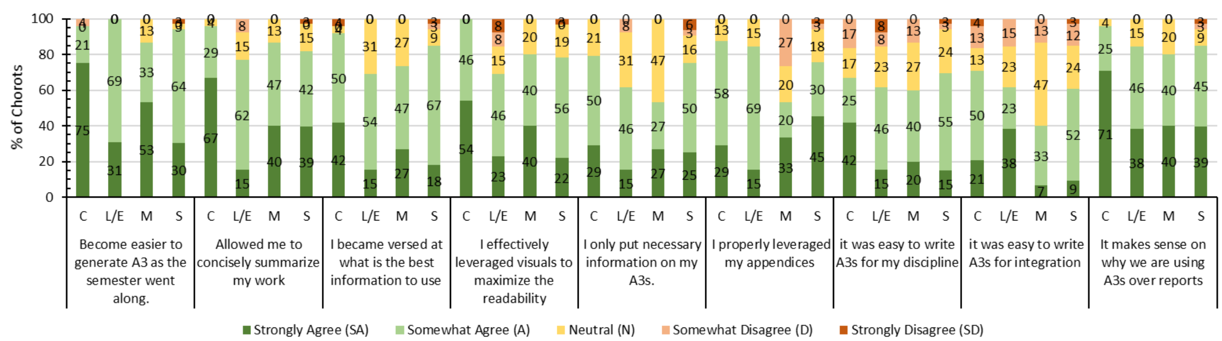


Figure 7: Student perception trends on how they approached A3 writing.

The third self-reflection question centered on general technical writing ability. This was measured with 6 metrics [42] which leveraged a 6-point Likert Scale from very poor ability (1) to exceptional ability (6). Cillers [43] and Wilson et al. [44] indicate that student perceptions can vary significantly based on the iterative feedback and student willingness to improve their writing rather than taking the assignment as a "to do" item. Results are broken down by discipline in Fig. 9.

Across all 6 metrics, nobody rated themselves very poor (1) and only a very limited number of construction and L/E students (4% & 8%) felt they performed at a poor level (2) in three categories (conciseness, grammar, and selecting technical content). This was good as faculty felt that most students had performance at higher level. There were two teams that did submit incomplete Assign. #4 A3s. Here the poor performance was more of a reflection on waiting too long to write and a lack of substance to write about (poor team dynamics lead to delays and demotivation to complete studies) over that of their skills. Also positive was having a low exceptional perspective given the scores that students receive (earlier Figs. 3 and 4). This indicates students reflect on their work and know that there is still room to improve.

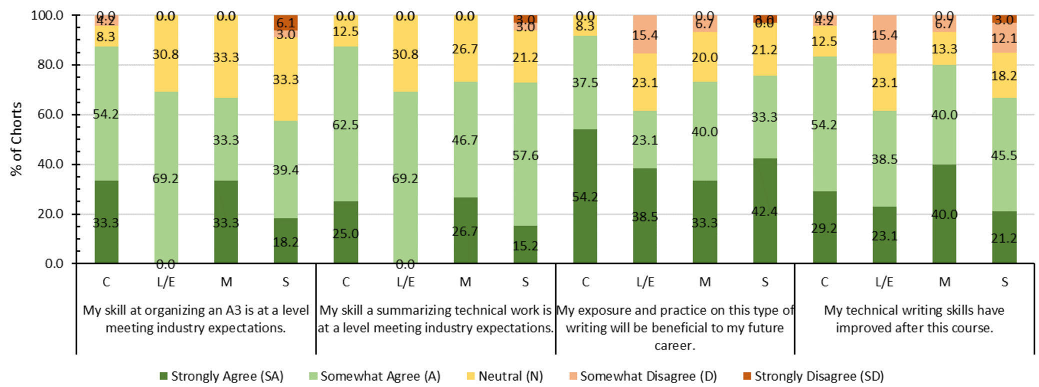


Figure 8: Student perception trends on how A3 writing might impact their careers.

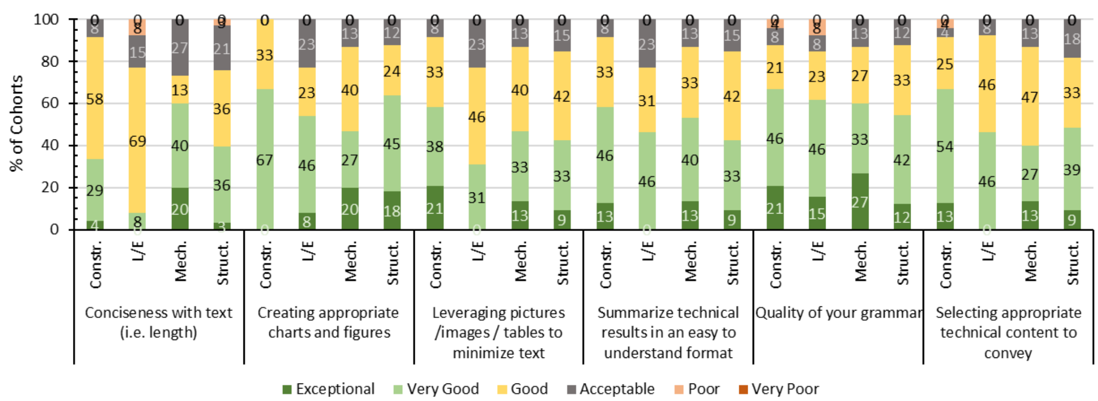


Figure 9: Student self-reflection on technical writing skills

To better understand actual performance vs student self-efficacy, a correlation analysis was performed using data from Fig. 9 and data from Assign. #4 and #5 rubrics. Due to the non-normal data distribution, A Spearman correlation (rho) was utilized [45] using both overall average and matching rubric categories with student perceptions. The resulting rho values are listed in Table 2 [using Dancey and Reidy [46] descriptor groupings].

In total 6 scales and 5 cohorts (60 comparisons) resulted in 60% having positive relationships, of which 26 had rho < 0.2, indicating a negligible relationship. Another 6 had rho < 0.3, indicating a weak relationship. From a more positive standpoint, 5 instances had a moderate relationship with another 2 strong and 3 very strong relationships. These relatively stronger relationships were only in L/E and Mech. students indicating this type of writing better resonated with them and made sense to them. Any strong to very strong relationships in Table 2 showcase good mindset to actual performance connections. These areas need to be examined more for improvements ideas for the delivery next cycle.

The last 40% had a negative relationship, with 23 being negligible, 4 being weak, 1 moderate, and 1 strong. For industry A3 often being driven by construction [19], there was almost no impactful correlation in the Constr. Cohort. Furthermore, numerically most Constr. students had negative numbers (n=11 instances, 78%). While most negative correlations were negligible, the amount of them showcases students could use some better intervention to change mindsets. Additionally, the strong Mech. Assign. #4 negative rho on "summarizing technical results" needs to be better understood and perhaps the assignment rethought some.

Table 2: Correlation results between Performance and Perceptions

Perception Scale	Full Class*		Construction		L/E		Mechanical		Structure	
Assignment #	#4	#5	#4	#5	#4	#5	#4	#5	#4	#5
Overall*	0.100	0.065	-0.226	-0.157	0.373	0.713	-0.104	-0.058	0.038	-0.020
Conciseness of Writing	0.021	0.107	0.178	-0.255	0.161	0.099	-0.195	-0.123	-0.007	0.015
Appropriate technical data used	0.118	0.058	0.152	-0.256	0.342	0.711	-0.092	-0.049	0.005	0.034
Appropriate use of Figs.	0.105	0.207	-0.055	-0.134	0.301	0.724	0.210	0.093	0.108	0.210
Leverage visuals to min. text	0.136	0.140	-0.351	0.084	0.467	0.566	0.316	0.236	-0.011	0.052
Summarize technical results	0.183	0.184	-0.114	-0.081	0.652	-0.232	-0.418	-0.126	0.244	0.157
Grammar	-0.112	-0.050	-0.195	-0.185	0.211	0.268	-0.334	-0.106	-0.094	-0.149

Note: * uses the average scores across the 6 metrics.

orange = weak; yellow = moderate; green = strong; blue = very strong; none= negligible relationship

Student Perceptions on Course Preparedness for A3 Writing

As the idea of A3 critical thinking and writing was new to nearly all students, it was important to survey the cohort on how well the course prepared them. To address Year 1 feedback requesting more explicit instruction, Year 2 included a formal A3 introduction by an alumni professional experienced in Lean Construction, with a set of A3 examples (curated industry and student). To capture preparedness, students rated the course outline and guidance on A3 writing in 5 areas (Fig. 10) that leveraged a 5-point Likert Scale using Very Satisfied (VS): 5 to Very Dissatisfied (VD): 1.

From the data, students felt positive the course provided a good introduction on why A3 writing (Fig. 10) given 67.8% were S to VS. Only limited L/E and Constr. students were dissatisfied (Constr: 8.3%, L/E: 23.1%). A plausible reason for the negative response was a lack of examples for those disciplines in the introduction verses what they had to write about. In providing extra reference samples, students' satisfaction was less (Fig. 10). Only 43.2% of all students had positive satisfaction while 32.3% negative satisfaction. Given that students always want more examples [47-48], these responses were not unexpected based on questions faculty got in class on what/how/why to write.

Tied to the samples, students positively (58.9%) liked how we told them what to put in the A3s. Requirement descriptions focused on what students needed to do first but would then describe what was expected in the summaries (even if it was to just concisely summarize the bulleted requirements). Faculty further gave introduction talks for each major assignment that discussed expectations and often provided examples of good and bad results from historical databases (before the A3 format but still applicable).

From the results regarding faculty feedback comments and faculty rubric grading, as well as just-in-time feedback (to student questions), limited very satisfied (VS) perspectives were encountered (3.3% to 3.8%); yet there was 30%-40% positive satisfaction with lastly neutral opinions taking 28%-39% depending on the discipline. Both sets of numbers were not surprising as students often didn't ask for writing feedback in general but those that did got good advice (not always taken though). In terms of rubric feedback, faculty tended to be holistic (why points were removed or pointing out errors). Several disciples did provide sample markups of sheets (while others opted for more verbal feedback when grades were returned).

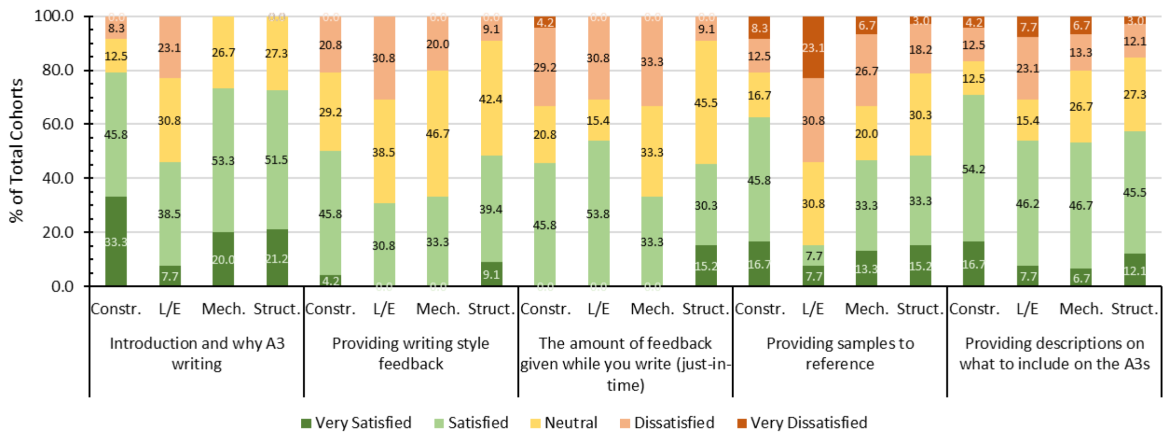


Figure 10: Student perceptions on our delivery regarding A3 writing.

From a discipline perspective, no major deviations from any one student discipline cohort were observed outside of the L/E responses being more negative to neutral on faculty provided samples. This showcased that A3 writing did not significantly sway any one discipline. Additionally, it showed that disciplines are not sensitive to this type of writing. That said, how students view and get feedback on A3 writing do need a careful review as neutral and dissatisfied was larger than anticipated. One area for this to feedback could be through interim submissions or live in-class (during work sessions).

Faculty Perceptions on Student A3 Writing Trends

Throughout the semester, faculty met regularly to discuss student performance, including grading and general progress. These meetings commonly included discussions on student outcomes (including writing) with suggested areas of improvement. Presented here are faculty perceptions of student writing on A3 writing.

With respect to student communication effectiveness, the outcomes were largely unsurprising. High-performing (excellent technical) students adapted quickly and effectively to the A3 format, particularly those with stronger presentation and visualization skills (based on faculty observation). In contrast, marginal performing students often produced correspondingly weak A3 writing. This trend may reflect differences in students' maturity in critical thinking and their ability to articulate their thought process in written form. More mature students tended to organize their ideas logically and outline their thoughts prior to writing; these students also frequently produced multiple drafts. For such students, the A3 template served as a concise and structured expression of their reasoning. These effective A3s exhibited clear organization, logical flow, and well-defined key points.

Students who were less accustomed to organizing their thoughts logically experienced greater difficulty with the A3 format. This led to the most challenging aspect of the A3 process, pushing students to think in a more concise manner that emphasized the most important information through limited text and well-balanced graphics. Early in the semester, many students demonstrated a tendency toward traditional rhetorical or technical report–style explanations. Although balancing text and graphics proved challenging initially, many students improved as the course progressed. As students gained experience producing A3s, the overall quality of the submissions increased, though improvement was slower for some students, even when specific errors were clearly pointed out to them.

Although faculty remained critical of certain aspects of A3 writing quality, a historical reflection on the old report format suggests that A3 generally trended on the positive side, in particular conciseness. Faculty believe that the results have been mostly positive as students are learning to be more direct with their narrative and developing better graphical skills to supplement text. Further improvements in conveying essential information and overall A3 quality are anticipated if this format is introduced earlier in the undergraduate curriculum. Lastly, by implementing an A3 format, A3s give the faculty a clear snapshot of how the student problem solve cognitively.

Discussions

Given the results provided up to this point, positive attributes regarding A3 writing has had on the capstone project can be found. This is evident across multiple sources. Given this, a richer discussion on why implementing this type of writing will immediately benefit students as well as provide reflection on what style writing did well (Continue) and what can continue to be improved for the next capstone offering (Improve) is provided.

Importance of A3 Analysis Approach for AEC Industry Preparation

While technical writing will always be an essential component in our students' education, the architecture, engineering, and construction (AEC) industry has been moving in the direction of more concise documentation of analysis and decisions and process efficiency. Lean practices have become more prevalent in the design and construction industry, and the use of A3 problem solving / analysis documentation is a growing trend amongst project teams. Building owners are driving the need to eliminate process waste, extending to both the design process and the construction of projects. Consequently, decisions need to be made more quickly and with better input from all stakeholder parties. The A3 analysis approach provides the ability to concisely identify the problem or decision to be made, evaluate potential solutions, and get consensus amongst the interested parties to arrive at the most optimal solution given the project goals and objectives. Furthermore, these decisions can be easily documented, filed/archived, and retrieved throughout the project, which reduces the need for reevaluation and reassessment as the project progresses. Because changes during design and construction often result in increased costs or schedule delays, the use of A3 documentation can directly contribute to cost and schedule reduction, while keeping a grasp on operation and maintenance cost.

During the construction phase of the project, lean thinking morphs the design decisions into efficient execution. Construction team members are faced with developing efficient means and methods to put these complex designs into place to create a high-performing facility based on models, drawings, and specifications. During construction, the use of the A3 analysis approach is very beneficial to assess changes to the budget, schedule, and quality. In addition, sustainability documentation has become a large part of the construction management practice. The A3 analysis method provides construction team members with efficient updates on the constant project challenges and keeps team members on task to deliver the project on time and under budget. Project dashboards are becoming the norm and include an A3 that summarizes project success / areas of improvement with links to other A3's for each category (i.e. budget, schedule, quality, economic trends, sustainability, etc.) which provides a deeper dive into progress on each topic and forecasted outcomes based on perceived variables. The A3 analysis method provides a good framework for current construction practices and allows for the future evolution of advanced practices such as virtual design and construction and the integration of artificial intelligence.

Given the current AEC industry trends to implement lean thinking and the highly intensive, fast-paced nature of capstone design experiences, transitioning to a more efficient form of technical communication, the logical choice for AE capstone. Currently, the A3 capstone approach has begun to positively mimic industry problem solving and shifts the classroom focus to important solutions features and less so on explaining every aspect of the work. Waste reduction in student effort has been shown but improvements can still be found to be more concise and precise in their writing. Another technique from industry that could be adopted here in writing is “begin with the end in mind” If we can instill in students to think about what needs presented and why, then their writing can be "outlined" on key tasks to complete.

Continuous Improvement: Continue and Improve

Taking notes from team performance mechanics and reflective practices to increase performance [49-50], the instructors took a reflective look back at the A3 done writing to date. In doing these reflections, two categories emerged: 1) Continue, meaning that we want to continue to implement and capture while 2) Improve, meaning what can be improved or delivered differently that is both logical and fill identified gaps. Summarized here are the two sets of reflections.

Continue:

Continuing to implement reflections, many positives were identified. Perhaps the biggest item for the faculty to continue is to keep the A3 format. These A3s did in fact allow for concise writing and a reduction in grading burden through trimming “filler” with good appendix leveraging for more detailed but less important information, software output, equipment information, and sample calculations.

- Keep the A3 format for most assignments (those centered on results and solutions).
- Allow more than one sheet as a single sheet often could not provide enough graphics or data to properly present the necessary solution(s). Particularly important since working drawings are not created in this capstone.
- Strive for as few sheets as possible.
- Keep appendices for the reasons mentioned above. Strive for minimization though.
- Continue to leverage interim deliverables for assignments. Here, force the habit and mindset of writing as you go.
- A3s better leverage the “learning through writing” so keep up sheet iteration and refinement.
- Promote the A3 sheets as a way to talk with outside professionals (when seeking advice) to quicky get professionals “up to speed”. This reinforces the notion of: “begin with the end in mind.”

Improve:

For the reflection on the areas of improvement, many of the tasks are aimed at bettering the results through clarity of descriptions and explanations that faculty provide to students. Admittedly, some of the assignments (across Table 1) continue to need adjustment to be more appropriate for A3 submissions since the history of the program has long been built around traditional technical reports and a history of individual student capstone delivery [39].

- Continue the discussion of A3 writing at the beginning of the capstone but expand by teaching more about proper visual leveraging with dedicated discipline sessions.
- Convey in the assignments more clearly regarding key items to report out (some options were too vague on this given the scope of technical work).
- Promote students to develop outlines for the A3s may reveal shortcomings in students' overall understanding of the tasks and/or technical content early in the assignment duration period.
- Conduct more formal intermediate critiques of A3 sheets in interim submissions to get iterative refinement.
- Promote the broader faculty to adopt A3 writing earlier in the curriculum.

- Be clearer on what should and should not be in appendices and how much is too little or too much. Some teams had none (Mech.) to over 30 pages (Struct.). Link appendix to A3's.
- Maintain better documentation on who is contributing to each sheet for grading disputes and individual adjustments.

Recommendations for A3 Writing in A3 Capstones.

Given the collected data, coupled with faculty interactions and student work, a series of recommendations were generated. These recommendations are constructed so that others can consider adopting this concise method of writing for their capstones or other writing/comparison heavy course projects.

Recommendations for Introducing A3s to Students

- Begin with the Why? Stress the importance of the A3 method in the AEC industry. Stress the importance of Lean Thinking in AE capstone.
- Provide an A3 introduction early to students. Ideally, the first week of class. Provide an implementation framework and keys to success.
- Introduce the A3 process in other classes (perhaps via projects) that are offered in advance of the capstone.
- Provide good representative examples and include bad examples of what not to do and why. Do this for all disciplines. These can be a mix of industry and education examples.
- Discuss writing trends in the AEC industry to provide students with expectations of effective communication of the problem-solving approach. Have peer industry members from each discipline validate their approach.
- Discuss pro-con regarding A3s vs report writing.
- Have disciplines provide short "lectures" on good practices for summarizing design and results through different means. Focus on what is important along with the best visual to convey a particular topic.

Recommendations for Assignment Writing

- For each assignment (in capstone), document the expected or anticipated length of "report" (# of A3 sheets including expected sheet scope).
- Tailor assignment descriptions to ensure A3 documentation will fully capture the key results.
- If there is specific mandatory information needed, a matrix, table, or list of these items must be given as a minimum.
- Leverage interim submissions with sample A3s or draft A3s to give feedback. This can be submitted and marked, or live sit-down meetings can be conducted to critically review.
- Have students submit A3s in discipline sets with each sheet documenting who contributed to it.
- Separate discipline sets to simplify scanning for the sheets if they are poorly labeled and/or organized.
- Instructors should consider making assignments in an A3 format to familiarize students with this writing technique.

Recommendations for faculty grading A3s.

- Conduct a first pass "skim" read to see the full scope across the generated sheets. From there, grade consistently within a topic. For example, grade all gravity sheets for structural before moving to lateral.
- Provide layered comments, first past vs detailed to showcase what was easy vs hard to identify.
- Print out sheets at full, half or quarter scale and mark them up. Alternative to direct markup is supplemental with sketching and notes on facts for how to improve.
- Use check lists or similar to look for key facts and to review for graphic quality impacts.

Recommendations for what students should focus on in their A3 summaries.

To aid in grading, and to give students an idea of what is good to include on A3 sheets, the following bullet items can be considered effective best practices. In all cases, students need to consider how to go about dedicating time to developing quality A3s. In addition to these bullets, Table 3 provides suggested recommended metrics to track/discuss on various sheets along with starting points for the types of valuable visuals students can leverage.

- Initially, have students think about any data used to convey 1) what the system is, 2) how it is composed, and 3) how it is performing.
- As they progress, have students document information they used to make their decisions.
- Require students to think about what and how to best show the design solution with quick ease of understanding: 3D model, plan, sections, etc. simple shapes and diagrams up to working drawings.
- Leverage good visuals that can reveal key features in a quick (<2min) review of any one sheet and be able to understand 80% of that sheet.
- Recommend generating a template, color palette, and other attributes so the A3 sheets are consistent across the team. Enforce actual 11x17 size for ease of printing and scaling.
- Develop outlines early. Storyboard A3 sheets early so students can work backward to do the analyses.

Table 3: Data types and visual formats recommendations A3 conciseness.

Scope of Writing	Key metrics /information to report out	Key Types of Visuals to Leverage
Integration	• Architectural Efficiency: GSF, NSF, MEP Service SF, Circulation Area, Floor to ceiling heights, Plenum Thickness, etc. • Enclosure performance: U-Value of assemblies, glazing to solid wall aspect ratios, embodied carbon, etc. • Acoustic performance: IIC, STC of key walls and floors, etc.	• F: Clear floor plans showing space allocation, circulation, and egress paths. Let the graphical presentation "speak for itself". • F: Integrative exterior wall sections developed at the intersections of structural and enclosure to indicate integration of thermal, structural, fire separation, moisture and air infiltration performance. • F: Integrative interior wall sections developed to provide total sound and vibration isolation. • F: Isolated 3D model visuals showcasing systems integration and pinch point constraints in key areas. • T & F: Clear summary images that showcase metric performance and tradeoffs from integration. • F & C: Relationship bubble diagrams showcasing stakeholder influences.

Table: T; Figure / Image: F , Chart : C

Note: The rest of Table 3 is continued on the next page.

Table 3: Continued.

Construction	•Cost summary •Total budgeted cost •System cost breakdown •Cost per square foot •Total project schedule including design and procurement •Milestone schedule highlighting critical activities, long lead times •4D Model •Site Logistic Plans •Constructability review of design selections •Quality control plan •Construction engineering analysis •Critical industry research topic •Sustainable Construction Plan	•C: Uniformat II cost breakdown highlighting system costs •F: Critical path schedule Gantt chart •C: Milestone activities •F: 4D schedule •F: Construction means and methods approach/examples •C: Quality assurance plan •C: Sustainability approach •F: Site Logistics Plans •C: Crane Analysis Table •F: Utility map
Electrical	•Electrical loads for normal and emergency power systems •Resiliency and reliability analysis •Electrical system efficiency with respect to cost, availability of equipment, system architecture •Methods to provide added redundancy. •Alternative energy sources such as photovoltaic systems, battery energy storage systems, etc. •Innovative ideas such as alternative fuels for backup generators •Power quality	•T: Prepare a summary of the load calculation •F: Schematic single line diagrams •F: Graphs or tables for comparison purposes
Mechanical	•EUI •Block loads (with peak) •Monthly energy profile •Review zoned areas considering: Ventilation rates. •Occupant Comfort •Distribution of ductwork and piping •Mech. shafts and shafts to spaces distances	•F & C: Clear graphics for loads and energy distribution, •F & C: initial and life-cycle costs, •T & C: Major building loads, occupancy, etc. •F: Concise floor plans and building cross-sections indicating zoning of systems and fire separation, air and water distribution system compositions. •F: Riser and system diagrams indicating major components and system layout. (not detailed system diagrams).
Structural	•Bay Aspect Ratios •Span to depth Ratios •Members sizes, Cross-section, thickness •Loading and analysis / design criteria •Load impact on foundations vs soil capacity as a DCR. •Lateral movement performance. •Lateral performance in load distribution: COM, COR, % lateral to frames/walls. •Gravity strength and serviceability performance. •Gravity system depth at critical location vs plenum allowance. •Embodied carbon per SF of gravity system. •Weight of systems per SF. •Structural gravity system $/SF	•F: System configurations in elevation and plan for lateral, bays for gravity with sizes •F: Overall floor plan with grids and members but decluttered (non-working drawings) • T & F: showcase key DCR, Technical performance facts, summaries. •T & C: showcasing comparisons of options with technical numbers and facts. % change, differences, absolute values. •F: Cross sections or 3D images showcasing structural integration with MEP and Arch. •F & C: Plots of lateral movement with limits. •F: Color coded image showing DCR limits / performance. •C: Line plots or bar charts showing iteration improvement between cycles.

Table: T; Figure / Image: F , Chart : C

Conclusion

Adopting A3 thinking in a multidisciplinary AE capstone greatly improved student focus on concise writing for the majority of students. It also aided students with the ability to derive potential solutions and improve the problem-solving process. The A3 approach allowed students to focus on what is critical vs what is convenient to fill gaps in a written report. Given that faculty time-commitment in capstone project consulting and grading is inherently intensive, another observed benefit of an A3 approach was a natural shift of invested faculty time from reading, searching, and collecting information (from long reports) to more important and rewarding mentoring activities such as consulting students on solution opportunities and eliminating technical roadblocks.

Both students and faculty reported generally positive perceptions, with evidence of incremental improvement between major assignments. That said, there were persistent challenges involving selecting the most important information, appropriately linking appendices to the A3 analysis, integrating bulleted text, and effectively balancing visuals that result in a sufficient level of performance (B range). Given the successes to date, the authors recommend introducing A3 style writing earlier in the curriculum and to ensure that the students understand the value of the A3 approach. Other areas that should be strengthened are discipline-specific guidance on visuals and expanding interim critiques. As this is still new for the studied capstone, continued writing trends should be documented for other assignments looking at consistency as well as collecting perceptions at the very end of the capstone to see if there are more gradual shifts.

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