Appendix 1 - Research Report

SUMMARY

This study investigates abstract conceptual learning and generalisation abilities, focusing on abstract financial concepts. This research is carried out within an ecological context of naturalistic social interactions, where the moment-to-moment dynamics are examined, including measures of both teacher and learner, and both behavioural and neural responses. The first objective of this project is to study whether brain-to-brain synchronisation can predict successful learning of financial abstract concepts, compared to cases in which children did not successfully learn the concepts. The second objective is to evaluate if behavioural coordination (e.g., questions and answers) predict learning. Finally, the third objective is to test the correlation between neural coupling and behavioural coordination to establish how specific behaviours contribute to brain synchronisation. Overall, this study allows us to achieve a comprehensive understanding of the underlying behavioural and neural mechanisms that support children's learning of financial abstract concepts within a naturalistic social interaction.

METHODS AND PRELIMINARY FINDINGS

Participants

This research study involves children aged between 5 and 12 years old. This broad age group is divided into three groups. We have now completed data collection for the first group (children aged 8-9) and we are collecting data from the other two groups: children aged 6-7 and 10–11-year-olds.

<u>Age group 8-9:</u> 26 dyads of caregivers and children were recruited for this study through London schools, social media, and UCL parents' community. Participants were native English speakers, and children were typically developing. Caregiver mothers (18) and fathers (7) had a mean age of 44.54 (*SD*=3.69). Children's mean age was 103.86 months old (*SD*=7.25), 17 girls and 8 boys. The study obtained full ethical approval from the UCL Research Ethics Committee (ID number: 24039/001).

Study design

In this study, the caregiver-child dyads engage in an interactive game-style task in which the caregiver teaches the meaning of novel abstract concepts to the child. The child is shown an array of four pictures in each trial and is asked to select the corresponding picture to the target concept. The child's overall learning outcomes are assessed within the main experimental session, as well as one week after, to evaluate whether the learning is sustained over time.

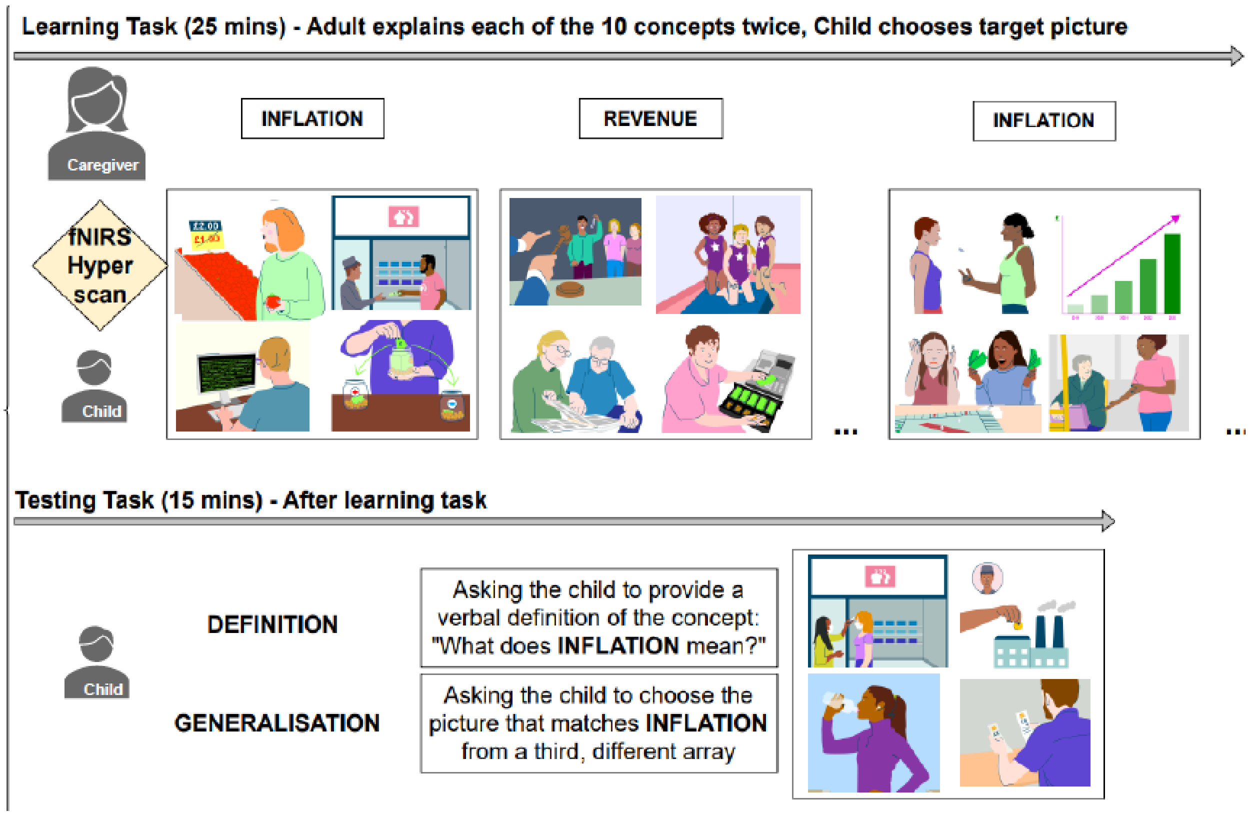
Experimental procedure

This study involves a short, pre-experiment online questionnaire where we collect demographic information about the participants and present additional information about the study to the caregivers as well as 3 experimental sessions: one main in-person session, an online follow-up session one week later, and a final face-to-face session where we implement language and cognitive evaluations.

The first, main experimental session is conducted in person and consists of a concept learning task and a testing task, in which the caregiver teaches novel concepts to their child while we record the brain activity of both caregiver and child simultaneously using functional near-infrared spectroscopy. In this learning phase, the adult and child are asked to interact naturally, and to have a conversation about the different concepts. The child is tasked with selecting a picture before the end of the trial using their touchscreen laptop. Across the learning phase, each concept is presented twice, each time with different target pictures and fillers. This has the goal of encouraging the child to learn about each concept across different contexts of real-world scenarios thus to generalise the meaning across varied situations. During testing, the child is asked to verbally explain what the meaning of the concepts they were exposed to is. Secondly, for each concept, the child is shown a third, yet different array of pictures to the ones seen during learning and is asked to select the corresponding picture for each concept. The main experimental session design including the learning and testing phase can be seen in Figure 1.

Figure 1

Main experimental session design: learning and testing phase



The second session is scheduled for a week after the first in-person session. The follow-up consists of an online video call between the child and the experimenter, who repeats the testing task conducted in the main in-person session. Additionally, we collect cognitive measures from both caregiver and child during a third face-to-face meeting at UCL or at participants' homes, scheduled within four weeks from the first main experimental session.

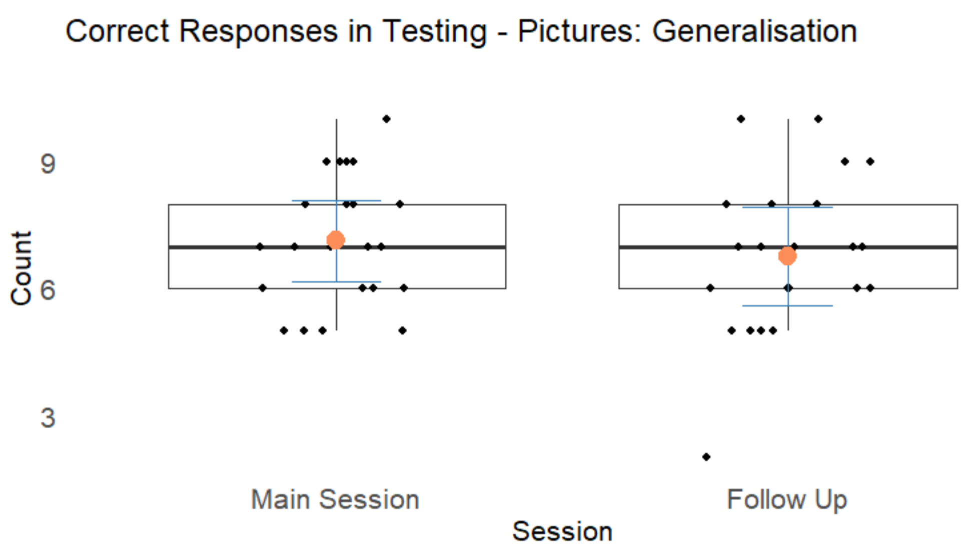
Learning Outcomes

During the learning phase, participants obtained a mean score of 7.32 (*SD*=1.29) in the first learning trial and a mean score of 7.5 (*SD*=1.30) from a possible total of 10 points in each trial.

Results from the testing phase indicate that the novel interactive game-style abstract concept learning task is working as intended. After taking part in the task, children's knowledge of the newly introduced concepts is evaluated. When tested for generalisation abilities in the picture selection test, children successfully generalised their knowledge of a newly learnt concept to new, different real-world situations, obtaining a mean score of 7.14 (*SD*=1.52) during the main session and a mean score of 6.77 (*SD*=1.88) at the one week later follow up (Figure 2).

Figure 2

Number of Correct Responses in Picture Selection Test evaluating Generalisation Abilities in the Main Session and at Follow-up.

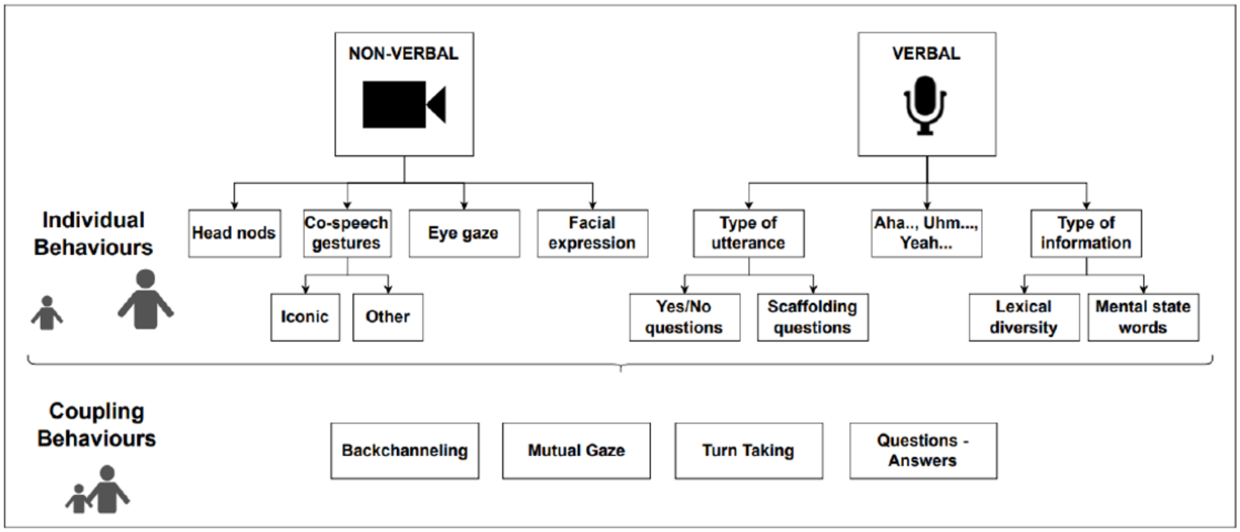


To determine if the proportion of correct responses differed from the chance level (0.5), which would be obtained by randomly selecting one of the two financially related pictures, we conducted a 1-sample proportions test with continuity correction The results showed a significant difference, X2(1,N=44)=58.24,p=2.32×10−14. The observed proportion of correct responses was significantly higher than the chance level (p^=0.770), with a 95% confidence interval ranging from 0.705 to 0.824. This indicates that children performed significantly better than what would be expected by chance, suggesting that children were making informed decisions rather than guessing randomly. Furthermore, when evaluated for their ability to define the meaning of the newly learnt concepts, children were able to successfully define concepts that they were not familiar with before taking part in the study, obtaining a mean score of 7.45 (SD = 3.51) in the main session and 7.5 (SD = 3.64) at follow up.

Multimodal behaviours

Annotation of multimodal communication is a complex task. In the case of this study, we video record the whole interaction allowing us to capture both verbal and non-verbal behaviours as summarised in Figure 3.

Figure 3
Data acquisition of multimodal behaviour: channels and outcomes

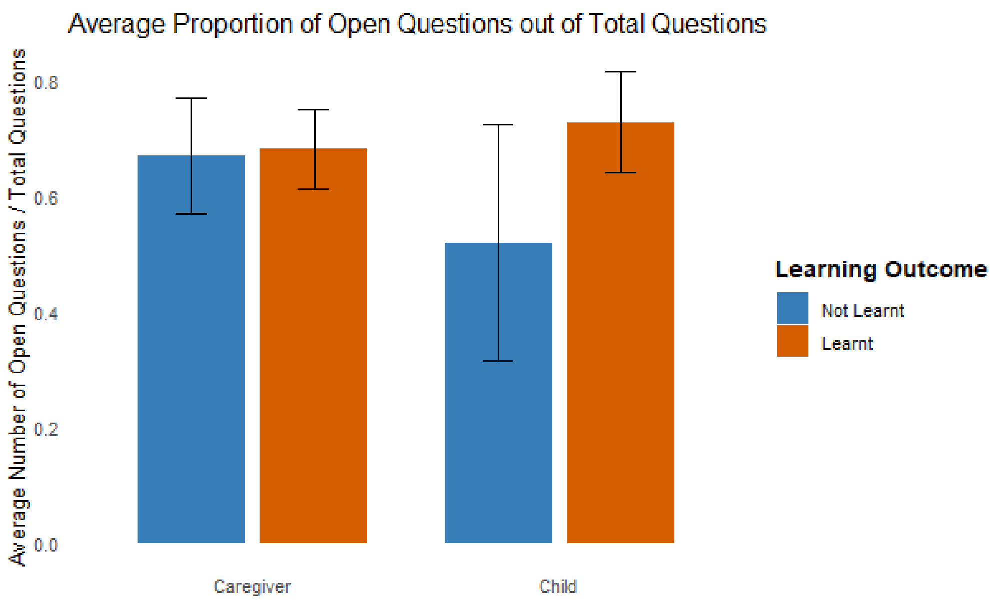


Novel Pipeline for Automatic Transcription and Annotation of Coordinative Verbal Behaviours

To analyse the verbal behaviours during the task, we developed a novel pipeline to automatically transcribe and annotate the conversations between caregivers and children, streamlining the analysis of verbal coordinative behaviours within the dyads.

The key coordinative verbal behaviours include sequences of questions and answers, differentiating between closed-ended questions (i.e., questions that were answered by the other speaker with one word only) and open questions (i.e., answered by the other speaker in larger extent), number of turns taken, and number of verbal backchannels produced by the caregivers and children during the game. This pipeline has been applied to an initial sub-sample of 17 dyads. Figure 4 shows the average proportion of open questions out of total questions produced by caregivers and children across trials that resulted or did not result in learning.

Figure 4



To investigate the effects of verbal coordinative behaviours on the learning outcome, we fitted a generalised linear mixed model (GLMM) with a binomial distribution and logit link function to the data (Table 1). The model included the fixed effects of speaker (caregiver or child), proportion of open questions out of total questions, the proportion of general backchannels out of total utterances, the number of utterances, the proportion of turn switches out of total utterances, BPVS score, digit span score, and age in months. Random intercepts were included for participants and trials. The model indicated significant effects of the proportion of open questions (p=0.046) and vocabulary raw score (p=0.002) on learning outcomes. No other predictors were found to be significant.

Table 1

Predictor	Estimate (β)	Std. Error (SE)	z-value	p-value	Odds Ratio	95% CI
Intercept	0.158	1.142	0.139	0.890	1.17	0.12 - 10.99
Speaker (child)	-0.580	0.835	-0.694	0.487	0.56	0.11 - 2.88
Proportion of open questions	**0.347**	**0.173**	**1.999**	**0.046 ***	**1.41**	**1.01 - 1.99**
Proportion of backchannels	0.176	0.307	0.573	0.567	1.19	0.65 - 2.18
Number of utterances	0.019	0.021	0.915	0.360	1.02	0.98 - 1.06
Proportion of turn switches	0.595	0.383	1.554	0.120	1.81	0.86 - 3.84
BPVS raw score	**0.886**	**0.281**	**3.151**	**0.002 ****	**2.42**	**1.40 - 4.20**
Digit span total score	0.276	0.270	1.019	0.308	1.32	0.78 - 2.24
Age in months	-0.285	0.265	-1.077	0.281	0.75	0.45 - 1.26

Note: *p < .05, **p < .01

These results suggest that the proportion of open questions and vocabulary scores are significant predictors of learning outcomes in this study.

Brain-to-brain Synchronisation:

Functional near infra-red spectroscopy is a non-invasive neuroimaging technique that exploits the natural occurring phenomena whereby different tissues in our body absorb light differently. With pre-processing and data analysis pipelines, we convert the changes in light intensity to changes in concentration of HbO2 and HbR and use it to analyse brain activity. This wearable and non-invasive technology allows us to measure brain activity in two people at the same time, and in a naturalistic context of face-to-face conversation. For this study, we use the Hitachi ETG 4000 device, an optical topography system for real-time cerebral cortex imaging and measurement. The device has a total of 18 sources and 16 detectors, which we split into two bundles of optodes to conduct the measurement in two participants simultaneously. For each participant, we use a 3x5 pre-made probe, each of which holds 8 sources (red) and 7 detectors (blue), creating 22 channels per participant.

Previous hyperscanning studies of social interaction have identified greater coherence in specific brain areas known to be involved in social interaction and particularly in social learning. These areas include dorsolateral prefrontal cortex (dlPFC), engaged in the perception of others' actions, the middle temporal gyrus, involved in language processing, and the temporoparietal junction (TPJ), implicated in processing of others' mental states and belief understanding, crucial for social learning.

In the current study, brain synchrony between caregiver and child during the learning task is assessed using wavelet coherence analysis performed with the MATLAB R2023b function wcoherence. To evaluate whether the regions of interest predict successful learning of novel abstract concepts, we build a general linear mixed effects regression model of inter-brain coherence between caregiver and child predicting learning outcome (definition performance) in the main session (Table 2).

Table 2

GLMER model output for the Medium Frequency Band (0.03-0.1 Hz)

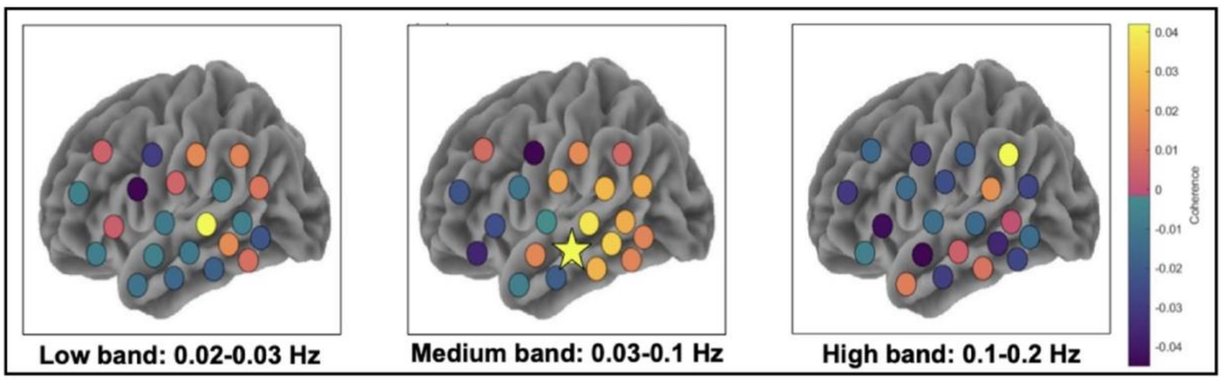
	definition_performance_numeric		
Predictors	*Odds Ratios*	*CI*	*p*
(Intercept)	1.67	0.73 – 3.83	0.222
ch 7 med	1.43	1.06 – 1.94	**0.019**
ch 14 med	1.20	0.90 – 1.61	0.221
ch 18 med	0.90	0.68 – 1.18	0.437
Random Effects			
σ^2	3.29		
$\tau_{00\ trial\_full}$	1.44		
$\tau_{00\ dyad\_num}$	1.50		
ICC	0.47		

N_{dyad_num}	18
N_{trial_full}	20
Observations	322
Marginal R^2 / Conditional R^2	0.027 / 0.486

The preliminary results on 18 dyads indicate that among the predictors, only channel 7, located over middle temporal gyrus (Figure 5) has a statistically significant effect showing that higher brain-to-brain synchronisation over this region is a relevant predictor of learning.

Figure 5

Preliminary results for n=18. Coloured dots show brain-to-brain Wavelet Transform Coherence (based on CBSI) by channel in trials that resulted (0 to 1: Learning > No Learning) vs. did not result (-1 to 0: No Learning > Learning) in learning.

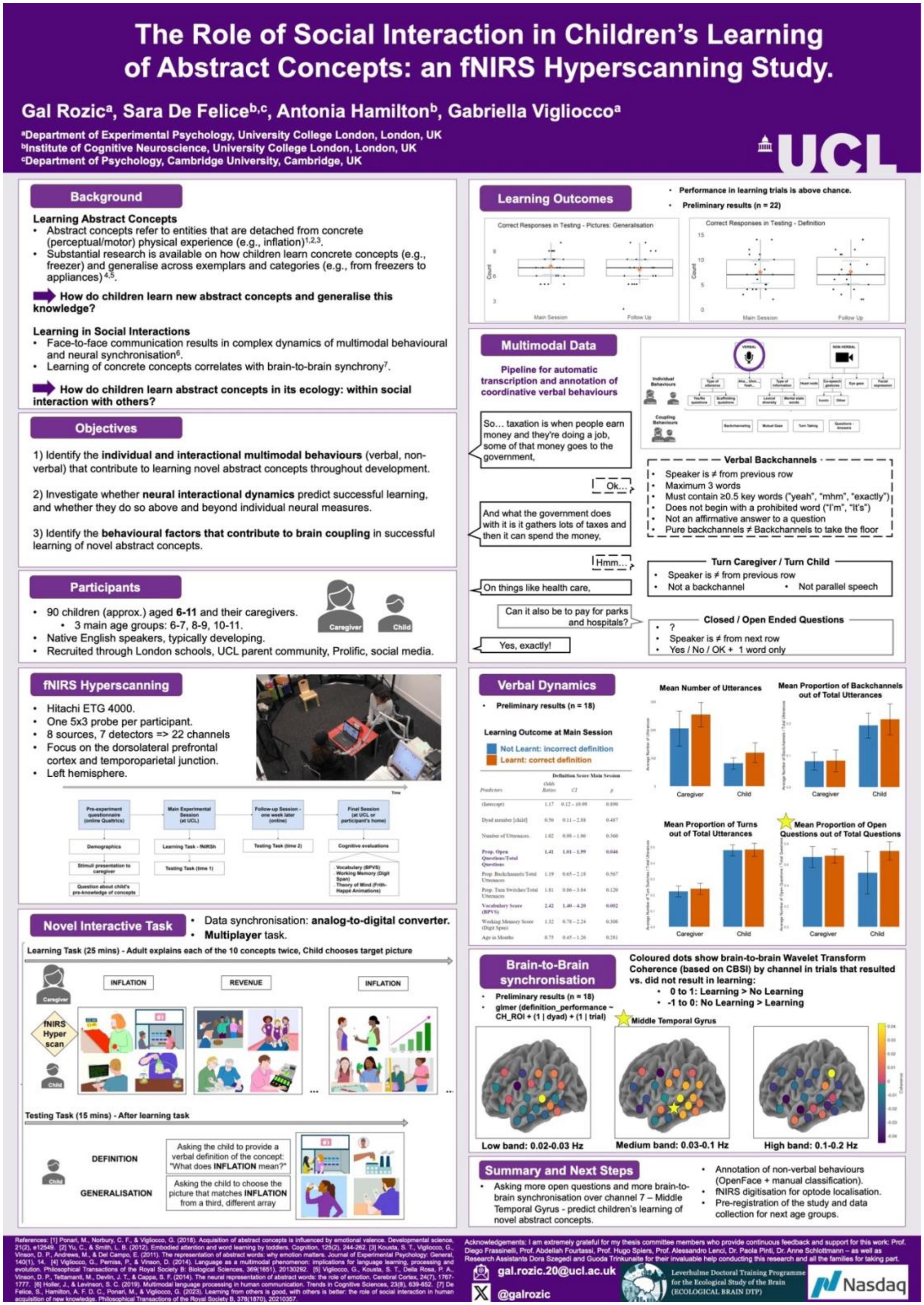


*These data are preliminary – results may change as the full sample is included in the analysis.

INTERIM SUMMARY AND NEXT STEPS

Overall, the study has been moving forward as expected and the preliminary data has yielded insightful findings regarding the different coordinative behaviours and neural dynamics that predict successful learning of financial abstract concepts. Not only are we validating that the newly developed interactive concept learning task works, as children are successfully learning the meaning of novel concepts, but we are also able to identify the specific coordinative behaviours of the dyad and brain-to-brain synchronisation dynamics that support this process. The study has also generated great interest in the research community, with several poster presentations being accepted at international research conferences and awards received for these. A crucial aspect of this project is being able to determine the developmental trajectories of learning and to investigate whether the predictors identified as significant for this first age group, are also relevant for other age ranges. We must take advantage of the materials, tasks, and analysis pipelines developed so far to further elucidate the mechanisms that support the learning of financial concepts of younger and older children, as this will provide a comprehensive understanding of the development of learning abilities and the role of naturalistic social interaction in this process.

Appendix 2 - Research Poster



Appendix 3 – Members update for Financial Education Forum UK

UPDATE: Investigating How Children Learn Financial Abstract Concepts within Social Interaction

At University College London, we've embarked on an exciting research project that explores how children learn complex financial abstract concepts through naturalistic, social interactions. Our goal is to uncover how children aged 6-11 learn the meaning of novel abstract financial concepts—such as inflation or fraud—when they learn with their caregivers in a face-to-face conversational setting.

Key Research Insights So Far

Our study is ongoing, but the preliminary findings are promising:

· Brain-to-brain Synchronisation Predicts Learning: We found that when parents and children engage in a concept-learning game-style task together, their brain activity can become synchronised. This brain-to-brain synchrony, particularly in regions responsible for language processing and comprehension, correlates with successful learning of financial concepts.

· Multimodal Communication Matters: We've also observed that coordinative verbal behaviours (such as asking open-ended questions) play a crucial role in learning. These dyadic behaviours during interaction appear to predict children's ability to learn novel financial concepts.

· Learning that Lasts: Children were able to generalise what they learned to new, real-world situations. Even when presented with new scenarios one week after the learning session, children demonstrated a sustained understanding of the concepts.

Why This Matters for Financial Education

This research has practical implications for how we teach financial literacy in classrooms and at home. By understanding the importance of interactive, social learning—and how children's brains respond to this engagement—we can develop more effective educational strategies:

· Interactive Learning Is Key: Instead of one-way instruction, fostering a two-way conversation where children can ask questions and engage in dialogue helps deepen their understanding.

· Role of Caregivers: Caregivers are not just facilitators but active participants in the learning process. Understanding this dynamic can help us create resources that empower parents to teach financial concepts more effectively at home.

· Generalisation and Long-term Retention: Our study shows that when children learn through real-life examples and social interaction, they are likely to retain and apply financial concepts over time to new, different contexts.

Next Steps

We will continue expanding the study to younger and older age groups (6-7 years and 10-11 years) to track the developmental trajectory of financial abstract concept learning. This work will help educators better understand how learning styles evolve with age and how to tailor financial education accordingly.

If you'd like to know more about our findings or how they can inform financial education programmes, please see our research poster, and feel free to contact Gal Rozic, gal.rozic.20@ucl.ac.uk, UCL.