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Understanding Learners' Negotiation Processes During Ill-Structured Engineering Estimation Problem-Solving

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Abstract: Estimation of physical quantities is an important practice in engineering. However, estimation problems are ill-structured and complex, and learners require support to solve them successfully. Modelling Based Estimation Learning Environment (MEttLE) is an open-ended learning environment (OELE) designed to support undergraduate engineering students in estimation problem-solving based on disciplinary model-based reasoning tasks and metacognitive scaffolds. When learners collaboratively solve estimation problems in MEttLE, its open-ended pedagogical design implies that different learners may have different approaches to reach a required common ground and learners' negotiation becomes crucial. This study aims to understand where, why, and how learners negotiate and how it influences estimation problem-solving. We analyze learners' problem-solving approach through their collaborative discourse and actions as they work on MEttLE to build and evaluate models to estimate a physical quantity. Our findings indicate that learners' negotiation strengthens the processes that underlie good estimation problem-solving.

Keywords: Negotiation, disciplinary model-based reasoning, open-ended learning environments, collaboration

1. Introduction

Estimation is an ill-structured problem involving determining approximate values for a physical quantity without access to complete information (Jonassen, Strobel & Lee, 2006). Making estimates is an important and frequent practice used by engineers and scientists when exact data and precise governing equations are unavailable (Mahajan, 2014). Estimation problems are challenging and hard to solve for learners as they involve applying knowledge from different topics to a real-world system, making assumptions, identifying the important physical quantities and those that can be neglected, and making judgments regarding numerical values (Jonassen et al., 2006). Prior research has shown that the processes underlying good estimation performance include model-building, model contextualization, evaluation, planning, monitoring, and revising the problem-solving approach (Kothiyal & Murthy, 2020). To learn estimation problem solving, learners need to be explicitly scaffolded through activities that allow them to engage in the above processes.

In this paper, we study learners' problem-solving processes when they collaboratively work on MEttLE, an open-ended learning environment (OELE) designed to support estimation problem-solving based on disciplinary model-based reasoning tasks and metacognitive scaffolds (Kothiyal & Murthy, 2020). MEttLE's pedagogical design requires learners to explore, grapple with incomplete information, make assumptions and decide the solution approach while they solve the estimation problem. The open-ended nature of these activities can be demanding for learners (Emara, 2018), and collaboration can aid learners in solving such tasks (Kirschner, Paas, & Kirschner, 2009). However, students' collaborative learning processes in approaching ill-structured estimation problems and their impact are not well understood. Learners may have different approaches or conflicting ideas while maintaining a common shared goal because of the open-ended nature of the tasks. Thus, learners' negotiation of which approach to choose, which concepts are relevant and why, and which resources to use become crucial in understanding their problem-solving processes. This study aims to understand learners' negotiation processes and strategies as they solve an engineering estimation problem related to power in MEttLE and its impact.

2. Theoretical Framework

Negotiation is crucial in CSCL research (Carell & Herrmann, 2009) as effective collaboration requires negotiation (Dillenbourg & Baker 1996), especially when learners face differing opinions, ideas, meanings, and concepts from their partners. It is most relevant and valuable in complex problems or tasks that require collaborators' ideas, contributions, and critical examinations to find a suitable solution by pursuing convergence (Carell & Herrmann, 2009). Thus, making it a crucial part of any supported method for complex problem solving (Richardson & Anderson, 1995). Negotiation is defined in multiple ways, such as resolving conflicts (Dillenbourg & Baker, 1996), an attempt to agree on the goals, actions, and beliefs that comprise the planning and acting decisions of the collaboration (Sidner, 1994), and a critical examination of reasons for and against different points of view (Baker, 1994, pp.200). While negotiating, learners must put forth their points and defend their positions using strategies such as argue, justify, refine, standpat, etc. (Baker, 1994, pp.200). Negotiation on a common ground is essential to ensure that all have argued and agreed upon a common understanding. Understanding how this takes place is important in problem-solving (Beers, 2006).

To analyze learners' negotiation strategies and processes, we have applied codes from social modes of co-construction (Weinberger & Fisher, 2006). These processes include Externalization (EX), Elicitation (E), Quick consensus Building (Q), Integrated oriented consensus building (I), and Conflict-oriented consensus (C) building. Externalization is articulating thoughts without reference to others' contributions and making one's knowledge external. Elicitation is questioning the learning partner to seek help, verification, and clarification to attain the same understanding of the content the partner intended to share. Once this knowledge is understood, it is contested for acceptance or rejection, followed by negotiation of common ground. Quick consensus building is accepting the contributions to move ahead in the task. Here agreement is merely for coordinating the discourse move, and a true common ground may not have been reached. Integrated-oriented consensus building is integrating and applying the perspectives of the collaborators. In this process, there stands a chance when one may give up their initial belief based on a peer's contribution. Conflict-oriented consensus building is working on the reasonings of peers by disagreeing, modifying, or replacing their perspectives. During this, learners criticize the proposals and find better arguments for their position.

2.1.1 Modelling-Based Estimation Learning Environment (MEttLE)

Modelling-Based Estimation Learning Environment (MEttLE) (Figure 1) is an OELE for estimation problem solving that triggers a model-based estimation process. It is structured into five sub-goals (Figure 1a). The three-phased model building sub-goals - functional, qualitative, and quantitative- help create, contextualize and evaluate models of complex problems essential to solving estimation problems, one calculation, and one evaluation. It has metacognitive prompts for evaluation, planning, monitoring, and reflection of models and problem-solving processes, simulators (Figure 1b), hints, an info center, guide me, question prompts, and a problem map that affords the modelling process. Novices can choose any path and revisit any sub-goals at any time in MEttLE. The problem solving is complete only when they have evaluated the reasonableness of their calculated estimate of power (Figure 1c). If the evaluation fails, they may need to reflect on their estimation by revisiting previous sub-goals.

In this study, to solve the problem, the solver must estimate a physical quantity (power of car), understand the problem system (the car), analyze how it behaves under the given operating conditions, determine dominant parameters for these conditions, and create an equation involving the dominant parameters. He has to make assumptions and approximations to create and determine a simplified model of the problem context and its corresponding mathematical equation.

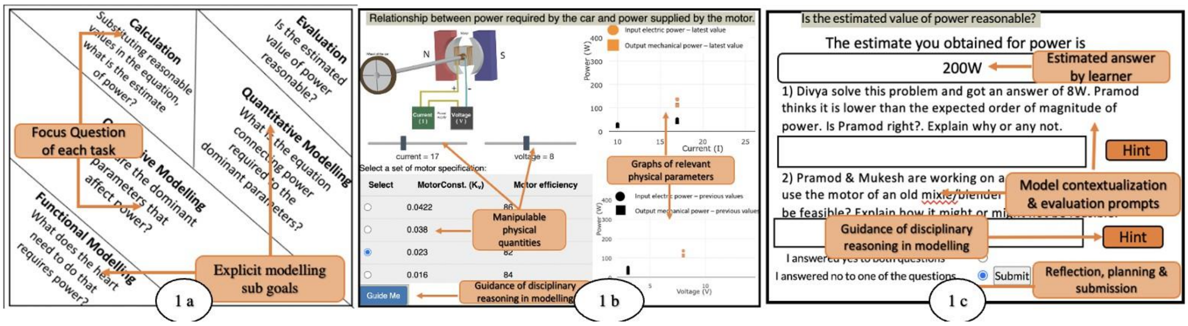

Figure 1. Overview of MEttLE Interface. (1a) Estimap with sub-goals; (1b) Simulator-4, and (1c) evaluation sub-goal with model contextualization prompts

3. Methods

3.1 Participants

5 females and 9 males of 3rd or 4th-year Mechanical and Electrical undergraduates from different engineering colleges in Mumbai participated in this study. Students from these disciplines were chosen because the problem in MEttLE had concepts that required knowledge specific to the disciplines. A google form to gather interested participants' demographic details and availability was circulated among students by their teachers. Only those who were double vaccinated were considered for this study. IRB approval from our institution was sought.

3.1.1 Procedure and Data collection

Seven groups of two students each visited the lab on different days for the study. The researcher explained the study's goal, the procedure, and the data to be collected, after which participants signed the consent form. The lab setup was of a single computer system with MEttLE. The researcher explained the collaborative script where one learner would be the "driver" and control the mouse and keyboard to interact with MEttLE. At the same time, the other would be the "navigator" and would question, argue, and encourage the driver to elicit his/her thought process. These roles would be switched every 20 minutes. They were asked to articulate their thoughts and views explicitly during collaboration. On average, the time taken by each pair to interact with MEttLE was about 90 minutes.

Data were collected using five sources (Screen recording, Video camera, Observational logs, Interviews, and paper-based tests). We used only two for this research. The primary source was the recording using the OBS studio (OBS, 2021), which ran on the computer containing MEttLE and captured learners' interaction with it, audio, and front video. The secondary source was the semi-structured interview where the researcher played the screen recording of the learners' interaction and asked questions to get a deeper insight into why learners did or said something during the intervention.

3.1.2 Data Analysis

Researchers viewed the recordings multiple times and used Baker's model of negotiation (Baker, 1994) to identify the segments of negotiation. These were transcribed to include the verbal and interaction data (such as entering text, clicking, changing values, etc.) with MEttLE and the facial, tone of voice, and learners' gestures wherever necessary. We then applied the codes from the framework for social modes co-construction (Weinberger & Fischer, 2006) to identify learners' negotiation strategies. Two researchers independently coded two episodes and attained inter-rater reliability of 0.945 Kappa, indicating almost perfect agreement.

4. Findings

For analysis, we chose only five groups out of the seven that participated in our study. The remaining were discarded as their data was either not recorded properly, or they were silent throughout the intervention. We report only two episodes of negotiation here in the order of the activities in MEttLE. Episode 1 is between two male friends, S3 and S4, from final-year Mechanical engineering at the same college. They had participated in many robotics contests, solved open robot design and building problems, and experienced projects that required understanding and applying power, energy, and related concepts. Episode 2 is between S1 (female) and S2 (male) pursuing degrees in Electronics & Telecommunication and Mechanical Engineering, respectively. They studied in different colleges and did not know each other. S1 was in her final year and had worked on a car designing project where she used MATLAB and Python programming. She had an understanding of power, energy, and related concepts. S2 had recently completed his graduation and had worked on designing and coding an AR simulation for a Lathe machine operation. All students were familiar with spoken and written English.

4.1 Episode 1

This episode begins when S3 (Driver) and S4 (Navigator) start working in MEttLE. S3 asked the researcher if they could converse in Hindi while solving the problem. They watched the video that discussed the example of estimating the power of a human heart in MEttLE and then moved to the explanation of the estimap related to it (Figure 1a). They took many turns negotiating the appropriate sequence of the sub-goals and the domain-specific details related to solving this problem.

Table 1. *Episode 1 between S3 and S4*

Learner	Verbal/Interaction with MEttLE	Time	WC
(L4) S3	Functional Model Qualitative Model [pointing the cursor to functional and the qualitative]	0:09:17	EX
(L5) S4	What does the car need to do that requires power? [Reads the question in Functional Model sub-goal]	0:09:20	
(L6) S3	what are the dominant parameters that affect power? [Reads the question in Qualitative Model] So this will come second	0:09:23	EX
(L7) S3	Substituting reasonable values in the equation, what is the estimate of power? [Reads the question in the Calculation sub-goal]	0:09:27	EX
(L8) S4	hey, this one is the second…once we have a value, we can go ahead and solve this	0:09:33	C
(L9) S3	this should come third [speaking about calculation mode] because [putting his cursor on the qualitative and then functional model sub-goal] you have to first figure out the parameters that you need in the equation to solve the equation.	0:09:38	C
(L10) S4	[interrupts S3 and points his finger to the qualitative model on the screen. S3 brings the cursor to the qualitative model] But those are not the power that you require to solve the equation; they are just the dominant parameters that you require to think	0:09:48	C
(L11) S4	… let’s just see the others.	0:10:09	Q

(L4) S3 externalized verbally and pointed the cursor to state that functional modeling should be approached first, (L6) qualitative modeling second, and the (L7) calculation sub-goal third. (L8) S4 stated that the calculation sub-goal should be second in the sequence, thus contradicting S3’s statement illustrating conflict-oriented consensus-building. (L9) S3 further contradicted S4 and justified his argument by explaining why the calculation sub-goal should be approached third. S3 defended his claim with a new argument, a trait seen while conflict-oriented consensus building. S3’s reasoning pushed S4 to bring another perspective (L10). The discussion abruptly ended when S4 (L11) suggested they read other sub-goals. Since they could not build common ground, they decided to opt for a quick consensus-building approach and moved ahead in the problem-solving process.

After repeated negotiation via different processes, they finalize a sequence most favourable to solve the estimation problem in MEttLE. When the researcher probed S3 on why they discussed the estimap, he elaborated that attaining a common understanding at the planning stage was crucial as it set a stage for the entire problem-solving. He added that it also put light on domain-specific details considered and contested by both as important parameters for this problem. The learners applied their understanding from their negotiation on the human heart problem to the actual car racing problem in MEttLE.

4.2 Episode 2

S1 (Navigator) and S2 (Driver) solved the problem and attained an estimate of 200W in the Calculation sub-goal. In the Evaluation sub-goal, they examined whether their calculated answer was reasonable against i) the order of magnitude and ii) how it compares with known values.

S2 found that the power requirement for the example 10-kg toy car was 20W in the Info Centre. Hence the discussion was about the estimated power value and the car's parameter (weight).

Table 2. *Episode 2 between S1 and S2*

Learner	Verbal/Interaction with MEttLE	Time	WC
(L1) S2	I think it is 20W	1:28:09	EX
(L2) S1	But it's a toy car [points her fingers on the screen and changes tone to emphasize the type of car] ...we weren't…	1:28:11	
(L3) S2	they didn't mention anything about toy car..they just say car	1:28:16	C
	S2 manipulates the parameters in Simulator 4	1:29:00	
(L4) S1	Is it only this much? [changes tone] ...current 10? It will increase a little, at least.	1:29:11	C
	S2 increases the value of the current	1:29:34	I

(L1) S2 externalized his view by announcing that their answer needed to be changed to 20W. (L2) S1 disagreed and argued that weight alone could not be the primary criterion to decide the electric car's power. She insisted on re-evaluating their solution approach for the electric racing car, which was a different context than the example in the Info Centre. (L3) S2 gave his reasonings, returned to the Calculation sub-goal, and clicked on Simulator-4 (Figure 1b). Here, he tried to reduce the parameter of Current to the minimum to acquire the power of 20W. (L4) S1 contended and insisted that the value of the current be raised to a reasonable number as it's an electric car. S2 increased the current to a value acceptable to both, depicting an integration-oriented consensus-building approach. S1 reasoned that the estimate of power for the racing car would always be greater than 20W even if the current were reduced to the minimum. Hence the answer should be the same, i.e., 200W. S1 used the simulator to facilitate the modelling process and tried questioning, explaining, and critiquing S2 (conflict-oriented consensus building), who stuck to a simplified model and tried to attain his desired answer of 20W (stand pat).

After many turns of conflicting views, they did not attain a common ground. They did new calculations and obtained an answer of 65W, which they agreed to retain and move to the next subsection. This was quick consensus building where the partners agreed merely to move ahead.

5. Discussion and conclusion

We saw evidence of social modes of co-construction of knowledge multiple times in the negotiation episodes. Neither partner was inclined to agree easily when students used a conflict-oriented consensus-building approach. The negotiation took multiple turns, each providing his/her arguments and counterarguments. When integration-oriented consensus building was used, an agreement was quickly reached and was robust. On the other hand, when quick consensus building was seen, learners did choose to move ahead; but circled back to their original standpoint later, indicating that the agreement may not have been complete or authentic. Whether learners agreed or disagreed at the final state, engaging in negotiation led to productive behaviors concerning their estimation problem-solving. In Episode 2, students could create, contextualize and refine their models and push to reason more as they attempted to reach a common ground. In Episode 1, students' negotiation at the problem-solving steps related to planning and domain concepts showed some impact on their metacognition and conceptual understanding, which was later applied to the actual car problem. This study reaffirmed that collaboration in TELEs encourages learners to critically reason, elaborate, and justify their claims more than they would individually on ill-structured problems (Jeong & Hmelo-Silver, 2016). Learners' negotiation supported their performance in MEttLE.

In our study, we observed potentially influencing factors of the amount and quality of negotiation, such as learners' comfort in effectively conveying their viewpoint or critiquing their partner's idea in their native tongue Hindi (national language). Thus, language familiarity plays a vital role in negotiation (Lai, Lin, & Kersten, 2010). Further, dyads of friends were more productive in negotiations towards problem-solving compared to the non-friends' group, which was substantiated by S1 in the interview. Thus, relationship with collaborators plays a role in the negotiation process (Maldonado, Klemmer, & Pea, 2009). In addition, the collaborative script gave learners a structure to articulate their thoughts and negotiate effectively. Lastly, the negotiation was heavily guided by MEttLE's design, which supported the complexity of tasks, intermediate reflection spots, and the degree of flexibility offered to learners. This increased the latitude for negotiation (Dillenbourg & Baker, 1996) and fostered them to converge on an acceptable common ground to navigate the other steps.

We see the following limitations: Our findings are based on a small sample and for a short duration in lab conditions. These findings form the basis of our next steps: expanding the analysis to a larger group of participants, confirming the conjectures related to factors influencing the negotiation quality, correlating negotiation and performance, and designing collaboration strategies to better support students in learning estimation problem-solving. Overall, we found that the negotiation process between learners impacted their estimation of problem-solving. We believe that the processes that underlie good estimation, that is, applying model-based reasoning processes and paying attention to planning and evaluation, are strengthened when learners collaborate and negotiate.

References

Baker, M. (1994). A model for negotiation in teaching-learning dialogues. *Journal of Interactive Learning Research*, 5(2), 199.

Beers, P. J., Boshuizen, H. P., Kirschner, P. A., & Gijselaers, W. H. (2006). Common ground, complex problems, and decision-making. *Group decision and negotiation,* 15(6), 529-556.

Carell, A., & Herrmann, T. (2009). Negotiation-Tools in CSCL-Scenarios-Do they have a valid use?

Dillenbourg, P., & Baker, M. (1996, June). Negotiation spaces in human-computer collaborative learning. In Proceedings of the International Conference on Cooperative Systems (pp. 12-14).

Emara, M., Rajendran, R., Biswas, G., Okasha, M., & Elbanna, A. A. (2018). Do Students' Learning Behaviors Differ when they Collaborate in Open-Ended Learning Environments?. Proceedings of the ACM on Human-Computer Interaction, 2(CSCW), 1-19.

Fischer, F., Kollar, I., Haake, J. M., & Mandl, H. (2007). *Perspectives on collaboration scripts. Scripting computer-supported communication of knowledge: cognitive, computational, and educational perspectives*. Springer, New York, 1-10.

Jeong, H., & Hmelo-Silver, C. E. (2016). Seven affordances of computer-supported collaborative learning: How to support collaborative learning? How can technologies help? *Educational Psychologist, 51*(2), 247-265.

Jonassen, D., Strobel, J., & Lee, C. B. (2006). Everyday problem-solving in engineering: Lessons for engineering educators. *Journal of Engineering Education, 95*(2), 139-151.

Kothiyal, A., & Murthy, S. (2020). Disciplinary Model-Based Reasoning and Metacognition Underlies Good Estimation Performance by Engineering Undergraduates.

Kirschner, F., Paas, F., & Kirschner, P. A. (2009). A cognitive load approach to collaborative learning: United brains for complex tasks. *Educational psychology review, 21*(1), 31-42.

Lai, H., Lin, W. J., & Kersten, G. E. (2010). The importance of language familiarity in global business e-negotiation. *Electronic Commerce Research and Applications*, *9*(6), 537-548.

Mahajan, S. (2014). The art of insight in science and engineering: mastering complexity (p. 408). The MIT Press.

Maldonado, H., Klemmer, S., & Pea, R. (2009). When is collaborating with friends a good idea? Insights from design education.

OBS (2021). Open Broadcasting Software. Retrieved from https://www.obsproject.org/

Richardson, G. P., & Andersen, D. F. (1995). Teamwork in group model building. *System Dynamics Review,* 11(2), 113-137.

Sidner, C. L. (1994, August). An artificial discourse language for collaborative negotiation. In AAAI (Vol. 94, pp. 814-819).

Weinberger, A., & Fischer, F. (2006). A framework to analyze argumentative knowledge construction in computer-supported collaborative learning. *Computers & education*, 46(1), 71-95