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The Impact of Diaries and Reflection on Self-Assessments of Learning in a First-Year Undergraduate Engineering Design Course

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Abstract

This work-in-progress (WIP) paper communicates the impact of diary and reflection activities on students' self-assessments of their learning in a first-year, studio-format undergraduate engineering design course. This work is implemented in an equity-minded frame to ensure that we support the learning and experience of all students. Students in first-year engineering design courses often ineffectively deploy design process phases and activities, which can limit their learning and negatively impact the quality of their deliverables. To further encourage students to intentionally engage in the appropriate design process phases and activities, we supplement our current instruction with a new activity that includes a modified time diary and a structured reflection activity. This work-in-progress paper begins analyzing our data to understand the role played by these activities in student learning.

We analyze students' self-assessments of learning and engineering identity, with data sourced from pre- and post-term surveys, with a phased deployment of the diary and reflection activities across multiple semesters. Given our centering of equity-mindedness, we analyze demographic data to identify and attend to any equity gaps in student learning and experience. In this work-in-progress paper, we include a subset of Student Learning Outcomes (SLOs) focused on the design process and teamwork and a single measure for students' identity as engineers. Data are analyzed using a two-factor Analysis of Variance (ANOVA). The factors include (1) the phased deployment of data-collection, diary, and reflection activities (PHASE), and (2) whether the student identifies as a member of a racial or ethnic group that is historically underrepresented in higher education (URM). This initial analysis identifies a statistically significant positive impact of the implemented diary and reflection activities on the student learning outcome "solve open-ended and ill-structured engineering problems" for students in the URM-identifying group. Beyond this outcome, this initial analysis also indicates that students report increased learning for engineering design outcomes but do not report a self-assessed growth in learning related to functioning effectively on teams. Furthermore, this course and the pilot activities, as currently implemented, do not enhance students' sense of their engineering identity. These shortcomings require innovations that carefully consider student experience so that we effectively prepare technically excellent, collaborative, and confident engineers.

Introduction

This work-in-progress (WIP) paper communicates the outcomes of a reflection activity deployed in a first-year engineering design course. This activity is assessed through previously described instrumentation created to measure students' growth in design learning, ability to function on a team, and their engineering identity, each as a function of instructional approaches and activities (1,2). Here, we focus on initial results after implementing a student-maintained diary and engaging in structured reflection activities. The data analysis informs instructional practice with a focus on transforming student learning and experiences. We employ equity-minded approaches to our instruction to support meaningful, inclusive, and equitable learning and to teach in such a way that there are equitable outcomes for our students (3).

It is well-documented that students in first-year engineering design courses can ineffectively navigate the phases and activities of design instead of deploying the most appropriate mindsets and activities for each question and problem at hand (4–7). Instructors proactively teach and encourage students to iteratively explore the design space throughout their courses. Because students are often learning how to solve engineering problems and manage projects for the first time, they can neglect to respond to this feedback when working independently due to their lack of experience. To support students in building their capacity in intentionally selecting their future design activities and phases, we deployed a Design Diary and reflection activity. As described in our prior work (1), the diary is a simplified time diary completed by students during class. Design Timeline visualizations generated from the diary responses, inspired by Atman et al.'s work (8), serve as the basis for structured, data-informed reflection activities (2). Through these reflections, students use their Design Timelines to consider past actions in engineering design together with current outcomes. The intent of this data-informed approach is to inspire responsive and intentional future deployment of design activities as individuals and as teams.

Data-informed reflection can improve students' design work (9) and supports planning, execution, and evaluation (10–14). Activities involving reflection guide students as they make sense of new information and past practice (15–17). Reflective students challenge outcomes, seek justification, interrogate sources of failure, and identify areas for improvement (10,18). Reflection inspires reexamination of past outcomes and planning new paths forward that employ activities and mindsets from across the phases of engineering design. In this way, reflection during design has the potential to encourage intentional approaches and may result in improved deliverables (19). Since the quality of design deliverables and students' engineering identity are coupled to how well teams function, student reflection includes a focus on teamwork-aligned learning outcomes (2,20). As students consider their own contributions to their team's culture, there is an opportunity for them to consider and employ effective strategies, either from course instruction or experience, for shaping their teams' dynamics (21,22). Furthermore, reflecting on engineering practice creates opportunities for students to consider their evolving engineering identity. As students, together with their teams and instructors, celebrate their accomplishments and learn from their failures they are situated to account for their increased skill as engineers

(23–26). As students reflect on their practice, our hope and intent are that students gain confidence and knowledge as engineers. This gained confidence can translate to a strong sense of engineering identity which fosters learning (27) and improves grit and persistence (28).

This work-in-progress paper begins analyzing our data to understand the role played by a Design Diary and reflection activities in engineering design learning. Specifically, we ask: *to what extent does maintaining a design diary and engaging in data-centered reflection activities influence student learning and ability to function on a team, as well as impact students' sense of engineering identity*?

Methods

Context. We conduct our study in a first-year engineering design course, *Introduction to Engineering Design and Manufacturing*, at Harvey Mudd College, a liberal arts institution in California. This course has an introductory Physics class in Mechanics and a Writing course as prerequisites. Participants consist of students enrolled in the course (1,2). Enrolled students are typically in their first or second year and often select this class to explore engineering as their major. Students learn engineering design and manufacturing techniques, utilizing their learning to solve ill-defined problems on teams. Projects require both conceptual design and tangible, mechanical solutions for an external client. In addition to engineering design, students learn teamwork through activities centered in giving and receiving feedback, resolving conflict, and leadership. Teams create contracts, meeting agendas, and project management documents as they work through a one-day design sprint, a two-week partner design project, and a 12-week team design project. Study participation is voluntary.

Activity Implementation. Our previous paper describes the complete set of student learning outcomes (SLOs) (1). For this WIP paper, we analyze a subset of these items to gain insight into the impact of our work. These items include students' proficiency in engineering design, solving open-ended and ill-defined problems, revisiting previous design activities, ability to function effectively on a team, and their ability to give and receive feedback (see Table 1).

Table 1: Student Learning Outcome and Engineering Identity Measures (Selected from (1)*).*

Student Learning Outcomes
● Engineering Design ○ IDP: **i**mplement a **d**esign **p**rocess to solve engineering problems. ○ SEP: **s**olve open-ended and ill-structured **e**ngineering **p**roblems. ○ RDA: **r**ecognize when it is necessary to revisit **d**esign **a**ctivities to improve a solution. ● Teamwork ○ FET: **f**unction **e**ffectively on a **t**eam. ○ GRF: **g**ive and **r**eceive professional **f**eedback.
Student Engineering Identity
● Engineering Identity ○ SME: I **s**ee **m**yself as an **e**ngineer.

We partition our study into three phases, where each phase represents a unique semester, that include a phased deployment of activities (see

Table 2). This partitioning is described with the PHASE parameter in our analysis. Throughout each phase, all other instructional activities are constant. In Phase 1, we collect pre- and post-term survey data regarding self-assessment of SLOs and engineering identity. Phase 2 includes the addition of a Design Diary activity. Phase 3 adds individual and team reflection activities. We seek to understand the impact of these activities on student learning and identity development.

Each reflection activity is discussed in detail in our prior work (2). Briefly, the 30-minute individual reflection activity, completed on a biweekly basis, engages students in forming written responses regarding their past experiences in class, using the Design Timeline visualizations as reference material. Reflection prompts center on engagement with engineering design, design process phases and activities, and team dynamics. Students then make an action plan about how they will engage with engineering design and with their team over the next two-week period. The 30-minute team reflection, which happens on a biweekly basis and in opposite weeks as the individual reflection, is a structured conversation in which team members share and discuss experiences and dynamics before moving onto a collaborative planning period. A written summary of this conversation is discussed with the project advisor, along with the team's design work, during a biweekly meeting.

Table 2: Reflection Activity Deployment by Phase

Activity	Phase 1	Phase 2	Phase 3
Pre/post term survey	✓	✓	✓
Design diary		✓	✓
Reflection activities			✓

Data collection. We derive the data examined in this WIP from the Engineering Design Ability and the Engineering Identity and Belonging instruments, as previously reported (1). Students complete these surveys at the beginning and end of each term. The Engineering Design Ability instrument solicits students' responses as aligned with course specific SLOs. The Engineering Identity and Belonging instrument is based on other studies and primarily relies upon Godwin's work (29–32). Most SLOs, an engineering identity instrument, and students' written responses included in our data collection are not yet analyzed and will be included in a future study.

Through these surveys, students self-assess according to each SLO and measure of engineering identity and may write responses to provide context for their self-assessment. Student self-assessment has the potential to improve learning, establish student autonomy and judgement, and support self-regulation of learning (33,34) which are important characteristics to develop in this first-year course and consistent with the study goals. It must be considered that, despite these clear benefits, given students' newness to the discipline, their self-evaluations may be prone to bias and may not accurately represent their learning and growth (35). Future work includes a comparison of self-assessments to instructor evaluations to assess divergence in our case.

Students complete a Design Diary entry at the start of each class meeting, three times per week. Through the Design Diary activity, completed using a Qualtrics form and described in our prior work (1), students select the design phases, aligned with the Stanford d.school phases (36), to give students common language, and activities they have deployed since our last class meeting and includes a written response asking students about their engagement with the team and the extent to which students identify as an engineer given their recent work. Design Timeline visualizations are automatically generated, using Cloud Firestore, from students' Design Diary submissions. Prior to the 12-week team-based project, we train students to complete diary entries and to interpret the visualizations using the two-week design project. These visualizations are central to students' reflection activities and are accessed through a custom portal.

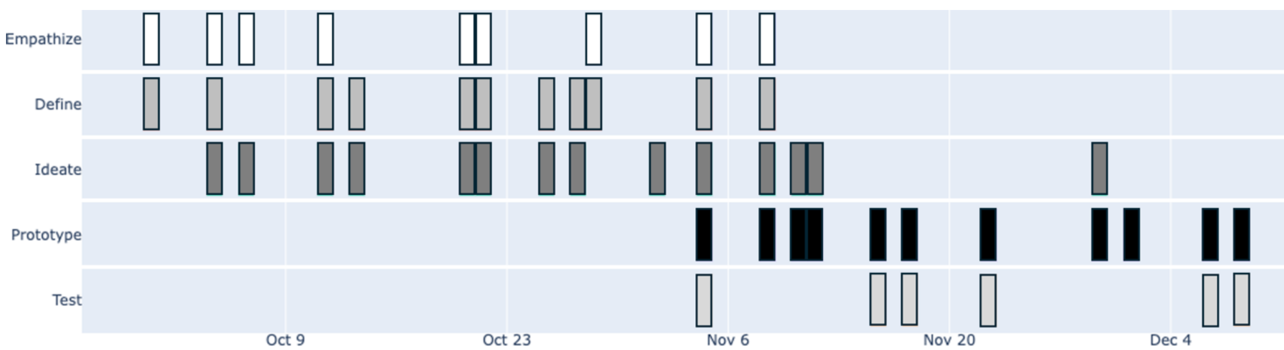

Figure 1: Sample Individual Design Timeline Visualization. This visualization demonstrates the design phase sequencing of an individual student. Grayscale shades represent each design phase.

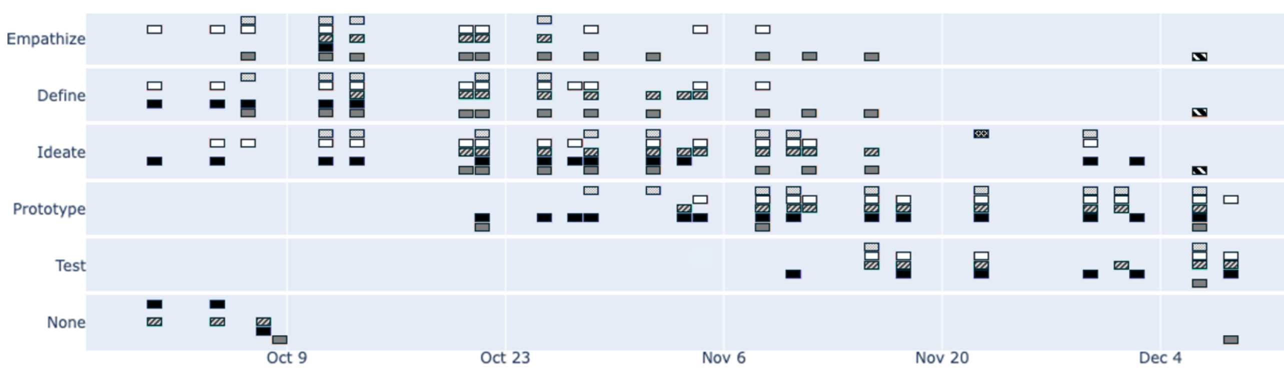

Figure 2: Sample Team Design Timeline Visualization. This visualization demonstrates the design process phase sequencing of a design team of 5 students. Grayscale shading represents individuals (and not a design phase as in Figure 1) and each row indicates each design phase. This visualization represents how the team has collectively deployed distinct design phases across the entire semester. None indicates that a given student reported having not completed any engineering design work since the last class meeting. This team's work spanned many design phases throughout the project with one student indicating engagement with empathize, define, and ideating near the end of the project.

Any student with incomplete pre- and post- survey data is excluded from analysis. Since we strive to create an inclusive culture and support students in achieving equitable outcomes through our courses and program, we additionally analyze outcomes as a function of student identity. Given the exclusion criterion, and our small class sizes, we mitigate the risk of identifying individual students by including an umbrella category for students' underrepresented minority (URM) status. All racial and ethnic variables were aggregated into a URM-identifying cohort where URM status includes students identifying as Black, American Indian or Alaska Native, Native Hawaiian or Pacific Islander, and Hispanic/Latiné. This approach gives us access to aggregated identity-aligned critical data while maintaining individual student anonymity. This is important as many students in our dataset identify as members of racial and ethnic groups with fewer than five members per study phase. Identities beyond racial and ethnic identities are not reported here given that there are fewer students than our requisite reporting threshold. The number of students for each identity status is uneven within and across each phase of the study (see Table 3).

Table 3: Total Students by Identity-Based Group Across PHASE

	URM-Identifying	non-URM-Identifying	Total Students
Phase 1	10	15	25
Phase 2	7	15	22
Phase 3	11	8	19

Data Analysis. We analyze changes in students' self-assigned scores (*ΔScore)*, calculated as the difference between the post- and pre-survey items, across each phase of this study, for each student-learning outcome and the singular engineering-identity measure as identified in Table 1. These measures are a subset of the full data collected and are selected as leading indicators. These data derive from Likert-scale questions and are analyzed using a two-factor Analysis of Variance (ANOVA) to identify statistically significant differences for each SLO. The factors include PHASE (Phase 1, 2, or 3) and URM status (identifies as a member of a racial or ethnic identity included in the URM category or does not). We employ a Tukey-Kramer post hoc test, with $\alpha=0.05$, to identify specific group pairwise differences. Furthermore, we perform a multiple comparison of means on ANOVA results to determine which estimates bear statistically significantly differences. For conditions of interest, we calculate the strength of association using omega squared (ω^2) and report this value as the percent of variation explained (PVE, $\omega^2 \bullet 100\%$). We expect that the diary and reflection activity (and thus PHASE) would result in growth in the engineering-design (IDP, SEP, and RDA) and teamwork (FET, GRF) SLOs and an increased sense of engineering identity (SME) because of the intentional reflection and discussion around approaches to team-based engineering design. We neither expect that URM-status nor the intersection of PHASE and URM-status will have an impact on student learning according to the stated SLOs and engineering identity because we anticipate that the implemented activity would inspire all students toward reflection.

Results

Analysis indicates that there are no statistically significant differences in students' changes in score (*ΔScore*) for each of the six measures for most factor combinations. The singular exception to this is the result for the SLO "solve open-ended and ill-structured engineering problems" (SEP). The ANOVA results for this learning outcome appear in Table 4. No other ANOVA results are reported given the lack of statistically significant differences in *ΔScore* values.

For the SEP SLO, $PVE_{PHASE}\approx 14.9\%$, $PVE_{URM}\approx 1.24\%$, and $PVE_{PHASE\times URM}\approx 4.63\%$. A comparison of means analysis indicates that there is a statistically significant difference between (1) URM-identifying students in Phase 1 (no Design Diary, no Reflection Activities) and URM-identifying students in Phase 2 (Design Diary, but no Reflection Activities) with $p\approx 0.017$, and (2) URM-identifying students in Phase 1 (no Design Diary, no Reflection Activities) and URM-identifying students in Phase 3 (Design Diary and Reflection Activities) with $p\approx 0.012$ as represented in Figure 3 and indicated in Table 5.

Table 4:ANOVA Results for the Solve Engineering Problems (SEP) SLO

SEP	***Sum of Squares***	***df***	***MS***	***F***	***p value***
PHASE	13.51	2	6.7549	6.7814	0.002212
URM	0.038606	1	0.038606	0.038757	0.8446
PHASE×URM	5.5797	2	2.7898	2.8008	0.068725
Error	59.765	60	0.99609		
Total	76.485	65			

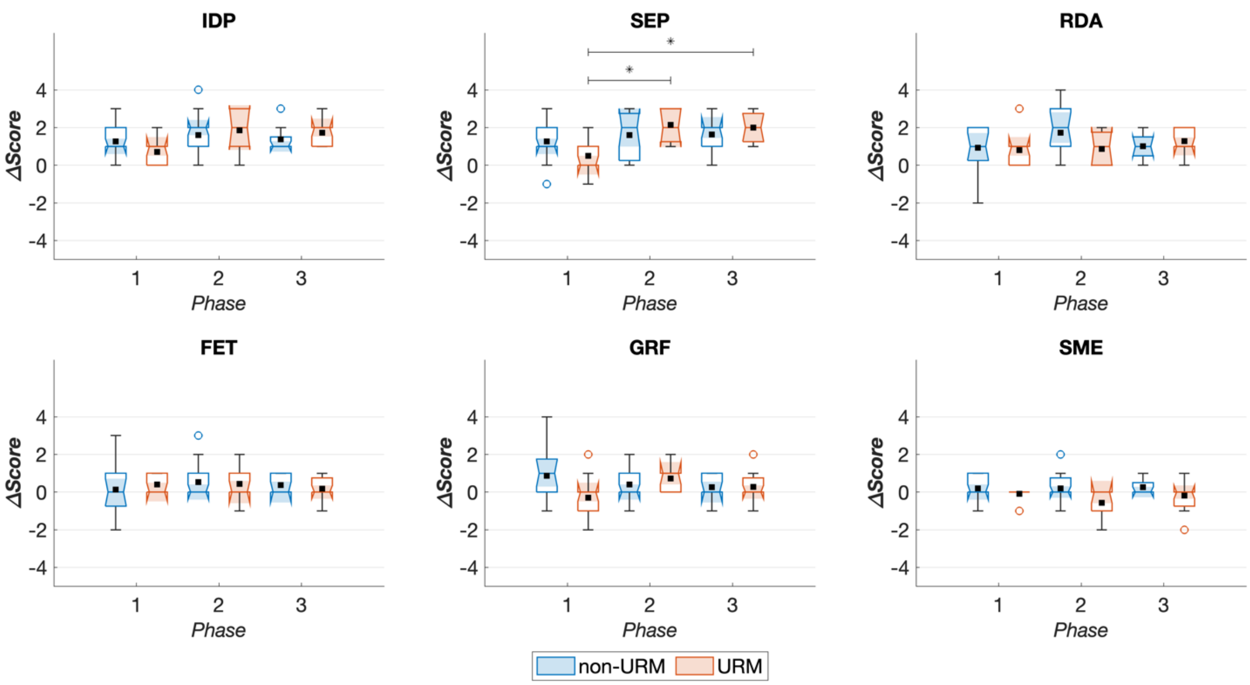

*Figure 3: ΔScore Outcomes by Phase and URM-status for each student learning outcome and one measure of engineering identity. Box charts show the median, the lower and upper quartiles, and any outliers (indicated with hollow circles) in red for URM-identifying students and in blue for non-URM-identifying students. Each box chart is overlayed with the mean (indicated with black squares) for each combination of factors. The figure indicates with * statistically significant differences (p<0.05) in students score differences, between the pre- and post-survey, for Phase 1 (no activities under study), Phase 2 (Design Diary Activity), and Phase 3 (Design Diary, Reflection Activities).*

Table 5: Excerpt of statistically significant results from a multiple comparison of means analysis on SEP (for URM-identifying students only).

Comparison Pair		***Mean Difference (MD)***	***MD Lower***	***MD Upper***	***p value***
Phase 1	Phase 2	-1.6429	-3.0907	-0.19498	0.017279

Phase 1	Phase 3	-1.5000	-2.7837	-0.21628	0.012996
Phase 2	Phase 3	0.14286	-1.2777	1.5634	0.99968

Discussion

The goal of this work in progress is to gain an initial understanding of the role played by (1) maintaining a Design Diary and (2) engaging in data informed individual- and team-based reflections on students' self-assessed growth in a first-year engineering design course. We interrogate our results through the question: *to what extent do data-centered reflection activities influence student learning and ability to function on a team, as well as impact students' sense of engineering identity*? As these activities are currently executed, the results indicate that the diary and individual- and team-based reflection activities neither had a significant impact on students' perceived growth in learning engineering design, nor on their ability to function on teams, nor on their engineering identity.

The student learning outcome *solve open-ended and ill-structured engineering problems (SEP)* is the only measure of note in this examined set. Given the lack of statistically significant differences between Phase 2 (Design Diary, but no Reflection Activities) and Phase 3 (Design Diary and Reflection Activities), these data (Table 5) suggest that, for URM-identifying students, completing the Design Diary activity may have affected students' self-assessed growth in solving engineering problems. By extension, it does not appear as if completing the structured reflection activities, as designed, impacted students' self-assessed growth in solving engineering problems. One possible reason for this result may be that students, by reporting their data at the start of class, resituate themselves in their prior actions thus establishing a foundation for intentional next steps. In this way, reflection may be a natural response without additional benefits from an activity prompting such reflection. Even though there are statistically significant differences in the means for SEP across phases of this study, the low percent of variance expected, less than 15% for each factor, suggests that the impact of this activity on student learning is small and that the results are influenced by complex factors not controlled or accounted for in this work. It is important to note that our data do not indicate the same impacts on student growth for students who do not identify as being members of an underrepresented group. Although the mechanism by which the Design Diary impacts URM-identifying students' growth in solving engineering problems is yet unknown, this result together with the students' net decreased means in response to the identity item *I see myself as an engineer* is notable and requires future attention and action.

For the other SLOs indicated in Table 1, the consistency in students' self-reported perceptions of their learning across each phase suggests that any growth for learning outcomes is derived from the project-based, studio format of the first-year engineering design course and not the implemented activity. As indicated in Figure 3, we observe notable growth in students' ability to *implement a design process to solve engineering problems* (IDP), which like the SLO *solve open-ended and ill-structured engineering problems* (SEP), is central to instruction in this course. We observe limited growth for students' ability to *recognize when it is necessary to* *revisit design activities to improve a solution* (RDA) which is a core motivation of this work. Similarly, we observe effectively no growth in both students' ability to *function effectively on a team* (FET) and *give and receive professional feedback* (GRF). For these teamwork SLOs this stagnation is consistent across each study phase. This lack of self-assed growth, across each of the SLOs, could be indicative of students' high initial self-assessments and is a risk of our student-reported data collection approach. Regardless of the cause, these results indicate that there are significant opportunities to better serve our students with respect to these SLOs; thus, we must carefully consider and develop future instruction in consultation with our students.

Consequently, the Design Diary and reflection activities, as currently implemented, appear to effectively have no discernable impact on learning, ability to function on a team, and engineering identity. This may be because the course, as implemented, requires students to consistently iterate on deliverables to create solutions to real clients' real problems. Thus, students are likely already reflexively reflecting on their practice as designers on teams and on the engineering deliverables they create. This reality likely undergirds their perception that they are better equipped to solve engineering problems by the end of the course. While we celebrate the areas corresponding to student self-assessed growth and seek opportunities to improve where self-assessed growth is missing, this outcome does not afford us insight in how to structure reflection activities to support students' development as engineers. Additional analysis of the full dataset and comparison to expert evaluation are needed.

We are unsatisfied with the current results for engineering identity (SME). Our data indicate limited growth for students who are not URM-identifying and a decreased sense of identity for URM-identifying students upon completing the course. These outcomes are independent of the study phase. While there aren't any statistically significant pairwise differences amongst these results, the negative means for URM-identifying students is alarming and requires immediate attention as it points to a need for immediate change with respect to inclusion and equity in each of our course, program, and institution. We expect that if students perceive that they are better equipped and able to solve engineering problems that would inspire an enhanced sense of engineering identity. This introductory design course is taken by students during early in their undergraduate career and is their first exposure to engineering in the program. Given the time point at which this course is taken, it is possible that students only see themselves as engineers to a small degree or that as they learn more about engineering there could be a misalignment between their prior conceptions of engineering and their newly acquired knowledge of the field that could challenge their engineering identity. It is also possible that negative interactions on teams negatively impact their engineering identity. This outcome could decrease the degree to which they see themselves as engineers. We anticipate analyzing the full set of SLOs and engineering identity measures along with qualitative data sourced from diary entries and reflection activities. This analysis may provide insight for activity redesigns. There is an opportunity to further develop students' engineering identity in the context of this course. One immediately actionable and valuable but still insufficient opportunity is for instructors and students to co-cultivate a culture of celebration regarding students' advancement through their journey of becoming engineers. In this way, students can embrace the not-yet state of their development while also recognizing that there will always be future growth throughout their professional lives.

Conclusions

This work-in-progress paper seeks to address the extent to which diary and reflection activities influence student learning in engineering design, their ability to function on a team, and their engineering identity. We found effectively no additional impacts on any of these items that derive from the reflection activities. This could be, in part, because of the reflection and iteration innate to the course's current structure as realized through practice in engineering design. This could also stem from the reliance on self-assessed learning and growth. The singular exception to this narrative is the impact of maintaining Design Diaries on URM-identifying students' enhanced ability to solve engineering problems. Additional analysis is necessary to fully understand the impact of these activities. Future work includes comparison of these results, derived from students' self-assessed growth, with SLO-aligned instructor evaluations to understand and benchmark students' scores and perceptions. Beyond analysis, the current results indicate that the course cultivates students' abilities and knowledge in engineering design but fails to both effectively enhance students' ability to function effectively on teams and to develop their engineering identity. These shortcomings must be met with intentional and sustained instructional innovations both within our course and across our curriculum. Any future developments should generate solutions while looking through the lens of student experience, with a goal to better prepare students to be technically excellent, iterative, collaborative, empathetic, and confident engineers.

References

1. Santana S. Instrumentation for Evaluating Design-learning and Instruction Within Courses and Across Programs. In: 2021 ASEE Virtual Annual Conference Content Access. 2021.

2. Sanchez A, Blake LP, Chen D, Jones M, Mao S, Mendelson L, et al. Building Better Engineers: Critical Reflection as a High Impact Practice in Design Learning. In: 2022 ASEE Annual Conference \& Exposition. 2022.

3. McNair TB, Bensimon EM, Malcom-Piqueux L. From equity talk to equity walk: Expanding practitioner knowledge for racial justice in higher education. John Wiley & Sons; 2020.

4. Newstetter WC, Michael McCracken W. Novice Conceptions of Design. In: Design Knowing and Learning: Cognition in Design Education. Elsevier; 2001. p. 63–77.

5. Taneri B, Dogan F. How to learn to be creative in design: Architecture students' perceptions of design, design process, design learning, and their transformations throughout their education. Think Skills Creat. 2021 Mar 1;39:100781.

6. Dym CL, Agogino AM, Eris O, Frey DD, Leifer LJ. Engineering Design Thinking, Teaching, and Learning. Journal of Engineering Education. 2005 Jan 1;94(1):103–20.

7. Hatano G, Oura Y. Commentary: Reconceptualizing School Learning Using Insight From Expertise Research. Educational Researcher. 2003 Nov 1;32(8):26–9.

8. Atman CJ, Chimka JR, Bursic KM, Nachtmann HL. A comparison of freshman and senior engineering design processes. Des Stud. 1999;20(2):131–52.

9. Di Stefano G, Pisano G, Staats BR. Learning by thinking: How reflection aids performance. In: Academy of Management Proceedings. 2015. p. 12709.

10. Turns J, Shroyer K, Lovins T, Atman C. Understanding Reflection Activities Broadly. In: 2017 ASEE Annual Conference & Exposition Proceedings. ASEE Conferences; 2017.

11. Turns J, Sattler B, Yasuhara K, Borgford-Parnell J, Atman C. Integrating Reflection into Engineering Education. In: 2014 ASEE Annual Conference & Exposition Proceedings. ASEE Conferences; 2014. p. 24.776.1-24.776.16.

12. Ash SL, Clayton PH. Generating, Deepening, and Documenting Learning: the Power of Critical Reflection in Applied Learning. Vol. 1, Journal of Applied Learning in Higher Education. 2009.

13. Kolb DA. Lifelong Learning and Integrative Development. Experiential learning : experience as the source of learning and development. Upper Saddle River, New Jersey : Pearson Education Inc.,; 2015. 346 p.

14. Schon DA. The reflective practitioner: How professionals think in action. Vol. 5126. Basic books; 1984.

15. Bostock SJ. Constructivism in mass higher education: a case study. British journal of educational technology. 1998;29(3):225–40.

16. Cook-Sather A. Returning to the mirror: reflections on promoting constructivism in three educational contexts. Cambridge Journal of Education. 2008;38(2):231–45.

17. Wu Y, Ming Z, Allen JK, Mistree F. Evaluation of Students' Learning Through Reflection on Doing Based on Sentiment Analysis. Journal of Mechanical Design. 2023;145(3).

18. Helyer R. Learning through reflection: the critical role of reflection in work-based learning (WBL). Journal of Work-Applied Management. 2015 Oct 6;7(1):15–27.

19. Safoutin MJ. A methodology for empirical measurement of iteration in engineering design processes. University of Washington; 2003.

20. Lewis P, Aldridge D, Swamidass PM. Assessing teaming skills acquisition on undergraduate project teams. Journal of Engineering Education. 1998;87(2):149–55.

21. Hirsch PL, McKenna AF. Using reflection to promote teamwork understanding in engineering design education. International Journal of Engineering Education. 2008;24(2):377.

22. Bhavnani SH, Aldridge MD. Teamwork across disciplinary borders: A bridge between college and the work place. Journal of Engineering Education. 2000;89(1):13–6.

23. Eliot M, Turns J. Constructing professional portfolios: Sense-making and professional identity development for engineering undergraduates. Journal of Engineering Education. 2011;100(4):630–54.

24. Liptow EE, Chen KC, Parent R, Duerr J, Henson D. A sense of belonging: creating a community for first-generation, underrepresented groups and minorities through an engineering student success course. In: 2016 ASEE Annual Conference \& Exposition. 2016.

25. Davishahl J, Alqudah S. Investigation of Sense of Belonging to Engineering in Introductory-Level Pre-Engineering Classes. In: 2020 ASEE Virtual Annual Conference Content Access. 2020.

26. Dishon N, Oldmeadow JA, Critchley C, Kaufman J. The effect of trait self-awareness, self-reflection, and perceptions of choice meaningfulness on indicators of social identity within a decision-making context. Front Psychol. 2017;2034.

27. Allie S, Armien MN, Burgoyne N, Case JM, Collier-Reed BI, Craig TS, et al. Learning as acquiring a discursive identity through participation in a community: Improving student learning in engineering education. European Journal of Engineering Education. 2009;34(4):359–67.

28. Verdín D, Godwin A, Kirn A, Benson L, Potvin G. Understanding How Engineering Identity and Belongingness Predict Grit for First-Generation College Students. School of Engineering Education Graduate Student Series. 2018 Apr 1;

29. Godwin A. The development of a measure of engineering identity. In: ASEE Annual Conference & Exposition [Internet]. 2016. Available from: https://par.nsf.gov/biblio/10042227

30. Godwin A, Lee W. A Cross-sectional Study of Engineering Identity During Undergraduate Education. ASEE Peer [Internet]. 2017 Jun 24 [cited 2021 Jan 27];2017-June. Available from: https://docs.lib.purdue.edu/enepubs/13

31. Choe NH, Borrego M. Prediction of Engineering Identity in Engineering Graduate Students. IEEE Transactions on Education. 2019 Aug 1;62(3):181–7.

32. Hamlet LC, Roy A, Scalone G, Lee R, Poleacovschi C, Kaminsky J. Gender and Engineering Identity among Upper-Division Undergraduate Students. Journal of Management in Engineering. 2021 Mar 26;37(2):04020113.

33. Kaul S, Adams RD. Learning Outcomes of Introductory Engineering Courses: Student Perceptions. In: 2014 ASEE Annual Conference & Exposition. 2014. p. 24–854.

34. El-Maaddawy T. Innovative assessment paradigm to enhance student learning in engineering education. European Journal of Engineering Education [Internet]. 2017;42(6):1439–54. Available from: https://doi.org/10.1080/03043797.2017.1304896

35. Ross M, Fosmire M, Wertz REH, Cardella M, Purzer S. Lifelong learning and information literacy skills and the first year engineering undergraduate: Report of a self-assessment. 2011;

36. Meinel C, Leifer L, Plattner H. Design thinking: Understand-improve-apply. Springer; 2011.