A. Task Details

1. Math Task

In Table 1. the difficulty levels for a math problems are displayed. In Table 2. the different guidance strategies per level are displayed. Moving up to or down from level 2, 5, 9, and 14 triggers a proactive guidance sequence, where the robot uses an example math problem to demonstrate the new breakdown strategy.

Table 1. Math problem difficulty levels.

Level	Problem	Example
0	{2, 5, 10} x [2, 10]	5 x 8
1	[2, 10] x [2, 10)	3 x 7
2	[2, 10] x [1, 10) * 10	6 x 60
3	[2, 10] x [1, 10) * {100, 1000}	8 x 700
4	[2, 10] * 10 x [2, 10) * 10	30 x 40
5	[2, 10] x [11, 20)	9 x 13
6	[2, 10] x [11, 100)	4 x 76
7	[2, 10] x [11, 100) * 10	5 x 340
8	[2, 10] x [11, 1000)	6 x 123
9	[11, 20) x [2, 10) * {10, 100, 1000}	17 x 6000
10	[11, 100) x [2, 10) * {10, 100, 1000}	36 x 700
11	[11, 20) x [11, 20)	12 x 14
12	([2,10) * [2, 10)) x ([2,10) * [2, 10))	36 x 64
13	[11, 100) x [11, 100)	34 x 65
14	([2,100) * [2, 10)) * ([2,10) * [2, 10))	128 x 42
15	([2,100) * [2, 10)) * [11, 100)	128 x 51
16	[11, 1000) x [11, 100)	374 x 34
17	([2,100) * [2, 10)) x ([2,100) * [2, 10))	220 x 310
18	[11, 1000) x [11, 1000)	221 x 307

Table 2. Guidance strategies

Name	Level	Example	Guidance
Table	0, 1 (2x, 5x, 10x)	5 x 4	Let's write down all the members of this multiplication table and solve them one by one until we get to our sum.. 5x1=, 5x2=, 5x3=, etcetera.
Support Sum	1 (3x, 6x, 9x)	6x7	Let's find the nearest support sum. Found it! It's 5x7. Our sum is only7 away from the support sum. Let's first solve 5x7 and then add 7 to get our answer.
Double	1 (4x, 8x)	4 x 9	Let's double our way to the answer. We start with 2 x 9. If we double the answer, we get to 4x9.
Split 7	1 (7x)	7 x 9	We can split 7 up in to 2 and 5. This gives two helper sums we have to solve. 2x9 and 5x9. By adding the answers to both helper sums, we get the answer we are looking for.
Small Sum	2, 3	3 x 400	400 is 100 times bigger than 4. We can first solve 3 x 4. We call this the small sum. Then we can multiply the answer with a 100 to get to 3 x 400.
Counting zeros	4	30 x 40	We can reduce it to the support sum of 3 x 4. To get to this base sum we leave out 2 zeros. These zeros will be appended to the answer.
Split right	5, 6, 7, 8	6 x 17	Let's split 17 into 10 and 7. This gives two helper sums we have to solve. 6x10 and 6x7. By adding the answers to both helper sums, we get the answer we are looking for.
Split left	9, 10, 11, 12, 13	12 x 14	Let's split 12 into 2 and 10. This gives two helper sums we have to solve. 2 x 14 and 10 x 14. By adding the answers to both helper sums, we get the answer we are looking for.
Column wise multiplication	14, 15,16, 17, 18	128 x 42	Write the biggest number on top of the smaller number. Hundred above hundred, tens above tens, and units about units. 128 42 Start on the right side. Multiple first he unit with the unit. Then the unit with the ten, hundred, etc. Continue until you multiplied every number from the bottom row with the top row. Right down every intermediate answer and add them together.

B. Data Details

1. Questionnaire

In Table 3 the individual items for the Likert scale for relationship formation together with the manipulation checks.

Table 3. Items of Relationship Formation Scale and Manipulation Checks.

	Items	
Relationship Formation	RF1. Do you feel comfortable around the robot?	
	RF2. Does the robot suit you well?	
	RF3. Does the robot feel like a friend to you?	
	RF4. Would you like to chat further with the robot?	
	RF5. Would you like to do more activities with the robot?	
	RF6. Would you like to see the robot more often?	
Manipulation Checks	Perceived Memory Reference	Did the robot use things you said while chatting to create a math story?
	Story Interest	Did you find the math stories the robot told interesting?
	Feeling Remembered	Did the robot remember you from last time?

Answer scale: 1 = *no, definitely not* till 4 = *yes, definitely so.*

C. Creative Details

A storyworld is a tool for creating dialogs for a multi-session child-robot conversation [1]. It is a transmedia narrative that situates the robot in a fictional world and connects it to the real world. Our storyworld describes the robot as a story character, with hobbies and quirks, but it takes into account its real physical and cognitive capabilities and limitations. This provides the necessary anchor points and topics for writing short connected dialogs. Hobbies can, for example, include cooking (albeit clumsily), but not swimming (because it would short circuit). A key quirk is the robot's curiosity. It provides a motivation for why the robot asks so many questions.

The storyworld furthermore provides fictional goals the robot wants to achieve. For example, the robot is trying to figure out what kind of robot it wants to become. This lead to a series of dialogs about different jobs the robot has tried out. The storyworld also describes goals the robot wants to achieve in the real world. The main goal is, of course, helping the child improve their math skills. Dialogs are created to reflect these goals.

Math dialogs were created to be consistent with the storyworld. They revolved around fictional jobs the robot had prior to being a math tutor robot. These jobs are all related to the most popular interests and hobbies among children of the targeted age groups. They are based on the concept op mini-dialogs by [1]. The math content was co-developed with a mathematics education researcher and tested in a prior study [2].

D. Ethical Details

We followed a child-centered design approach, this includes, for example, configuring the software and the study set-up in such a way we can safeguard the privacy of children. The speech recognition and memory system did not process identifiable information (e.g. child’s name). The child’s name was entered manually in the system each session, for using it during the conversation, and was not persistently stored. The child’s preferences that were stored, were selected based on their low-risk nature (e.g. favorite farm animal, (dis)like of reading). See chapter 6.6 in [1] for a more extensive discussion of the ethical considerations that are important to make for these type of applications and running these type of studies.

E. Technical Details

We developed a rule-based artificial cognitive agent to allow the robot to autonomously manage a multi-session child-robot conversation. Sensor data, such as audio from the microphones and button presses, are streamed to the agent. The agent has access to services, such as Google Dialogflow for speech and intent recognition, and a database for persistent storage. The agent has a knowledge base filled with templated dialogs including meta-data that includes a topic, required information to fill the template slots, and relationships to other dialogs. The knowledge base also has a multi-session template specifying required dialogs and goals for each session. Finally, the agent has a rule base that specifies rules for dialog management and personalization. Using the incoming perceptual information and the knowledge and rule bases, the agent reasons about which conversational action to perform next.

Code is available here: https://bitbucket.org/socialroboticshub/sorocova-back-to-school/src/main/

References

[1] M. E. U. Ligthart, “Shaping the Child-Robot Relationship: Interaction Design Patterns for a Sustainable Interaction,” PhD-Thesis - Research and graduation internal, Global Academic Press, Culemborg, 2022.

[2] Anonymized.