The Future of Engineering Education
2024 Annual Conference & Exposition
Oregon Convention Center
Portland, OR . June 23 - 26, 2024
Paper ID #41896

Board 164: Exploring Coaches' Use of Engineering Notebooks in the FIRST LEGO League Challenge Robotics Competition (Work in Progress)

Mr. Michael Graffin, Curtin University of Technology

Michael Graffin is an experienced, International Society for Technology Education award-winning STEM educator and sessional academic in the Curtin University School of Education, in Perth, Western Australia. He is currently completing a PhD research project examining the use of scaffolded engineering notebooks to scaffold students' development of 21st-century collaboration and communication skills.

Rachel Sarah Sheffield, Curtin University of Technology
Rekha Bhan Koul

Exploring coaches' use of engineering notebooks in the FIRST LEGO League Challenge robotics competition (Work-in-Progress)

Introduction

The *FIRST LEGO League (FLL) Challenge* is one of the world's largest pre-college educational robotics competitions, involving over 225 300 students (aged 9-16) from 92 countries [1]. Educational robotics competitions are typically designed to support students' development of 21st Century skills through their application of real-world engineering practices to collaboratively design solutions to real-world problems, such as transportation logistics, space exploration, and urban design [2], [3]. *FLL Challenge* participation has significant, positive short-term impacts on students' development of 21st Century problem-solving, collaboration, and communication skills, which are highly valued in professional engineering disciplines and communities of practice [3], [4], [5]. There is compelling evidence that *FLL Challenge* participation influences students' future engagement in engineering and computer science college education and careers; however, there is a gap in the literature regarding effective pedagogical strategies to support students' knowledge construction and skill development during the competition learning experience [3], [4].

Research conducted in pre-college classroom learning environments suggests that educators' design and implementation of scaffolded engineering notebooks as epistemic learning artifacts may support students' knowledge construction and collaborative engagement in engineering design and STEM project-based learning [6], [7], [8]. Engineering notebooks are used in real-world engineering contexts, and their educational implementation is grounded in social-constructivist and constructionist learning theories [9], [10], [11]. This work-in-progress paper presents the preliminary findings of an ongoing qualitative multiple case-study project undertaken in Perth, Western Australia aimed at developing a coaching resource and engineering notebook template for new *FLL Challenge* robotics teams.

Literature Review

Engineering professionals draw upon disciplinary-specific or epistemic ways of knowing, designing, decision-making, collaboration, and communication within their social and cultural context [5]. These are reflected in their use of specific tools and approaches while problem-solving, modelling, prototyping, evaluating, and sharing design solutions [5], [12], [13]. Many engineers use notebooks or design journals to document their knowledge construction and reflections as they engage in the engineering design process and communicate with various audiences [9], [13], [14]. Engineers learn how to use these notebooks through a process of apprenticeship within their professional community of practice and practical experience [5], [9], [12], [13], [15]. As such, the notebook can be considered an epistemic tool or artifact which both shapes and is shaped by the knowledge, design activities, and discourse of its users within their context [5], [7], [13], [15], [16].

The design and pedagogical implementation of engineering notebooks in pre-college educational environments is the subject of ongoing research. There are two types of engineering notebooks commonly used in educational contexts [14]. The first, the process notebook, is a "living document" used by individuals and/or teams to document or record their thinking, notes, decision-making, prototyping, and testing during the engineering design process [14, p. 2], [17]. This is very similar to the use of process notebooks in professional engineering contexts [14]. The second type, the product notebook, is a formal, curated record of the problem, prototypes, and final design solution [9], [14]. Developed through a process of discussion, synthesis, and reflection, product notebooks are used to support the design team's communication with external audiences, often for summative assessment [14], [16], [17]. In real-world contexts, companies create product engineering notebooks for marketing and intellectual property purposes [14].

A key difference between industry and educational engineering notebooks is the degree of structure provided to guide their users' understanding of what information to include. While industry notebooks are typically blank, research suggests that the integration of age-appropriate prompt questions and graphic organiser scaffolds in educational engineering notebooks helps teachers structure their lessons and supports students' learning and development of epistemic engineering practices [8], [13], [18], [19]. Impacts on students' learning outcomes are highly dependent on teachers establishing explicit expectations for notebook use through their teaching, learning, and assessment routines; however, they need to carefully balance and adjust their scaffolding over time to promote team autonomy [6], [13], [18], [19]. While it is important to embed notebook use into team communication and collaboration routines, relying on verbally prompting students' discussions around notebook scaffolds does not necessarily result in effective written documentation and reflection, especially during hands-on, time-intensive engineering design activities [13], [19], [20], [21]. The use of process notebooks for formative assessment and facilitating teams' reflective development of product notebooks to prepare for oral presentation summative assessments, may promote more effective documentation practices [7], [22]. Finally, the design and development of digital or app-based engineering notebook tools for educational use are the subject of ongoing research [7], [23].

Purpose of Paper

To date, there has been limited exploration of the design and implementation of engineering notebooks in informal pre-college learning environments [24], [25], and their use in educational robotics competitions is not well understood. This work-in-progress paper reports on the preliminary findings of an ongoing study examining the design and pedagogical integration of engineering notebooks in the context of the *FLL Challenge*. An anticipated outcome of the study will be the publication of teaching and learning resources to support new *FLL Challenge* teams, and it is expected that these resources could be adapted to support students' engagement in educational robotics activities in formal classroom environments.

Research Question

How do coaches design and use engineering notebooks to support their students' engagement and learning in the *FLL Challenge* robotics competition?

Methodology

This study adopted an interpretivist multiple case-study methodology, and explored the lived experience of *FLL Challenge* coaches and students using engineering notebooks during the 2021, 2022, and 2023 competition seasons [26], [27]. It was conducted in two phases, and involved a total of 8 teams, 8 coaches, and 53 students across 6 case-study sites in Perth, Western Australia. The case studies are based on extensive data collection from multiple sources, including pre- and post-season semi-structured interviews with coaches and student teams, naturalistic semi-structured observations, and engineering notebook work samples [27], [28]. The first author used *NVivo* software to conduct qualitative thematic content analysis, systematically creating descriptive codes to analyse data across multiple sources and cases, before organising these codes into categories and descriptive themes (findings) [29], [30]. These themes were triangulated and extensively discussed and refined over time by all authors [31]. They remain work-in-progress as the full cross-case analysis (including the Phase 2 case-studies) and member-checks have not yet been formally completed [28], [32].

This paper specifically focuses on the findings of one of three Phase 1 case studies examined between August and early December 2021. This case was purposefully selected for this paper due to its setting in a family home-school learning environment, and it being the only Phase 1 case to involve female students and students with special needs. The participants included Claire and Eleanor (parents and coaches), and 7 of their combined 8 children (3 male, 4 female, aged 9-15), competing as the *Logistics Crew* during the 2021 *FLL Challenge CARGO CONNECT* season. Both coaches, and four of the students, had one year's prior competition experience. The team included several neurodiverse members, including two gifted students and one autistic student. The study was situated in a metropolitan family home, with students working in the living room and around the robot game board set up in the backyard. The participating coaches were invited to contribute to the development of a draft engineering notebook resource created by the first author, which included scaffolded discussion prompt questions, success criteria, and suggestions for what evidence to include for competition judging. Following Phase 1 data analysis, this resource was heavily revised and trialled in Phase 2 of the study, conducted during the 2022 and 2023 competition seasons.

Preliminary Findings

Coaches' prior competition experience informed their instructional use of process and product engineering notebooks in the *FLL Challenge* competition.

Claire and Eleanor described their first year coaching the *FLL Challenge* in their home-school learning environment in 2020, a year prior to this study, as "*the blind leading the blind*". While they did not use engineering notebooks in their first competition season, the coaches realised a need for team documentation after an incident where a student made erroneous, undocumented changes to the robot programming without consulting with his team members. Describing this incident as a "*teachable moment*", the coaches encouraged the students to keep printed screenshots and handwritten notes about their code and robot design changes. These were loosely organised in shared plastic file folders, alongside notes and drawings relating to the team's innovation project and team logo designs. The coaches and students didn't realise the importance of this documentation until their judges asked to review it after the students mentioned it in their official tournament judging interview.

As part of their participation in this study during the *2021-22 CARGO CONNECT* season, the coaches took inspiration from "*the idea and the concept"* of an engineering notebook, and supported their students' use of unstructured, individual (process) notebooks to document team activities, learning, and reflections. They chose not to use the official FIRST *Engineering Notebook* [33] or the draft engineering notebook resource provided by the first author, as they believed these didn't suit their neurodiverse children's learning needs. During team meetings, students were routinely observed handwriting or drawing meeting notes in physical exercise books with lined pages, although some team members used laptops or tablets. The coaches explained that the use of digital tools was influenced by students' preferences, special needs (e.g., hypermobility), and their familiarity with typing and word-processing programs. Claire often scribed key ideas and modelled correct spelling for notetaking of team discussions on a small whiteboard, supporting the younger and reluctant writers. Both coaches monitored and formatively assessed students' notebooks, and several weeks into the season, they began to explicitly allocate time within team meetings for the students to write/draw their research notes and to record their assigned homework tasks. This typically occurred halfway through team meetings following coach-facilitated innovation project activities, and before the team moved onto more independent, student-directed robot design and programming activities in the backyard.

Claire and Eleanor were routinely observed asking guided questions to encourage students' articulation and reflection of what evidence should be included in their notebooks. These questions were informed by the coaches' understanding of the tournament judging process, but they stressed that they wanted the children to make their own decisions about what to include. This was reflected in how Claire facilitated the team's curation of a product notebook for tournament judging in the final weeks of the competition season. Following her suggestion, each team member sat down with Kevin (a team leader and a strong writer) to discuss what information was important to share with the judges. Kevin created a colourful product notebook in *Microsoft Word*™, typing up his team members' contributions based on their verbal conversations and process notebook entries. He also included robot photos, code screenshots, drawings, a robot game mission strategy planning spreadsheet, and team members' personal reflections on their perceived teamwork and communication skill development during the competition season. Entries were dated and colour coded to illustrate individual contributions to the product notebook. Claire later reported that the tournament judges were very impressed with the team's documentation.

Coaches' understanding of instructional scaffolding informed the structure, format, and design of their engineering notebook.

The home-school coaches' use of individual unstructured notebooks and extensive use of verbal scaffolding or questioning reflected the instructional and assessment strategies they routinely used in their home-school learning environments. Reflecting on their implementation of engineering notebooks at the end of the 2021 *FLL Challenge* season, Claire found that the notebooks had been "*a very good tool for recording and diarising*" team activities, especially for documenting their development of an RFID parcel tracking and delivery innovation project solution to address the real-world problem of parcel theft, aligning with the competition's cargo transportation theme. Claire was especially pleased to see that the engineering notebooks had elicited meaningful contributions from every student, including a particular student with social challenges who often withdrew into herself and refused to talk or engage with her team members. Claire noted that it had been challenging to support students' use of the notebooks as "*a tool for engineering*", particularly for recording their robot design and programming changes over time. She found that providing "*a blank page*" had created some confusion about what to include in the notebook, and that verbally prompting students to document technical changes had not been especially effective.

Reflecting on their 2021 season experience, both coaches recommended the integration of written and visual graphic organiser scaffolds in the design of an engineering notebook template for new *FLL Challenge* teams. Claire proposed a paper-based design inspired by a "*botany book*", incorporating blank pages for drawing or sketching robot designs, and lined sections for the students to respond to written reflection prompt questions at the end of team meetings, such as "*What do you need to look at next? What did you do today? … What is it that worked? What didn't work? What do you need to do for next time?*" Eleanor gave very similar suggestions, emphasising the need to offer students the choice of paper-based or digital notebook scaffolds to support the inclusion of children with special needs. She recommended including a scaffold for recording and tracking the completion of team tasks and suggested organising the notebook into sections for the innovation project, robot design, and core values (teamwork), aligning with the official *FLL Challenge* judging process.

Discussion

The findings of this case-study are similar to those of engineering design and STEM education case-studies in formal classroom learning environments. During the 2021 *FLL Challenge* competition season, the home-school coaches employed both process and product notebooks to support students' learning, collaboration, and individual documentation of their team activities and engineering design processes [14], [19]. The notebook became an artefact documenting students' engagement, problem solving, and collaboration during the competition, and it was used to support the team's communication with their tournament judges [7], [16], [20]. The coaches employed verbal guided questioning, and provided time during team meetings for students to document their team-building tasks and innovation project processes [13], [19]. While coaches routinely verbally prompted students to document their robot design, building, and programming processes and changes, these hands-on, time-intensive activities were poorly documented [19], [20]. In their post-season reflections, the coaches identified the integration of visual or written scaffolds, and the explicit allocation of time for written reflection at the end of team meetings, as potential strategies to support students' more effective use of engineering notebooks in the informal robotics competition learning environment [8], [13], [20], [21]. Coaches' perceptions of the purpose and utility of the engineering notebook, particularly the product notebook, were informed by their prior coaching experience and observations of tournament judging [7], [14].

Conclusion

The design and implementation of engineering notebooks to support pre-college students' learning and development of collaboration, communication, and documentation skills within the informal *FLL Challenge* robotics competition learning environment is a complex and challenging undertaking. While the design, format, and structure of the engineering notebook are important, so too are the instructional strategies coaches and teachers employ to support their students' collaboration and communication using engineering notebooks within their particular social, cultural, and educational context.

Limitations

By their nature, case-studies are context specific, and this work-in-progress paper explores how the thematic findings from three Phase 1 case-studies are reflected in a single home-school context. The next step will be the completion of a full cross-case analysis of all six case-studies which include primary (elementary) and secondary education contexts.

Acknowledgements

We are deeply grateful to our case-study coaches and students for sharing their time and experience with us.

References

[1] For Inspiration and Recognition of Science and Technology (FIRST), "FIRST annual impact report: More than robots," 2022. [Online]. Available: https://firstinspiresst01.blob.core.windows.net/annual-report/annual-report/first-fy22-annual-impact-report.pdf

[2] S. Evripidou, K. Georgiou, L. Doitsidis, A. A. Amanatiadis, Z. Zinonos, and S. A. Chatzichristofis, "Educational robotics: Platforms, competitions and expected learning outcomes," *IEEE Access,* vol. 8, pp. 219534-219562, 2020, doi: 10.1109/ACCESS.2020.3042555.

[3] M. Graffin, R. Sheffield, and R. Koul, "'More than robots': Reviewing the impact of the FIRST LEGO league challenge robotics competition on school students' STEM attitudes, learning, and twenty-first century skill development," *Journal for STEM Education Research,* vol. 5, no. 3, pp. 322-343, 2022/12/01 2022, doi: 10.1007/s41979-022-00078-2.

[4] C. Burack, A. Melchior, and M. Hoover, "Do after-school robotics programs expand the pipeline into STEM majors in college?," *Journal of Pre-College Engineering Education Research,* vol. 9, no. 2, pp. 85-97, 2019, doi: 10.7771/2157-9288.1244.

[5] G. Kelly and C. Cunningham, "Epistemic tools in engineering design for K-12 education," *Science Education,* vol. 103, no. 4, pp. 1080-1111, 2019, doi: 10.1002/sce.21513.

[6] L. English and D. King, "STEM integration in sixth grade: Designing and constructing paper bridges," *International Journal of Science and Mathematics Education,* vol. 17, no. 5, pp. 863-884, 2019/06/01 2019, doi: 10.1007/s10763-018-9912-0.

[7] K. B. Wendell, C. J. Andrews, and P. Paugh, "Supporting knowledge construction in elementary engineering design," *Science Education,* vol. 103, no. 4, pp. 952-978, 2019, doi: 10.1002/sce.21518.

[8] S. Tientongdee and K. Ficklin, "How engineering notebook supporting Thai elementary student practice in STEM learning," *Journal of Physics: Conference Series,* vol. 1835, 2021, Art no. 012041, doi: 10.1088/1742-6596/1835/1/012041.

[9] T. Kelley, "Engineer's notebook- A design assessment tool," *Technology and Engineering Teacher,* vol. 70, no. 7, pp. 30-35, 2011.

[10] L. Vygotsky, *Thought and language*. Cambridge: The MIT Press, 1986.

[11] S. Papert, "Situating constructionism," in *Constructionism*, S. Papert and I. Harel Eds. Norwood, N.J.: Ablex Publishing Corporation, 1991, ch. 1.

[12] C. Cunningham and G. Kelly, "Epistemic practices of engineering for education," *Science Education,* vol. 101, no. 3, pp. 486-505, 2017, doi: 10.1002/sce.21271.

[13] J. Hertel, C. Cunningham, and G. Kelly, "The roles of engineering notebooks in shaping elementary engineering student discourse and practice," *International Journal of Science Education,* vol. 39, no. 9, pp. 1194-1217, 2017, doi: 10.1080/09500693.2017.1317864.

[14] L. Berland, W. McKenna, and S. Peacock, "Understanding students' perceptions on the utility of engineering notebooks," *Advances in Engineering Education,* vol. 3, no. 2, pp. 1-21, 2012.

[15] E. Wenger, "Communities of Practice and Social Learning Systems," *Organization,* vol. 7, no. 2, pp. 225-246, 2000, doi: 10.1177/135050840072002.

[16] T. Kelley, "Construction of an engineer's notebook rubric," *Technology and Engineering Teacher,* vol. 73, no. 5, pp. 26-32, 2014.

[17] K. A. Douglas, T. J. Moore, and H. E. Merzdorf, "Informed designers? Students' reflections on their engineering design process," *International Journal of Education in Mathematics, Science and Technology,* vol. 6, no. 4, pp. 443-459, 2018, doi: 10.18404/ijemst.440347.

[18] K. Taylor and Y. Baek, "Collaborative robotics: More than just working in groups," *Journal of Educational Computing Research,* vol. 56, no. 7, pp. 979-1004, 2018, doi: 10.1177/0735633117731382.

[19] H. Merzdorf, A. Johnston, K. Douglas, and T. Moore, "Teacher implementation of structured engineering notebooks in engineering design-based STEM integration units (Fundamental),"

presented at the ASEE Annual Conference & Exposition, Atlanta, June 23-27, 2018, Paper Presentation. [Online]. Available: https://doi.org/10.18260/1-2--31044.
[20] P. Brady and J. Rushing, "Using engineering design notebooks to evaluate student understanding of physics concepts in a design challenge," presented at the ASEE Annual Conference and Exposition, New Orleans, June 26-29, 2016, Paper Presentation. [Online]. Available: https://doi.org/10.18260/p.27142.
[21] K. Bergsman, "The 'structured' engineering design notebook: A new tool for design thinking within a studio.," presented at the ASEE Annual Conference & Exposition, Salt Lake City, Utah., June 24-27, 2018, Paper Presentation. [Online]. Available: https://doi.org/10.18260/1-2--31076.
[22] K. B. Wendell and C. Andrews, "Elementary student engagement with digital engineering notebook cards (Fundamental)," presented at the ASEE Annual Conference & Exposition, Columbus, Ohio, June 25-28, 2017, Paper Presentation. [Online]. Available: http://doi.org/10.18260/1-2--28212.
[23] J. Han, H. K. Park, and T. R. Kelley, "Engineer's notebook as a cognitive device: Developing a realtime collaborative engineer's notebook iOS application," (in English), *Technology and Engineering Teacher,* vol. 82, no. 5, pp. 20-26, 2023.
[24] B. Larkins, C. Moore, L. Rubbo, and L. Covington, "Application of the cognitive apprenticeship framework to a middle school robotics camp," presented at the Proceeding of the 44th ACM technical symposium on computer science education, Denver, Colorado, USA, 2013, Paper Presentation. [Online]. Available: https://doi.org/10.1145/2445196.2445226.
[25] M. Dunham, J. Deboer, D. Radhakrishnan, and N. Brhide, "Teacher and student perception of engineering design notebook utility," presented at the ASEE Annual Conference & Exposition, Balitmore, June 25-28, 2023, Paper Presentation. [Online]. Available: https://strategy.asee.org/44402.
[26] L. Cohen, L. Manion, and K. Morrison, *Research methods in education*, 8th ed. London, UK: Taylor & Francis, 2017.
[27] S. Merriam and E. Tisdell, *Qualitative research: A guide to design and implementation*, 4th ed. Jossey-Bass, 2016.
[28] J. Creswell and T. Guetterman, *Educational research: planning, conducting, and evaluating quantitative and qualitative research* 6th ed. Pearson, 2019.
[29] M. Schreier, *Qualitative content analysis in practice*. Los Angeles: SAGE, 2012.
[30] J. Davidson, "NVivo," *The SAGE Encyclopedia of Educational Research, Measurement, and Evaluation*, B. Frey, Ed., Thousand Oaks: SAGE Publications, Inc., 2018. [Online]. Available: https://sk.sagepub.com/reference/sage-encyclopedia-of-educational-research-measurement-evaluation
[31] Y. Lincoln and E. Guba, *Naturalistic inquiry*. Beverly Hills, California: Sage Publications, 1985.
[32] V. Clarke, V. Braun, and N. Hayfield, "Thematic analysis," in *Qualitative psychology: A practical guide to research methods*, J. Smith Ed., 3rd ed.: SAGE Publications, 2015, ch. 10, pp. 222-248.
[33] For Inspiration and Recognition of Science and Technology (FIRST). "FLL challenge: Cargo connect engineering notebook." https://info.firstinspires.org/hubfs/Education_Resources/CARGO%20CONNECT/CARGO%20CONNECT%20Challenge%20EN%20(regular).pdf (accessed 2021).