Novel Pair- and Topic-Swapping

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1 Introduction

In higher education, activity-based teaching has become increasingly popular as an alternative or complement to lecture-based teaching [4, 3]. Work in computer-supported collaborative learning has been ongoing in computing education [7]. Laat & Laaly [1] state that learning and tutoring processes in a networked learning community are complex and have many relationships. Group learning depends on individual contributions, and individuals have different motivations that affect both themselves and the group learning process.

Instructional orchestration is a classroom method in which the teacher serves as the conductor for themed activities [2]. There are certain considerations to keep in mind for effective classroom orchestration, for example, the activity needs to work under various conditions with minimal preparation. Research on instructional orchestration frames teaching as the real-time coordination of multiple activities, tools, and social configurations [2]. From this perspective, group formation is not merely a logistical task but a form of pedagogical decision-making that shapes the space of possible interactions.

We introduce the *topic-swapping* peer-teaching classroom activity, which works as follows: first, each student acquires a topic; then, over rounds, they form pairs and swap their *last* acquired topic within the pair until every student has acquired every topic. Note that *only* the last acquired topic can be swapped, as there is a physical object tied to each topic. Note that a student can be absent from a round, for example, if the number of students is odd. The idea behind the topic swapping activity is for students to acquire knowledge about each topic and interact with many students. The topic-swapping activity can be formulated as a constrained optimisation problem (COP). An ideal solution to the COP is one where (1) each formed student pair is unique and (2) each student acquires a novel topic each round (one they have not had). For example, consider the set $\{s_1, s_2, s_3, s_4\}$ of 4 students and the set of $\{t_1, t_2, t_3, t_4\}$ of 4 topics, where student s_i starts with topic t_i. In the first round, say that the pairs are $\langle s_1, s_2\rangle$ and $\langle s_3, s_4\rangle$, and student s_1 acquires topic t_2, student s_2 acquires t_1, student s_3 acquires t_4, and student s_4 acquires t_3. After the first round, each student has acquired two topics. In the second round, say that the pairs are $\langle s_1, s_3\rangle$ and $\langle s_2, s_4\rangle$, therefore student s_1 acquires topic t_3, student s_2 acquires t_4, student s_3 acquires t_1, and student s_4 acquires t_2. After the second round, each student has acquired three topics. For the third round, pairs must be identical to round one, namely $\langle s_1, s_2\rangle$ and $\langle s_3, s_4\rangle$, as student s_1 needs to acquire t_4 from s_2, student s_2 needs t_3 from s_1, student s_3 needs t_2 from s_4 and s_4 needs t_1 from s_3. After the final round, each student has acquired all the topics. In this example, neither students s_1 and s_3 nor students s_2 and s_4 will be paired. We have not found any solution where n students learn all n topics and meet all other $n-1$ students for $n > 2$.

2 Model

We now describe a model for the topic-swap problem. Consider the set $\mathcal{S}$ of n students; the parameter array $\mathcal{T}$ of size n of topics, where $\mathcal{T}[s]$ is the topic that student $s \in \mathcal{S}$ begins

n	#topics	$r_{\max}$	obj	time
6	4	6	2	0.137
6	6	9	3	0.354
12	6	5	5	0.297
12	8	11	7	1010.536
12	12	18	6	t/o

n	#topics	$r_{\max}$	obj	time
24	12	11	11	697.842
24	18	23	–	t/o
24	24	36	–	t/o
48	24	23	10	t/o
48	36	47	–	t/o
48	48	72	–	t/o

Table 1 The results for the topic-swapping problem instances with different numbers of students (n), topics, and max rounds ($r_{\max}$). In the time column: if the reported time is less than the time-out (1 hour here), then the objective value in the corresponding objective column is the *proven* optimum, else the timing out is indicated by `t/o` and the objective value is either the best one found but not proven optimal before timing out, or '-' indicating that no feasible solution was found before timing out.

with; and an integer $r_{\max}$ denoting the maximum number of rounds. Furthermore, consider an $n \times r_{\max}$ matrix $\mathcal{P}$ of variables, where each variable $\mathcal{P}[s,r] \in \mathcal{S}$ denotes the student that student s is paired up with in round $1 \leq r \leq r_{\max}$; an $n \times 1 + r_{\max}$ matrix $\mathcal{K}$ of variables, where each variable $\mathcal{K}[s,r]$ denotes the last acquired topic t student s has in round $0 \leq r \leq r_{\max}$; an $n \times n \times r_{\max}$ matrix $\mathcal{R}$ of binary variables, where each variable $\mathcal{R}[s_1, s_2, r]$ takes value 1 if students s_1 and s_2 met in round $1 \leq r \leq r_{\max}$, and 0 otherwise; and an $n \times n$ matrix $\mathcal{M}$ of binary variables, where each variable $\mathcal{M}[s_1, s_2]$ takes value 1 if students s_1 and s_2 met in any round, and 0 otherwise. First, we fix the initial acquired topic of each student in $\mathcal{K}$ to be the topic each student begins with. We constrain the $\mathcal{P}$ matrix to be symmetric over the diagonal and such that any student is paired with at most one student in any round. Using $\mathcal{P}$, we constrain $\mathcal{K}$ so each student swaps their last acquired topic with whom they are paired. We constrain $\mathcal{K}$ so that each student acquires each topic. Finally, using $\mathcal{P}$, we constrain the objective variable, which is to be maximised, to be the number of distinct students met by the student who met the fewest number of distinct other students.

3 Preliminary Results and Conclusion

We created a model in the solver-independent MiniZinc [5] language, inspired by the model in Section 2, but with implied and symmetry-breaking constraints[1]. We ran our experiments on a desktop computer with an ASUS PRIME Z590-P motherboard, a 3.5 GHz Intel Core i9 11900K processor, and four 16 GB 3200 MT/s DDR4 memories, running Ubuntu 24.04.4 LTS. For each instance, a single run was made under a 1-hour time limit, using Google OR-Tools CP-SAT [6] with 16 threads and free search enabled. Our results are shown in Table 1. The results show that the difficulty increases as n increases and the difference between n and the number of topics decreases.

We have described the topic-swapping classroom activity and its formulation as a COP, and we have presented a model for solving it. Based on our experimental results, we argue that even medium instances of the topic-swapping COP are hard to solve. For future work, we have ideas for different models for the topic-swapping problem that we want to test. We also want to see if our solutions work in practice for the topic-swapping activity.

[1] The model and results are publicly available at `https://github.com/astra-uu-se/topic-swapping`

References

1 Maarten De Laat and Vic Lally. Complexity, theory and praxis: Researching collaborative learning and tutoring processes in a networked learning community. *Instructional science*, 31(1):7–39, 2003.

2 Pierre Dillenbourg and Patrick Jermann. Technology for classroom orchestration. In *New science of learning: Cognition, computers and collaboration in education*, pages 525–552. Springer, 2010.

3 Peter Doolittle, Krista Wojdak, Amanda Walters, et al. Defining active learning: A restricted systematic review. *Teaching and Learning Inquiry*, 11, 2023.

4 Scott Freeman, Sarah L Eddy, Miles McDonough, Michelle K Smith, Nnadozie Okoroafor, Hannah Jordt, and Mary Pat Wenderoth. Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the national academy of sciences*, 111(23):8410–8415, 2014.

5 Nicholas Nethercote, Peter J. Stuckey, Ralph Becket, Sebastian Brand, Gregory J. Duck, and Guido Tack. MiniZinc: Towards a standard CP modelling language. In Christian Bessière, editor, *CP 2007*, volume 4741 of *LNCS*, pages 529–543. Springer, 2007. The MiniZinc toolchain is available at `https://www.minizinc.org`.

6 Laurent Perron and Frédéric Didier. Cp-sat. URL: `https://developers.google.com/optimization/cp/cp_solver/`.

7 Gerry Stahl, Timothy Koschmann, and Dan Suthers. *Computer-supported collaborative learning: An historical perspective*, pages 409–426. Cambridge University Press, 2006.