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Ackoff Doctoral Student Award Proposal

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Title: The Development of Common Knowledge Representation
Faculty Advisor: Robert Kurzban

Descriptive Summary

The aim of this project is to investigate the development of common knowledge representation. Individuals A and B have *mutual knowledge* of X if they both know X; A and B have *common knowledge* of X if, in addition to mutual knowledge of X, A knows that B knows that A knows… ad infinitum… X (Schelling 1960, Lewis 1969). Philosophers and game theorists have explored at some length the difference between these knowledge states with regard to decision making, perhaps most famously in the "dirty faces problem" (Littlewood 1953) often repeated in game theory textbooks (e.g. Fudenberg & Tirole, 1996). Given the critical difference between mutual and common knowledge in decision making theory, it is of interest to know whether and how people distinguish these knowledge states. In cognitive terms, the question is whether people can *represent* common knowledge as distinct from mutual knowledge. This project employs a developmental approach to this question. At what age are children able to represent common knowledge? How does fluency with reasoning about common knowledge change over the course of development? A developmental mapping of common knowledge representation will facilitate inferences regarding its relation to other cognitive abilities.

Game theory examines decision making in circumstances in which other decision makers are a principal source of uncertainty. Standard game theoretic models assume agents possess several types of knowledge regarding other agents' minds: agents know other agents'

1) *desires* or preferences, as operationalized by a utility function,
2) *beliefs*, represented as probability distributions over states of the world,
3) *finite recursive beliefs*, i.e. beliefs about beliefs about beliefs etc. to arbitrarily numerous levels of recursion, and
4) *common knowledge*, which implies an infinite recursion of belief as described above.

From a psychological perspective, it is these assumptions which are most interesting. How do people represent others' desires, beliefs, recursive beliefs, and common knowledge? How are these representations updated, manipulated, and employed? The project of mapping the cognitive skills and inference procedures that underpin "mentalizing" abilities is well underway, particularly in cognitive neuroscience and developmental psychology (Frith & Frith, 2003). It has been found that mentalizing follows a definite developmental trajectory, including special attention to human faces in infants, gaze following at 1 year, joint attention and pretend play at 1.5 years, mental verb use among 2 year olds, and perhaps most famously, the ability to represent false beliefs at age 4. Limitations on adult mentalizing abilities have also been explored (Birch & Bloom, 2004), including the limits of recursive reasoning (reviewed by Colman, 2003).

While desire, belief and recursive belief have been substantially investigated, common knowledge representation remains largely unexplored. Since Schelling's (1960) early discussion of common knowledge, it has been suspected that people are able to use common knowledge of focal points to solve the problem of equilibrium selection in coordination games. Empirical investigations (Mehta et al., 1994, Bardsley et al., 2001) have supported Schelling's informal experiments, indicating that adults use common knowledge to solve coordination problems. This is intriguing because common knowledge, requiring an *infinite* recursion, cannot practically be computed by belief recursion. This suggests that common knowledge representations require cognitive mechanisms distinct from those underpinning belief recursion. Common knowledge may have its own set of proxies for identifying when common knowledge obtains, and perhaps an independent developmental timetable. A developmental assay can clarify the relations of common knowledge representation to other types of mentalizing abilities.

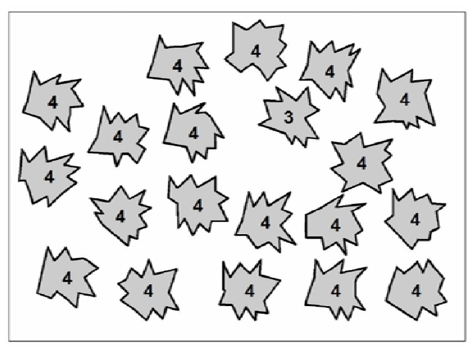
The foregoing analysis yields the following experimental hypothesis:

***Hypothesis**: Common knowledge representation is underlain by cognitive mechanisms distinct from those associated with other types of mentalizing, and has a distinct developmental time course. In particular, common knowledge representation will reach adult proficiency in late adolescence, well after belief and belief recursion are known to approach adult levels.*

Methods. Coordination games will be used to examine common knowledge representation. Participants play games for points, which are redeemed for cash or school supplies, depending which is age-appropriate. In all games, there is common knowledge of a focal solution, but this solution is designed to be different from the choice that an individual would choose in isolation, and different from what an individual would guess that another would choose in isolation, and so on. Thus one equilibrium or set of equilibria will be chosen by agents possessing common knowledge of a focal point, while a different set will be chosen by agents without common knowledge.

Task 1 seeks to replicate Bardsley et al.'s (2001) result and to extend the method to examine children's competence. In addition to adults, children of various ages will be examined to pinpoint developmental shifts. Participants will be randomly divided into two groups. They will be presented with 15 games consisting of a box containing four word items. Participants are asked to circle one item in each box in four different within-subject conditions: matching, picking, guessing, and odd-one-out.

In the matching condition, participants are anonymously paired with a partner in the other group. If both partners pick the same word, they earn a point; if they pick different words, they earn no points. In the picking condition, participants pick their favorite item. In the guessing condition, participants guess which items most others will pick in the picking condition. Finally, in the odd-one-out condition, participants choose the item that is most different from the other three items. Experimental stimuli have been pilot tested to ensure that the "picked" items are different than the "odd-one-out" item.



Task 2 extends the investigation to another coordination game. Choice sets consist of 20 nondescript shapes. Participants circle one shape. If they circle the same shape as a randomly chosen partner in the opposite group, they receive the number of points indicated inside the shape. This game induces individual preferences, while a different item stands out by virtue of its lower payoff. Common knowledge reasoning uniquely yields the rare item with lesser payoff since any number of belief recursions must begin with a preference for the greater payoff. Note that participants are aware (checked by a quiz) that their partners will view the same objects in a different configuration. Thus object position cannot be used to coordinate.

Analysis. Coordination success will be measured by converting all responses to a probability of a match with an individual in the opposite group. These match probabilities will be averaged across responses for each individual, and then across individuals, allowing mean tests of success across conditions and ages. It is predicted that adult level proficiency will be attained in late adolescence.

References
Bardsley, N., Mehta, J., Starmer, C., & Sugden, R. (2001). Coordination: Derivative or Schelling Salience? University of East Anglia working paper.
Birch, S. A. J. & Bloom, P. (2004). Understanding children's and adults' limitations in mental state reasoning. *Trends in Cognitive Science*, 8, 255-260.
Colman, A. (2003). Depth of strategic reasoning in games. *Trends in Cognitive Science*, 7, 1–2.
Frith, U. & Frith, C. D. (2003) Development and neurophysiology of mentalizing. *Philosophical Transactions of the Royal Society of London B*, 358, 459–473.
Fudenberg, D. & Tirole, J. (1991). *Game Theory*. Cambridge, MA: MIT Press.
Lewis, D. (1969). *Convention: A Philosophical Study*. Cambridge, MA: Harvard University Press.
Littlewood, J. E. (1953). *Mathematical Miscellany*, ed. B. Bollobas.
Mehta, J., Starmer, C., & Sugden, R. (1994). The nature of salience: An experimental investigation in pure coordination games. *American Economic Review*, 84, 658–73.
Schelling, T. (1960). *The Strategy of Conflict.* Cambridge, MA: Harvard University Press.

Project Budget and Justification

Undergraduate RA's		
	1 @ 10hr/week 36 weeks ($7.50/hr)	$2,520.00
	EB's (@ 9.7%)	$488.88
Participant Payments		
	$10/adult 30 participants	$300.00
	$5/child 120 participants	$600.00
Conference Expenses		
	Travel & Lodging	$750.00
Total		$4,658.88

Undergraduate Research Assistant. Working with young children is labor-intensive. To help with running the experimental sessions, I am asking for one part-time undergraduate research assistants for the weeks when the University is in session.
Participant Payments. All adult participants are guaranteed a $5 show up fee. They will earn additional money during the course of the experiment depending on the decisions they make. Adult participants will earn an average of $10 in an experimental session. Children's incentives will be prizes consisting of school supplies. All children will receive a prize for participating, and will be able to earn more prizes as a result of their decisions. Children's prizes will have an average value of $5. Thirty participants in each of four age levels will be studied.
Conference Expenses. Experimental results will be presented at a conference, requiring funding for travel and lodging.

Other Sources of Funding

This project is not receiving funds from any other sources at this time. However, the project is supported by a wealth of non-financial resources. Regarding adult participants, I act as the administrator of the Experiments @ Penn internet recruitment system and have access to a subject pool of over 1200 undergraduates. Also, I will run adult experimental sessions at the PLEEP laboratory at the University of Pennsylvania. Regarding child participants, I am a former 2nd grade teacher, and I belong to an association of Philadelphia teachers (Teach For America Alumni Association), which has allowed me to network into schools to recruit school children as participants.