Mixed-Integer Programming for Adaptive VR Workflow Training

Yongqi Zhang[1 [0000−0002−9159−5016]], Chuan Yan[1 [0009−0009−2252−1185]], Haikun Huang[1 [0000−0002−5962−0533]], Simon Su[2 [0000−0002−2460−3899]], and Lap-Fai Yu[1 [0000−0002−2656−5654]]

[1] George Mason University, Fairfax VA 22030, USA
{yzhang59,cyan3,hhuang25,craigyu }@gmu.edu
[2] National Institute of Standards and Technology,Gaithersburg, MD 20899, USA
simon.su@nist.gov

1 Virtual Environment And Task Setting

In our simulated virtual restaurant, trainees will use an interaction panel to interact with customers. Table 1 and 2 shows task description and difficulty settings for all tasks. Table 3 shows examples of speech trainees need to respond to the customers with different requests. Once a trainee's speech is recognized and matches with the current task's desired response, the customer will respond or react. Moreover, Our optimizer will incorporate task difficulty and assign suitable task difficulty levels according to the trainee's performance

2 Additional Details of Simulation Study

We performed a simulation experiment to evaluate the effectiveness of our approach in reducing mistakes and the use of hints. 4 to 6 shows a group of steadily improving trainees's initial performance and overall improvement after training under three different training conditions are shown. The improvement pattern produced by the Performance-Only MIP approach closely follows the shape of the trainee's initial performance, demonstrating its effectiveness in addressing the trainee's weaker areas. Subsequently, the MIP approach also follows this trend.

2.1 Simulation Experiment

To validate our approach, we conducted a simulation experiment. The goal of this experiment is to determine whether our approach can train people more efficiently compared to other approaches given the same trainee as input. In particular, we focus on the development of individual psychomotor skill components. We compared our approach (MIP) with a random assignment approach (Random) and a performance-only MIP approach (Performance). In the random assignment approach, the optimizer randomly assigned two to four tasks for each training session. In the Performance-Only MIP approach, we only consider the repeated mistake (M) and familiarity of workflow (H) objectives.

Task	Name	Description	Diff. level	Property (value)	Walking Path
1	Ready To Order	Interact with customers and ask what they want to order	3	Talk-centric(1)	Table->POS
2	Want Food	Grab food from kitchen and deliver food to each customers;Grab dirty plates.	3	Service-centric(10)	Table->Kitchen ->Table
3	Reqeust Recipt	Print out receipt and deliver it to the table	3	Time-sensitive(100)	Table->POS ->Table
4	Checkout	Process payment for the customers	3	Time-sensitive(100)	Table->POS ->Table
5	Order More	Interact with customers, pick up dirty plates and ask what food they want to add	3	Talk-centric(1)	Table->POS
6	Replace Food	Interact with customer and replace the unwanted food with new one	1	Walk-centric(1000)	Table->POS-> Kitchen->Table
7	Drop Drink	clean up the mess and deliver a new drink	1	Walk-centric(1000)	Table->Cleanup Tool->Table ->Cleanup Tool ->POS->Kitchen ->Table
8	Special Request	interact with customers and ask about the taste of their food; deliver extra item (e.g., empty plate) to them	3	Service-centric(10)	Table->Kitchen ->Table

Table 1. The details of different tasks.

	Easy	**Medium**	**Hard**
t1	Two customers, Each order one type of food	Three customers, Each order two types of food	Three customers, Each order two types of food
t2	Two customers, Each waiting for one food	Two customers, Each customer waiting for one food	Two customers, Each customer waiting for one food
t3	Completion time within 90 seconds	Completion time within 80 seconds; Generate dirty plates for pick up	Completion time within 70 seconds; Generate dirty plates for pick up
t4	Completion time within 90 seconds	Completion time within 80 seconds; Generate dirty plates for pick up	Completion time within 70 seconds; Generate dirty plates for pick up
t5	Two customers, Each order one type of food	Three customers, Each order two types of food	Three customers, Each order three types of food
t6	Replace food	N/A	N/A
t7	Clean up	N/A	N/A
t8	No special request	Ask for extra fork	Ask for extra fork and plate

Table 2. Details of task difficulty settings.

Greeting	**Ask for Repeat**	**Ready To Order/ Order More**
How can I help you?	I'm sorry?	What would you like to order?
What can I do for you?	Pardon me?	Sure. Anything else?
Want Food	**Want Receipt**	**Checkout**
I will be right back with you food	I will be right back with your receipt.	I will process the payment for you.
Sure. I'll be right back.	Sure. I'll be right back.	Sure. I'll be right back.
Replace Food	**Drop Drink**	**Special Request**
Sure. I'll replace that for you.	Don't worry. I will clean it up and get a new drink one for you.	Is everything alright?
No problem. I can replace your food.	No problem. I can replace your drink.	How was everything?

Table 3. Response categories and speech examples.

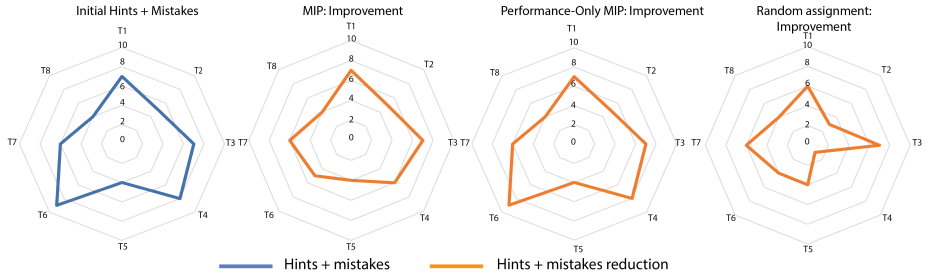

Fig. 1. We performed a simulation experiment to evaluate the effectiveness of our approach in reducing mistakes and the use of hints. By simulating a group of steadily improving trainees, we can compare their performances after receiving three different training conditions. The initial performance of a hypothetical trainee and his improvement after training in three conditions are shown. The improvement pattern resulting from the Performance-Only MIP approach resembles the shape of the trainee's initial performance, showing that it helps improve the trainee's weakness the most, followed by the MIP approach.

Procedure. We created a simple simulator that simulated trainee performance in a training session. Our assumption is that if a trainee received training of a task, her performance of that task could be improved (or stay the same). Thus, this simulator will reduce the number of mistakes and hints asked from zero up to three randomly after each training session.

We first randomly initialized a trainee performance (1 (left)) as preevaluation of a hypothetical trainee. Our goal is to compare trainee performance results under three different training conditions, each with 15 training sessions. In each training session, the trainee will receive training tasks generated based on the trainee's updated performance record. The trainee will improve her skills through training. For comparison, we generate 20 hypothetical trainees, each coming with a different initial performance record.

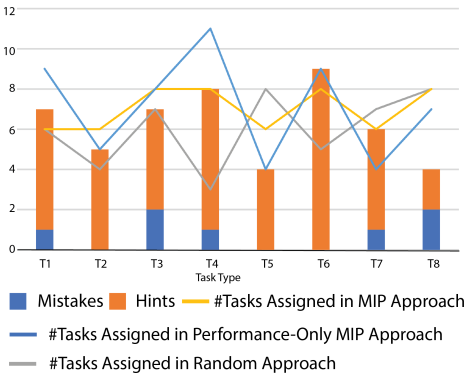

Fig. 2. Results of the simulation experiment of a trainee. The columns show the trainee's initial performance in terms of the number of mistakes made and the number of hints requested for different tasks. The curves show the numbers of times that the tasks were picked for training.

Analysis. We evaluate the improvement of the trainees by comparing the reduction in the number of mistakes and hints from their initial performance results to their final performance results, and then aggregating the results for all tasks. **??** shows descriptive statistics. We conduct a one-way repeated measures ANOVA

on the improvement results of the three approaches to test whether there was a significant difference in trainees' performance due to different training conditions. The results showed that the amount of improvement achieved by trainees was significantly different across the three approaches ($F(2,38) = 122.30$, $p < 0.001$).

We performed paired t-tests to find where the significant effect lies for each pair of approaches(e.g., MIP vs. Random). In general, trainees who received the Performance-Only MIP training had the highest improvement for all tasks in all three conditions; trainees taking the MIP approach has better improvement than those taking the random assignment training. The difference in improvement across the three approaches was significant with $p < 0.05$ for all pairs).

Figure 4 to Figure 6 shows a group of steadily improving trainees's initial performance and overall improvement after training under three different training conditions are shown. The improvement pattern produced by the Performance-Only MIP approach closely follows the shape of the trainee's initial performance, demonstrating its effectiveness in addressing the trainee's weaker areas. Subsequently, the MIP approach also follows this trend.

Discussion. To further understand what causes the different improvement effects across three training approaches, we use a hypothetical user as an example to explain the training effect in three conditions. As shown in 1, this trainee had the largest amount of hints and mistakes reduction in all tasks in the Performance-Only MIP approach compared to the other two approaches. The MIP approach had similar performance except for task 6 and task 4. The Random approach has the worst performance of the three approaches, especially for task 2,4 and 6. This is because the trainee received different amounts of training in each condition (see number of times played for each task in 2).

As we can observe, the Performance-Only MIP approach only considered the trainee's weakness regardless of whether the trainee was tired of doing that task, so it frequently generated tasks that needed to improve the most. Similarly, the MIP approach considered the trainee's weakness, and additionally, her eagerness to learn. Thus the trainee had a chance to perform other tasks that she might already be good at in the beginning. What's more, since the optimizer in the random assignment approach randomly selected tasks for training, the trainee did not have enough opportunities to improve on tasks that she was not good at (i.e. task 2,4 and 6). Instead, she spent a substantial amount of time in training tasks she already knew (i.e. task 5 and 7).

Our assumption is confirmed as the Performance-Only MIP approach focuses solely on performance and ignores two key aspects of user experience: eagerness to learn and tolerance with repetition, leading to a heavily performance-driven training process. In accordance with game design principles and for a more engaging and positive training experience, we choose the MIP approach over the Performance-Only MIP Approach for the virtual reality training experiment. It is noteworthy that the desired level of training effects can be adjusted by changing the weights of the training objectives in our formulation.

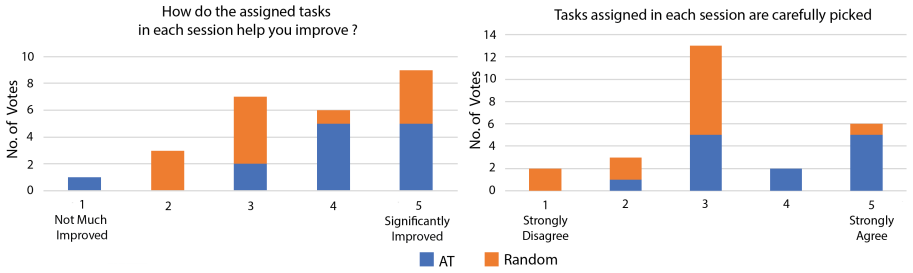

Fig. 3. The open response ratings. In general, all participants believe that they have improved through training. On average, participants from the AT group gave a higher rating (M=4.0, SD = 1.3) for *"How do the assigned tasks in each session help you improve"* than those from the random assignment group (M=3.5 SD=3.4). Besides, participants from the AT group (M=3.8, SD= 1.1) had more confidence in believing that the training sessions assigned to them were carefully picked, compared to the participants from the random assignment group (M=2.7, SD=1.1). This rating difference has a statistical significance (f(24)= 2.8, p<0.01).

3 Additional Details of Virtual Reality Training Experiment

Analysis Discussion. This statistical analysis suggests that adaptive VR training is more effective than random assignment in improving both skill and strategy levels. In general, participants believed that the restaurant simulation training is "realistic", "fun" and "interactive", and all participants enjoyed using VR for training.

Participants from the AT group generally believed that our tool targeted their weaknesses during training and they improved significantly after the training. *"Each step showed a good and well-balanced gradual improvement."* (P7); *"The sessions would get progressively harder, but not overwhelmingly"* (P5); *"It definitely challenged my weak spots, but I was able to train and learn from them."* (P11); Some believed that the overall training task is not difficult enough. *"It is easy to remember to not make huge mistakes after a few sessions."* (P23); *"I improved a lot after the first couple of training, but towards the end, I didn't improve as much and it felt more like refining the skills I had than improvement."*(P13).

Participants from the random assignment group believed that they had some improvement, probably as a result of repetition of practices. *"It is random; sometimes easy, sometimes difficult to me."* (P10); *"My check out tasks failed every time, but I didn't feel that the training session had focused on my weakness."* (P12); *"I felt there was a pattern kind of"* (P18); *"If I were given tasks that I was failing a lot, I would have been able to improve in my opinion."* (P22). Moreover, some believed that the tasks were not complex enough *"It did help me to be more familiar with the drill, but they are not challenging tasks, to begin with."*(P8). One participant was frustrated and confused because he did not think the training session help him improve (P24).

Other Questionnaire Responses. To learn more about the participants' VR training experience, we asked them to fill out questionnaires after the post-evaluation session and collected their general feedback. The results are shown in 3. For the question *"How do the assigned tasks in each session help you improve?"*, the ratings from the AT group participants(M=4.0, SD=1.1) are generally higher than those from the random assignment group(M=3.5, SD = 1.2).However, a two-sample t-test showed that there was no significant difference in the ratings. In general, participants from both groups believed that their restaurant service knowledge and multitasking skill had improved.

Fig. 4. We generated 20 hypothetical trainees to compare the training performance of three different conditions. Their initial performance and improvement records(in terms of reducing number of hints use and mistakes made) are shown.


User 9 Performance
User 10 Performance
User 11 Performance
User 12 Performance
User 13 Performance
User 14 Performance
User 15 Performance
User 16 Performance
T1
T2
T3
T4
T5
T6
T7
T8
Initial Hints+mistakes
MIP Approach Improvement
Performance-Only MIP Approach Improvement
Random Approach Improvement

Fig. 5.

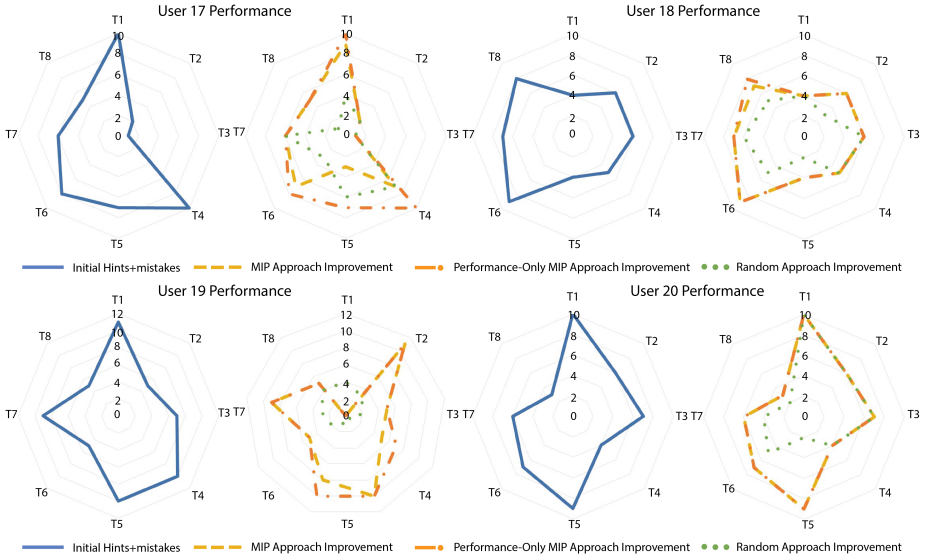
User 17 Performance
User 18 Performance
User 19 Performance
User 20 Performance
T1
T2
T3
T4
T5
T6
T7
T8
Initial Hints+mistakes
MIP Approach Improvement
Performance-Only MIP Approach Improvement
Random Approach Improvement

Fig. 6.