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Heil, Cathleen

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Double perspective taking processes of primary children – adoption and application of a psychological instrument

Cathleen Heil

Leuphana University, Lüneburg, Germany; cathleen.heil@leuphana.de

Perspective taking can be conceptualized in the framework of mental transformations in terms of subsequent egocentric transformations. Kozhevnikov and Hegarty's (2001) PTSOT is a test instrument for adults that investigates double perspective taking processes. Both perspective taking processes can be defined by certain egocentric transformations. An adoption of this test for primary children reveals that they are able to understand the test and verbalize easily their thinking processes. 8 items were solved by 254 fourth graders. Results show a variety of typical difficulties that can be interpreted in detail using the egocentric transformations framework. The theoretical framework and the straightforward way of item construction allow us to systematically generate items for various applications in psychology and mathematics education.

Keywords: Egocentric transformations, geometric thinking, perspective taking, spatial abilities.

Theoretical background

Spatial abilities have widely been debated within mathematics education, with a multitude of meanings and definitions (Mulligan, 2015). Discussions within WG4 in CERME highlight implicitly the implication of those abilities on all four geometrical competencies to support geometrical thinking that were proposed by Manschietto et al. (2013).

Psychometric studies on individual differences have shown that the construct of spatial ability is multidimensional and consists of several spatial ability factors (e.g,, McGee, 1979; Linn & Petersen, 1985). Although the exact factor structure of spatial abilities remains a subject of intensive debate, some of these factors were studied in detail, both for adults and children. One of these factors, spatial orientation, also denoted as perspective taking in the literature, was proposed to measure the ability to imagine the appearance of a set of objects from different orientations (perspectives) of the observer (McGee, 1979).

In the experimental cognitive literature, spatial abilities have been conceptualized as the ability to engage different mental transformations that require the subject to update an encoded visual stimuli with respect to three different frames of reference: the intrinsic reference frame of objects, which encodes relations among objects, the egocentric frame of reference, which encodes object locations with respect to one's body, and the environmental frame of reference (Huttenlocher & Presson, 1973; Zacks et al., 2000). Perspective taking ability has been defined as the ability to perform a set of egocentric transformations on objects, in which the relationship between the environmental coordinate frame and those of the objects remain fixed, while each of their relationships with the observer's egocentric reference frame are updated. Although the conceptualization of perspective taking within the theoretical framework of mental transformations is logically equivalent to the qualitative description of the factor spatial orientation, it adds value for the deconstruction of complex perspective taking into separable, analyzable transformation processes.

Perspective taking abilities have been studied extensively in the developmental psychology literature (see Newcombe, 1989, for a full review). It has been highlighted that children demonstrate first perspective taking abilities even in infancy, show first achievements on more advanced tasks at around 4 or 5 years and improve performance considerably between the age of 6 and 8 (Frick et al., 2014). Complex perspective taking tasks that involve typically conflicting frames of references such as Piaget and Inhelder's (1956) *Three Mountains Task* are not fully mastered until the end of primary school. Although the involvement of conflicting frames of reference in perspective taking tasks, e.g. the involvement of a to-be-imagined frame of reference that conflicts with the child's direct relation to the visual stimulus, has received criticism (see Huttenlocher & Presson, 1973, for a detailed discussion), it is valuable from a spatial cognition point of view. Tasks with conflicting frames of reference are of high interest, because they demand for the ability to represent, maintain and coordinate multiple frames of references within one coherent spatial framework. This ability is meaningful and predictive for a whole range of everyday life spatial abilities, such as misaligned map reading (Lobben, 2004), environmental learning and wayfinding (Allen, 1999; Hegarty et al., 2006). A deeper understanding of perspective taking processes involving conflicting frames of references allows us therefore to discuss spatial abilities of primary children in a much broader context. This is consistent with the mathematics curriculum but also curricula of applied sciences and geography.

A qualitative re-analysis of typical markers of perspective taking ability such as the Guilford and Zimmerman (1948) Spatial Orientation Test for adults turned out not to be construct valid as being solved mostly by mental rotation strategies (Barratt, 1953). Kozhevnikov and Hegarty (2001) proposed a novel, psychometric paper and pencil perspective taking/spatial orientation test (PTSOT) for adults in order to overcome the drawbacks of the Guilford-Zimmermann task. The test instrument consists of 12 items that display an arrow of seven 2D-objects. On each item, the participant is asked to imagine being at the position of one object (anchor point), facing another object (defining the imagined perspective within the array) and is asked to indicate the direction to a third object (target). Item formulation stimulates therefore complex perspective taking processes with conflicting frames of references. The answer is noted on an "arrow circle" (see example item in Figure 1, left side, item adopted for better readability). Participants are neither allowed to rotate physically the object array nor the "arrow circle".

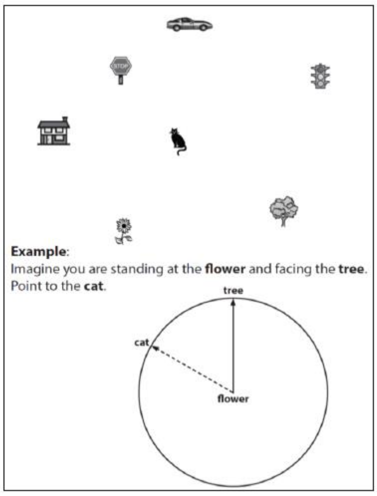
The PTSOT has been shown to be construct valid by the authors themselves, involving mostly self-reported perspective taking processes in adults (Kozehevnikov & Hegarty, 2001). Due to its accepted validity the test has been used to underline perspective taking abilities to be predictive for environmental layout learning in real world and virtual contexts (Hegarty & Waller, 2004).

The present study aimed to address the development of an instrument that stimulates complex perspective taking processes with conflicting frames of reference. One goal of the study was an adoption of the original PTSOT for primary children. A second goal was to describe the instrument with respect to test characteristics and typical error patterns that are caused by problems or failure in a set of mental transformations that are necessary to solve the items. Finally, an overall goal was to conclude potential applications of the instrument within the field of psychology and mathematics education.

Adoption and item construction

Design of an adopted instrument

The adoption process was conducted throughout a qualitative study with 25 fourth graders in a bachelor thesis project. We adopted the PTSOT with respect to 12 design parameters that are listed in Figure 1. We will elaborate in detail on the literature background in a following publication.



PTSOT	Design parameter	Adopted instrument
Investigation of perspective taking abilities	Goal of the instrument	Investigation & stimulation of perspective taking
Adults	Target group	Children
In Groups	Test procedure	Individually
Speed Test (5min)	Format	Power Test
2D	Dimensionality	3D
concrete, practical	Object specification	Concrete, practical
Directed & undirected	Object directionality	Exclusively directed
Seven	Number of objects	Six
unsorted	Object arrangement	unsorted
Written	Item Formulation	Verbally
"Arrow Circle"	Documentation of the solution	Circular Disk with 12 numbered sections
Angle difference	Scoring	Dichotomous (0-1)

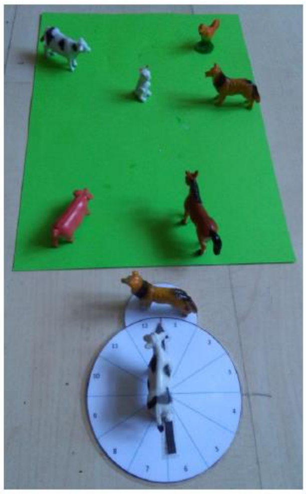


Figure 1: Comparison between the PTSOT and the adopted instrument with respect to 12 design parameters. One item of the PTSOT is shown on the left, the whole adopted instrument is shown from a quasi-bird perspective on the right side, showing the object field and the solution answering disk

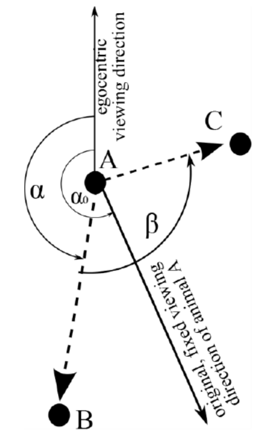
The adopted instrument consists of a 3D, small scale array of six farm animals that are placed on a green sheet of paper (the "meadow"). The child is sitting in front of the fixed array of objects, taking an oblique view on the whole scene. Just in front of the child there is a fixed, circular disk with 12 numbered sections and a mobile arrow on it. Animals can be stuck on the disk using glue dots. Verbal item formulation is standardized as following:

Tutor: "Imagine that you are animal A (sticks animal A in the middle on the arrow of the disk) on the meadow and are facing animal B (places animal B on on the semicircle attached to the disk). In which direction do you have to turn in order to see animal C?"

The child turns the arrow of the answering disk at the section which corresponds to the right direction and the tutor notes the answer. During the solution process, the child is allowed to gesture but not to turn the array, the answering disk or itself.

Item construction & framework for item analysis

We constructed eight initial items with the help of two parameters that describe two perspective taking processes within one item. In Figure 2 you can see that each item is defined by a set of four subsequent mental transformations of the egocentric frame of reference, which – pairwise – define one perspective taking process within the item.



Process	Item construction parameters	Defining mental transformations
1	**Shift of egocentric viewing direction - angle *α*** *"Imagine that you are animal A and you are facing animal B…"*	T_1 transformation of the egocentric frame of reference from an opaque view into the field view of animal A (adoption of viewing angle α_0) T_2 rotational transformation of the egocentric frame of reference by α-α_0 towards animal B (adoption of viewing angle α)
2	**Localization angle *β*** *„…in which direction do you have to turn in order to see animal C?"*	T_3 rotational transformation of the egocentric frame of reference by β towards animal C (adoption of viewing angle α+ β) T_4 transformation of the egocentric frame of reference from the resulting field view to an egocentric opaque view

Figure 2: Item analysis for an arbitrary item showing the two mental viewing directions (dashed lines), the original viewing direction of animal A (black line), the egocentric viewing direction of the observer as well as the item construction parameters α and β

Exploratory Studies

We studied the range of strategies that children use to solve different items in a qualitative interview study with 16 fourth graders in the context of a second bachelor thesis. Interviews served as an aid for the interpretation of results of the exploratory study as well as verification of the goal of the instrument.

In a main study, we performed the eight items of our adopted test instrument with 254 fourth graders (mean age was 9.17 years; 116 boys and 138 girls) out of 11 classes in Lüneburg; forming a heterogeneous sample in terms of scholar achievement and social background. The test was administered in a separate room in a 1:1 situation with the experimenter. We documented children's solutions, but we did not film the children.

Results and discussion

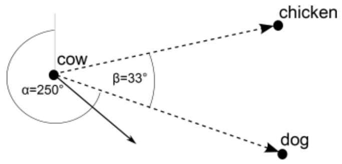
Test theoretical considerations

In a first approach, Item Response Theory (IRT) analysis, we scaled the data using a Rasch-model[1] in *Conquest*. The characteristics prove that data fit well with dichotomous data from the exploratory study with a MNSQ within 0.95 and 1.07 for all items. EAP reliability is poor, 0.456, yet might be influenced by the small number of items. Discrimination values show poor discrimination (0.24 and 0.33) for two items and acceptable (0.42- 0.56) discrimination for the other items. Item difficulties are between -0.52 and 2.8 (0 being medium difficulty), yet showing a tendency towards a selection of very difficult items. We conclude that from a test theoretical point of view, our selection of eight items is still far away from been applied as a psychometric measure of perspective taking. However, a first analysis pointed out a set of items with good characteristic values.

Quantitative results

[1] Rasch-models are one specific class of measurement models in IRT in which latent trait estimates depend on both persons' responses and the properties of the item (difficulty, discrimination).

In a second analysis, we interpreted the number of answers per section in the answering disk within the mental transformation framework that was presented in Figure 2.



(Item 6) *"Imagine that you are the cow and you are facing the dog. In which direction do you have to turn in order to see the chicken?"*

Item 6 is characterized by $\alpha=250°$, thus demanding the child to rotate its egocentric frame of reference by more than 90° to the right while indicating the direction of the chicken ($\beta=33°$), thus asking for a clear left/right decision at this point of view. IRT analysis showed that the item is difficult (1.06) and has an acceptable discrimination value (0.55).

We performed the analysis of item solutions within our mental transformation framework. Errors were classified into *"problems"* (task is basically understood but there are a few inaccuracies within one transformation), *"failure"* (one transformation is not performed at all, but the item is solved within the general item structures) and *"neglect"* (the goal of the item is changed due to a misunderstanding/heavy problem with one of the two perspective taking processes) in order to stress the amount of difficulty that a child showed during the solution of an item.

A detailed analysis in Figure 3 demonstrates the depth in which item solutions might be interpreted with the mental transformation framework. Figure 3 shows typical error patterns, such as

- neglect of the first perspective taking process, thus solving the item from a fixed egocentric viewing direction
- failure at the last transformation $\mathcal{T}_4$, thus having left-right problems
- failure at $\mathcal{T}_2$, the item is thus solved by taking the initial, fixed heading of the first animal (cow) and the child fails to shift the viewing direction from α_0 to α
- problems with estimation of the angle β in $\mathcal{T}_3$
- neglect of the first perspective taking process and projection of the egocentric viewing direction on the first animal (cow), thus pointing towards the relative position of the dog

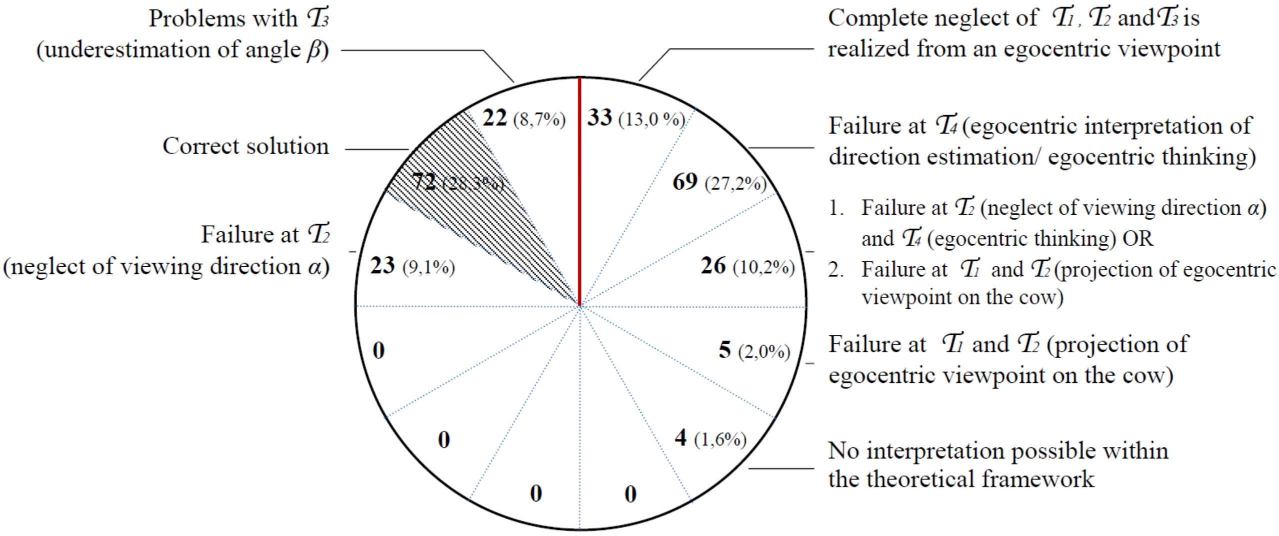
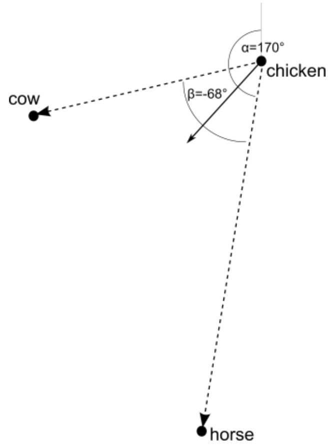


Figure 3: Analysis of solutions for item 6.

(Item 8) *"Imagine that you are the chicken and you are facing the horse. In which direction do you have to turn in order to see the cow?"*



Item 8 is characterized by *α=170°*, thus demanding the child to transform its egocentric frame of reference by almost 180° while indicating the direction of the cow (*β=68°*), thus asking for clear left/right decision at this point of view. IRT analysis showed that the item is very difficult (2.48) and has an acceptable discrimination value (0.53). The high difficulty of this item results from the need to take almost an opposite perspective while indicating to the front right.

For the analysis we expected therefore a large percentage of children to fail at the last transformation $\mathcal{T}_4$ (thus producing right-left-errors) as well as a high number of children to neglect the first perspective taking process, thus solving the item from an egocentric viewpoint. Figure 4 demonstrates that the last item shows a whole range of typical difficulties.

However, although the solution rate is for this item was low, many children managed to perform most of the transition processes correctly. Almost 77% of the children succeeded on performing at least $\mathcal{T}_1$, 47% succeeded in doing at least $\mathcal{T}_1$ and $\mathcal{T}_2$ correctly, 30% managed $\mathcal{T}_1$, $\mathcal{T}_2$ and $\mathcal{T}_3$ and almost 10% managed to do all the transformations correctly. Figure 4 shows that problems with the first perspective taking process may occur due to egocentric behavior, the failure to perform $\mathcal{T}_2$ or due to the projection of the egocentric viewing direction on the chicken. We explain errors in the first perspective taking process by difficulties that are inherent to children at this age (see Huttenlocher & Presson, 1973) but also by problems in understanding the item formulation and the item structure itself. The latter might be improved by doing multiple examples with the children (we explained the item structure with only one example).

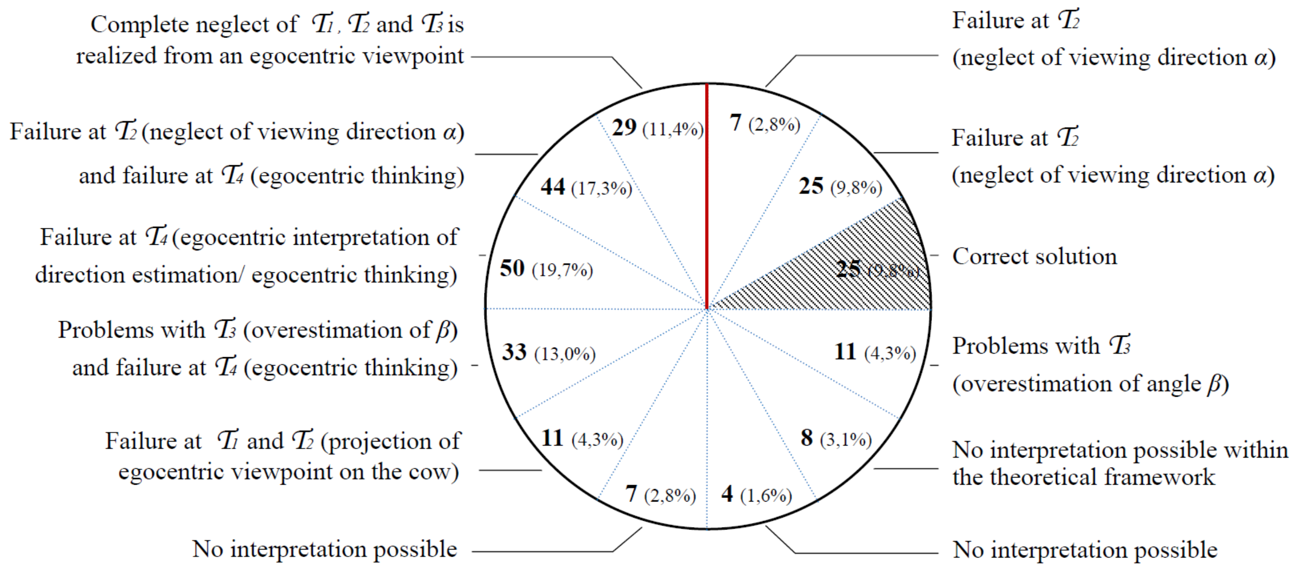


Figure 4: Detailed analysis of item 8, revealing problems in the $\mathcal{T}_4$ transformation process. Answer patterns that are not interpretable within our framework might be explained by counting in the field of animals or arbitrarily guessing the answer.

Applications of the instrument in different contexts

We analyzed performance on our adopted version of the perspective taking test at two different levels in order to underpin the argumentation on possible applications of the instrument.

Diagnostics

We demonstrated that item construction is straight forward using the construction parameters α and *β*. Our instrument allows therefore purposeful item construction in order to investigate individual differences and developmental issues in complex double perspective taking abilities. Children verbalized easily their thinking processes in our qualitative study, using gesture for showing viewing directions and the direction of the third animal. A combination of item solution and explaining aloud the solution process might help to diagnose the transformation processes that are still problematic for each child.

During construction and evaluation process, we identified two problems with our instrument that should be considered during item formulation: First, we measured angles from head to head of each animal. As the animals are quite large, the correct estimation of the angle *β* might depend on whether the child focuses on the head or the tail of each animal. Second, as the rabbit was placed at the center of the animal array, children had problems with taking the viewing direction of the rabbit. Instead, they projected their egocentric viewing direction onto the rabbit and answered items as giving relative positions of animal C to the rabbit.

Learning environment

Our adopted instrument consists of easily purchasable, inexpensive material. Again, our study showed that children are able to verbalize their spatial thinking processes with ease, using a whole range of gestures. Our instrument might be used for teaching of complex perspective taking processes (children solve pre-formulated items by the teacher), in communicative settings (children formulate items on their own), in discussions that address the transformation processes explicitly ("Can you explain me why this item is so complicated?"), or in creative settings (formulation of own items within constraints, e.g. difficulty, or re-configuration of all animals on the meadow).

Psychological test instrument

The original PTSOT has gained much attention concerning psychometric measurement of perspective taking ability because it is construct valid and reveals the predictive nature of perspective taking abilities for environmental learning. Another wishful application of our adopted version of the PTSOT is therefore in psychometrical measurement of children's perspective taking abilities. IRT analysis revealed a poor reliability and pointed out some inappropriate items with low discrimination values. In a further study, an exploratory analysis on a larger set of items of intentionally different difficulties is planned. IRT analysis might then reveal good items for a psychometric test of spatial ability in children. An IRT analysis of the test instrument might then be linked to our analysis technique based on egocentric transformations in order to develop a typology of complex perspective taking in children.

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