Characterizing Student Engineering Problem Engagement Through Process Diagramming

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Abstract **– This work in progress research seeks to understand how the underlying processes of authentic/open-ended/ill-structured problem-solving evolve among engineers. With this broader research aim in mind, this paper reports on a proposed reflective approach to facilitate engineering students' sharing their strategies and process during authentic problem-solving. The reflective approach asks individuals to consider an authentic and significant problem-solving experience and then: 1) diagram their problem-solving process, 2) relate it to an established problem typology classification by Jonassen, 3) relate it to an instructor's process diagrams interpretating Jonassen, and 4) update their process diagram. Preliminary results from a pilot implementation with two students are reported. In sharing this preliminary work, we consider the potential for the proposed approach to support research that accesses students' awareness and thinking about their problem-solving processes.**

Keywords **–** Authentic Problem-solving, Framing, Recognition, Problem Types, Experiential Learning, Professional skills, Process Diagrams, Engineering Education

I. Introduction

In this work-in-progress (WIP) paper, we report on early efforts to explore students' thinking about the underlying processes that govern their engagement with authentic engineering problems. Skills related to formulating and solving complex problems and applying design are important student outcomes [1]. We contend that such outcomes are related to an important professional competency of "devise process" [2] -- determining the what, when, and how necessary to reach a goal, monitor and regulate the process, projects, and budgets among other things. This WIP's research question is: *To what extent can a constructivist approach enable undergraduate engineering students to articulate a process for their engagement with open problems?* We utilize changes in the visual diagramming and self-reported perceptions of participants as a point of analysis for assessing the potential usefulness of the proposed approach.

There is an emphasis in engineering education on closed-ended/well-structured problems that is more focused on the results and which can fixate individuals on certain problem-solving habits that do not translate to open problems [3], [4]. Consequently, students may think that engineering knowledge is an external reality that must be comprehended and adopted as the teacher suggests [5]. Students may memorize solution strategies and technical details without reflecting on the purpose of strategies or exploring alternative strategies [6]. This can lead to the creation of disconnected "islands" of knowledge for learners and may make it difficult for students to make connections and incorporate knowledge from a variety of courses into an integrated process for engaging engineering problems.

To help students develop problem-solving competencies necessary for the engineering profession, authentic (also known as open-ended or ill-structured) problems are encouraged to be integrated into the classroom and taught in a flexible rather than fixed manner [3], [7]–[9]. Authentic problems encompass engineering processes, are complex, and can have multiple novel solutions [10], [11]. When authentic problems are not taught or assessed solely based on a fixed approach (i.e., closed-ended problem-solving), the pedagogy can promote more diverse and experiential knowledge constructions. Such practice moves away from a solely cognitivist and towards a constructivist pedagogical perspective where students' internalization of knowledge and learning is shared and constructed socially [12], [13].

Prior work in engineering education has offered strategies embedded in a constructivist framework to teach students the skills needed for engineering problem-solving. The strategies span from the instruction of problem-solving strategies to using explicit learning frameworks and creating communities of practice [6], [14]–[16]. Past work has also examined differences in expertise [17]–[19], the role of beliefs, and epistemic doubt as a driver to teach problem-solving skills [20], [21]. The work of Jonassen and Woods each offers classifications that advocate for the qualitative study and communication of strategies adopted by the problem-solvers [22]–[27]. Yet, the initial problem recognition, framing, and broad processes of students are less often studied or captured in engineering education [28], [29]. The preliminary work reported here explores the potential for a scalable data collection approach based on process diagramming to yield insights into the evolving thinking and abstraction of engineering problem-solving processes among engineering undergrads.

II. Methods

Our research goal is to codify and classify both visually and textually the qualitative thinking of individuals (in this work students) towards solving an authentic engineering problem. Data is collected by an online survey instrument with the potential for a follow-up interview. Rooted in a constructivist framework, the core of the survey instrument includes five sections in which respondents are asked to:

S1) Describe a prior open-ended engineering problem that they recently worked on and that they considered having significantly impacted their learning. As part of the description, they are asked to rate their performance and justify their rating. Additionally, they are asked to share evaluation/feedback they may have received from someone else (e.g., mentor, work supervisor). Finally, they are given the option to upload up to three relevant problem artifacts.

S2) Draw a process diagram that represents the approach taken to solve the problem. Respondents are asked to use the shapes shown in Figure 1 and an example diagram related to project planning is provided (not shown here). Respondents are instructed to upload a digital or hand-drawn diagram.

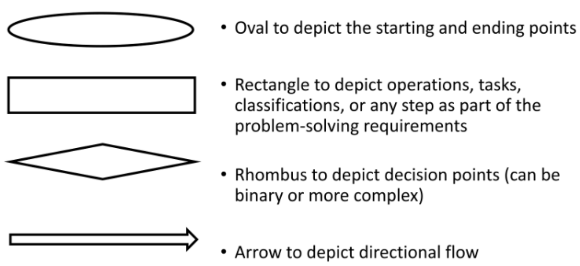

FIGURE 1. PROCESS DIAGRAM SHAPES

S3) Select a problem-type description that best aligns with the problem and problem-solving process in which they engaged. Six descriptions were provided and were derived from Jonassen's [22] problem typology descriptions (design, case analysis, selection, troubleshooting, story problem, algorithm). For example, selection was described as a *decision situation with limited alternatives and set criteria; problem-solving activities oriented around considering benefits and limitations, weighing options, and justifying selection of an alternative.* "None" was also an option.

S4) Select an instructor diagram, also derived from Jonassen's classification, representative of the problem-solving process they followed. An example of an instructor diagram for selection is shown in Figure 2.

S5) Relate their diagram to the selected instructor diagram. Respondents were able to upload a modification of their process diagram if they thought it was appropriate. They were also able to provide a written response to describe similarities or differences.

This approach is situated in an interpretive/constructivist paradigm since it is ideographic and aims to bring out and socially share the individuals' internal schemas and interpretations of their authentic engineering problem-solving process. This order of steps specifically enables the students' assimilation of knowledge through sharing their process diagrams first followed by accommodation through anchoring to Jonassen's problem types and the instructor's drawn process diagrams for those problem types. We examine this through observation in changes of student process diagram pre and post as well as self-reported perceptions towards our proposed approach.

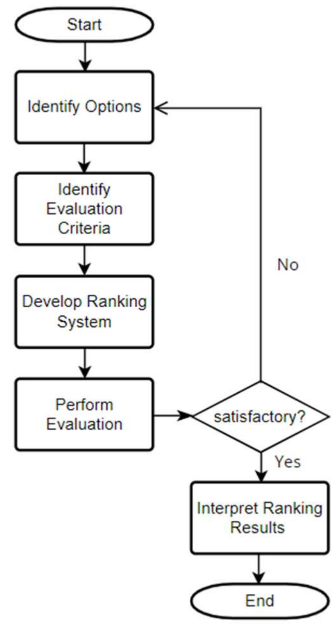

FIGURE 2. INSTRUCTOR'S PROCESS FOR SELECTION

III. PRELIMINARY FINDINGS

For the scope of this work, we explored our approach with two students. Nathan and Craig (pseudonyms) are both fourth-year White men who speak English as their first language and hold internship positions at an engineering company. Each student completed the survey and responded to a few reflective questions about the ease of use and usefulness of the instrument. We conducted a 30-minute follow-up interview a few days after with each participant and had them reflect on their engagement with our online instrument. Both are high-achieving students who, through involvement with personal projects, student clubs, and extended internships, have had a multitude of open-ended problem-solving experiences in various environments. In this respect, the experiences of these two students exceeds that of many students.

Nathan fully engaged the survey tool. He referenced a problem from his internship, summarized as (S1) to "verify the actuator is safe for flight" and considered his prior work to be rated well by his supervisor and the client. His initial (S2) and final (S5) process diagrams are shown in Figures 3 and 4, respectively. He selected the description of troubleshooting (S3) and the troubleshooting process diagram (S4). He indicated that trying to draw a process diagram to reflect his problem-solving process was difficult: "Trying to simplify the process of the data analysis and creating the loop of working independently then sharing with my supervisor, making adjustments, and getting new results was tricky." His response may suggest that his inexperience with the problem made it difficult for him to abstract his problem-solving as a more general process.

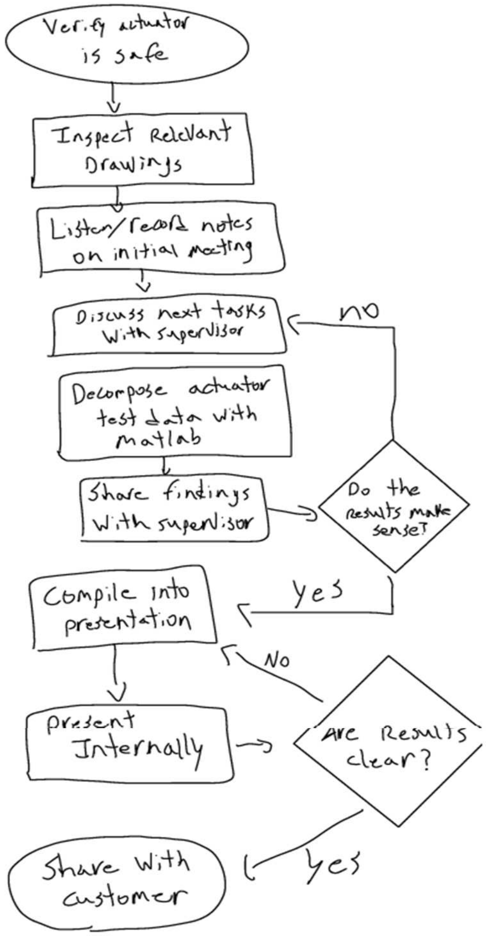

FIGURE 3. NATHAN'S INITIAL PROBLEM PROCESS DIAGRAM

Nathan elaborated in the interview that for his process diagram, and in his mind, he had started with a rectangle (operational) visual element and filled it with "What could cause an actuator to behave strangely?" What branched off from there, however, was limited to what his role allowed him to investigate and thus focused more on the simulation model. He noted that his problem was a standard troubleshooting problem most failure analysis and inspection interns are expected to perform. Thus, he found it easy to associate his process diagram with the descriptions and process diagrams in the survey. Due to his prior familiarity with process diagrams, he considered reflective diagramming a useful approach. In the interview he indicated that seeing the interpretations of Jonassen and the instructor helped him categorize and sort information in a more holistic and organized way, as evident in Figure 4. As he reported in the survey, the descriptions and process diagrams "made the process seem a little less random than before. It showed that there were some formulaic aspects to the problem that I solved that could be applied to a future problem."

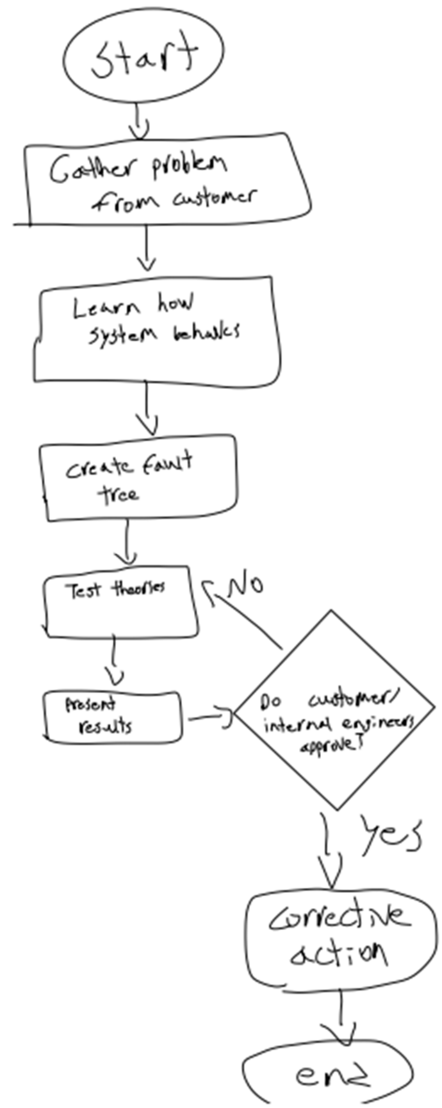

FIGURE 4. NATHAN'S FINAL PROBLEM PROCESS DIAGRAM

Craig was more skeptical of the survey tool. He referenced a personal project (S1) in which "the goal [was] to extend the range of an existing electric skateboard." He also seemed satisfied with the outcomes of his personal project. He did not participate in drawing process diagrams for his problem-solving at the pre (S2) and post (S5) survey stages (he did draw a diagram during the follow-up interview; see Figure 5. He chose the description for selection (S3) but the process diagram for design (S4).

Craig justified not uploading a diagram by saying that the instructor diagram was representative (though this required him to skip ahead in the survey). Additionally, he wrote that he "[follows] this diagram in a much more continuous, rather than discrete, sort of way. There are no distinct steps for a project like this." In the interview, he described his problem-solving processes as "intuitive" and rationalized that since most of his

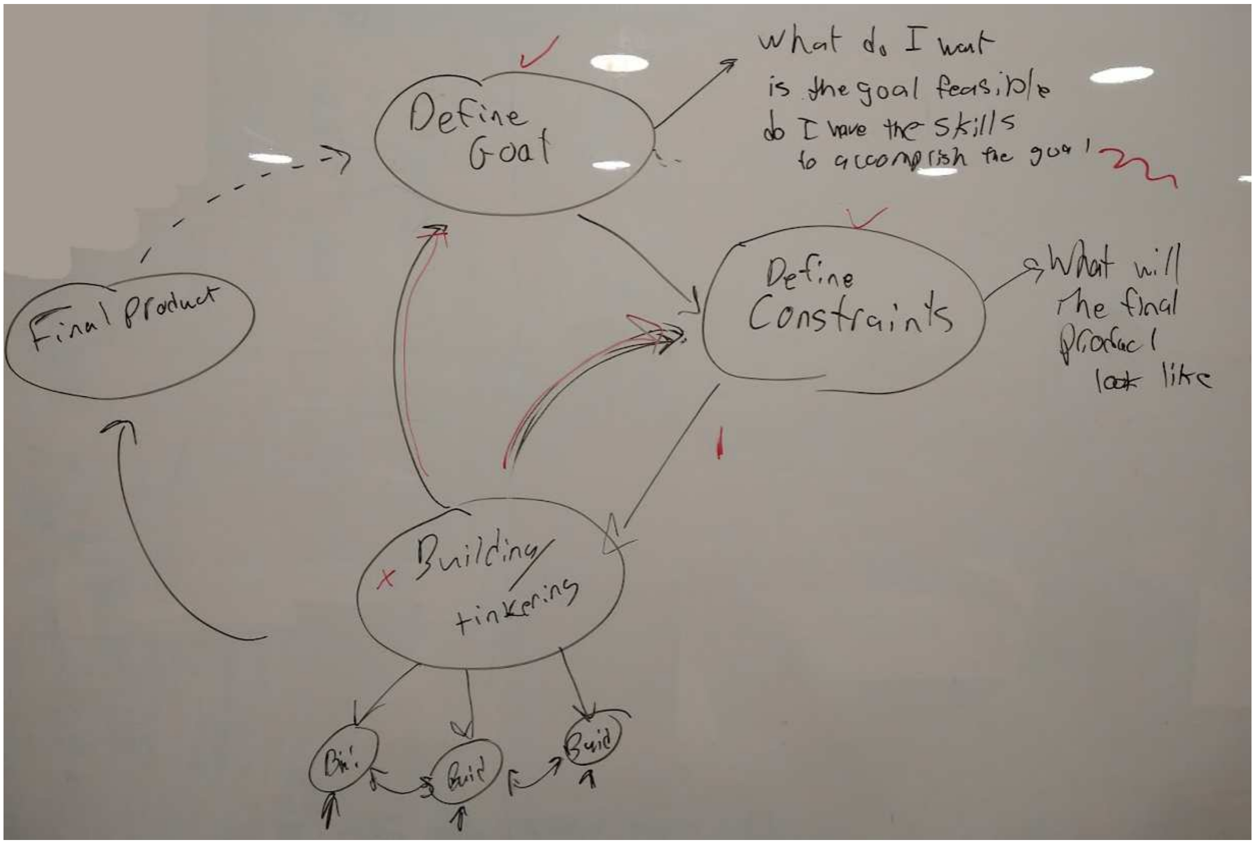

FIGURE 5. CRAIG'S PROBLEM-SOLVING PROCESS DIAGRAM, DRAWN DURING INTERVIEW

project experiences are personal, he "never really had much like outside force pushing me to really nail down this process." Yet, in the interview, he was able to draw his abstracted design process model (Figure 5) and describe it in detail without hesitation. Further, he was able to relate his model to that of the instructor (not shown). This might suggest that Craig has developed an advanced way of thinking about problem-solving that can be abstracted and shared meaningfully with others to coordinate activity. He validated this in his survey response in which he described the utility of process-modeling: "Where I see these processes having the most utility is not to specific engineers working on specific tasks, but rather a larger integration engineering who is designing a whole system at once without so much thought on the nitty-gritty details."

IV. CONCLUSIONS

The students' responses suggest that the proposed approach provides promise and challenges in terms of understanding students' evolving thinking about processes that support planning and regulation of open-ended problem-solving. The approach may be useful to different extents under different problem-solving contexts (e.g., problem types) and demographics of students (e.g., those who pay attention to details versus high-level operations). Using this approach to support communication and capacity building among students engaged in authentic problem-solving is achievable but perhaps difficult because of multiple facets. Examples include domain expertise, argumentation and reasoning skills, metacognition, affective, and visual schemas [17], [30]–[34]. Ultimately, we aim to use this approach as a medium to understand and track changes in the students' problem engagement, differentiate between experts and novices, and explore the possibility of visual process diagram/problem type heuristics for different kinds of authentic engineering problems. Future work may supplement a framework that facilitates the assessment of and feedback on developing expertise based on students' verbal and visual deliverables.

REFERENCES

[1] ABET, "Criteria for Accrediting Engineering Programs, 2020 – 2021," 2021, [Online]. Available: https://www.abet.org/accreditation/accreditation-criteria/criteria-for-

accrediting-engineering-programs-2020-2021/.
[2] C. H. Passow, H. J., & Passow, "What competencies should undergraduate engineering programs emphasize? A systematic review," *J. Eng. Educ.*, vol. 106, no. 3, pp. 475–526, 2017, doi: 10.1002/jee.20171.
[3] N. Mourtos, N. Okamoto, and J. Rhee, "Defining, teaching, and assessing problem solving skills," in *7th UICEE Annual Conference on Engineering Education*, 2004, pp. 1–5.
[4] E. Douglas, M. Koro-Ljungberg, N. McNeill, Z. Malcolm, and D. Therriault, "Moving beyond formulas and fixations: solving open-ended engineering problems," *Eur. J. Eng. Educ.*, vol. 37, no. 6, pp. 627–651, 2012.
[5] E. Redish, J. Saul, and R. Steinberg, "Student expectations in introductory physics," *Am. J. Phys.*, vol. 66, no. 3, pp. 212–224, 1998.
[6] C. A. Ogilvie, "Changes in students' problem-solving strategies in a course that includes context-rich, multifaceted problems," *Phys. Rev. Spec. Top. Educ. Res.*, vol. 5, no. 2, p. 020102, 2009, doi: 10.1103/PhysRevSTPER.5.020102.
[7] I. Denayer, K. Thaels, J. Sloten, and R. Gobin, "Teaching a structured approach to the design process for undergraduate engineering students by problem-based education," *Eur. J. Eng. Educ.*, vol. 28, no. 2, pp. 203–214, 2003.
[8] P. Winkelman, "Perceptions of mathematics in engineering," *Eur. J. Eng. Educ.*, vol. 34, no. 4, pp. 305–316, 2009.
[9] R. Adams, J. Turns, and C. Atman, "Educating effective engineering designers: The role of reflective practice," *Des. Stud.*, vol. 24, no. 3, pp. 275–294, 2003.
[10] N. Shin, D. Jonassen, and S. McGee, "Predictors of well-structured and ill-structured problem solving in an astronomy simulation," *J. Res. Sci. Teach.*, vol. 40, no. 1, pp. 6–33, 2003.
[11] M. Reid, N., Yang, "Open-ended problem solving in school chemistry: a preliminary investigation," *Int. J. Sci. Educ.*, vol. 24, no. 12, pp. 1313–1332, 2002.
[12] J. D. Bransford, A. L. Brown, and R. R. Cocking, *How people learn: Brain, mind, experience, and school: Expanded edition*. Washington, DC: National Academy Press, 2000.
[13] P. A. Cooper, "Paradigm shifts in designed instruction: From behaviorism to cognitivism to constructivism," *Educ. Technol.*, vol. 33, no. 5, pp. 12–19, 1993.
[14] E. Hamilton, R. Lesh, F. Lester, and M. Brilleslyper, "Model-eliciting activities (MEAs) as a bridge between engineering education research and mathematics education research," *Adv. Eng. Educ.*, vol. 1, no. 2, pp. 1–25, 2008.
[15] K. Wolff, "Engineering problem-solving knowledge: the impact of context," *J. Educ. Work*, vol. 30, no. 8, pp. 840–853, 2017, doi: 10.1080/13639080.2017.1380299.
[16] M. Cardella, C. Atman, and R. Adams, "Mapping between design activities and external representations for engineering student designers," *Des. Stud.*, vol. 27, no. 1, pp. 5–24, 2006.
[17] P. Kavousi, S., Miller, P., Alexander, "The role of metacognition in the first-year design lab," *Educ. Technol. Res. Dev.*, vol. 68, no. 6, pp. 3471–3494, 2020, doi: 10.1007/s11423-020-09848-4.
[18] M. T. Chi, R. Glaser, and M. J. Farr, *The nature of expertise*. Psychology Press, 2014.
[19] M. T. Chi, R. Glaser, and E. Rees, "Expertise in problem solving," in *R. Sternberg (Ed.), Advances in the psychology of human intelligence*, NJ: Erlbaum, 1982.
[20] B. Hofer and P. Pintrich, *Personal epistemology: The psychology of beliefs about knowledge and knowing*. Routledge, 2012.
[21] L. Mason, "High school students' beliefs about maths, mathematical problem solving, and their achievement in maths: A cross-sectional study," *Educ. Psychol.*, vol. 23, no. 1, pp. 73–85, 2003.
[22] D. Jonassen, "Toward a design theory of problem solving," *Educ. Technol. Res. Dev.*, vol. 48, no. 4, pp. 63–85, 2000, doi: 10.1007/BF02300500.
[23] D. Jonassen, J. Strobel, and C. B. Lee, "Everyday problem solving in engineering: Lessons for engineering educators," *J. Eng. Educ.*, vol. 95, no. 2, pp. 139–151, 2006, doi: 10.1002/j.2168-9830.2006.tb00885.x.
[24] D. Jonassen, *Learning to solve problems: A handbook for designing problem-solving learning environments*. Routledge, 2010.
[25] D. R. Woods *et al.*, "Developing problem solving skills: The McMaster problem solving program," *J. Eng. Educ.*, vol. 86, no. 2, pp. 75–91, 1997, doi: 10.1002/j.2168-9830.1997.tb00270.x.
[26] J. M. Woods, D. R., Kourti, T., Wood, P. E., Sheardown, H., Crowe, C. M., & Dickson, "Assessing Problem-Solving Skills Part 1: The Context for Assessment," *Chem. Eng. Educ.*, vol. 35, no. 4, pp. 300–7, 2001.
[27] J. M. Woods, D. R., Kourti, T., Wood, P. E., Sheardown, H., Crowe, C. M., & Dickson, "Assessing Problem Solving Skills Part 2: Assessing the Process of Problem Solving," *Chem. Eng. Educ.*, vol. 36, no. 1, pp. 60–67, 2002.
[28] D. H. Jonassen, *Learning to solve problems: A handbook for designing problem-solving learning environments*. Routledge, 2010.
[29] N. Chapin, "Flowchart," *Encyclopedia of Computer Science*. pp. 714–716, 2003.
[30] G. J. Evans, "Windmills of your mind: metacognition and lifelong learning," 2018.
[31] J. Newell, K. Dahm, and R. Harvey, "Developing metacognitive engineering teams," *Chem. Eng. Educ.*, vol. 38, no. 4, pp. 316–320, 2004.
[32] R. Marra, D. Hacker, and C. Plumb, "Metacognition and the development of self-directed learning in a problem-based engineering curriculum," *J. Eng. Educ.*, vol. 111, no. 1, pp. 137–161, 2022.
[33] R. E. McCord and H. M. Matusovich, "Naturalistic observations of metacognition in engineering: Using observational methods to study metacognitive engagement in engineering," *J. Eng. Educ.*, vol. 108, no. 4, pp. 481–502, 2019.
[34] T. Nelson and L. Narens, "Why investigate metacognition," *Metacognition: Knowing about knowing*, vol. 13, pp. 1–25, 1994.