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Gestures as part of discourse in reasoning situations: Introducing two epistemic functions of gestures

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In this paper, I present how gestures can contribute to reasoning actions in social epistemic processes. In an empirical study, I investigated possible benefits of students’ use of gestures in social learning processes. Integrating an analysis of students’ gestures in a reconstruction of epistemic processes led to the identification of epistemic functions of gestures as ways in which gestures contribute to the accomplishment of epistemic actions. Two of these epistemic functions appear to be of special interest when students carry out reasoning in social interaction. Therefore, they will be presented in this paper by means of illustrative examples.

Keywords: Gestures, epistemic processes, social reasoning actions, embodiment.

INTRODUCTION

During the last 15 years, the study of gestures as part of the discourse in the mathematics classroom has increasingly gained attention (see Arzarello & Edwards, 2005). Gestures are considered to be a core resource in mathematical learning processes, a resource that can fulfill both a representational as well as an epistemic function in collaborative working processes (Dreyfus, Sabena, Kidron, & Arzarello, 2014; Krause, in press). Gestures have been identified to simplify the communication of ideas that are not yet fully elaborated (e.g. Reynolds & Reeve, 2002), reducing the cognitive effort needed for finding suitable mathematical words. Other studies point out benefits of collaboratively making use of the shared gesture space as mathematical experimental space in social interaction (Yoon, Thomas, & Dreyfus, 2011). Nevertheless, research investigating the use of gestures in mathematical reasoning is still scarce, although reasoning and argumentation are considered an important mathematical activity (Krummheuer, 2007).

This study is related to my PhD-project on the role of gestures in social processes of mathematical knowledge construction (Krause, in press). Although reasoning situations have not been in the focus of the study, they constituted a particular part of these processes. The investigation of gestures’ contribution to epistemic processes within an embodied and multimodal framework led to the suggestion that gestures may support reasoning actions in different ways when mathematical knowledge is constructed. Evidence of this hypothesis will be presented more in detail in this paper.

THEORETICAL FRAMEWORK

Gestures are considered “idiosyncratic spontaneous movement[s] of the hands and arms accompanying speech” (McNeill, 1992, p. 37), “being done for the purposes of expression rather than in the service of some practical aim” (Kendon, 2004, p. 15). Underlying all the research on gestures is the assumption that gesture and speech are co-expressive, that is, they refer to the same idea: McNeill sees “gesture and the spoken utterances as different sides of a single underlying mental process” (McNeill, 1992, p. 1) and claims that “speech and gesture must cooperate to express the person’s meaning” (p. 11), “each can include something that the other leaves out” (p. 79). According to the Information Packaging Hypothesis (IPH) (Kita, 2000, p. 163), gestures can help speakers to “package” spatial information into units appropriate for verbalization (Alibali, Kita, & Young, 2000, p. 593). By the use of gestures, information is parsed into entities more convenient to put into words, “consequently, the collaboration between the two modes [gesture and speech] provides
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“something that stand to somebody in some respect or capacity” (Peirce, CP 2.228) and an analysis within the semiotic bundle. The semiotic bundle is a dynamic structure that consists of different semiotic sets (e.g. speech, inscription and gestures) and relationships between them (Arzarello, 2006, pp. 280–282), both evolving in time. Some synchronous relationships can be described by two features of gestures; one concerning gestures’ relation to speech, the other concerning its relation to inscription (Krause, in press). Each is considered to frame the interpretation of the utterance as it is shaped by speech, gesture, and inscription in social interaction:

- Gestures can specify aspects of the mathematical object referred to and by this, enrich the verbal utterance. They can specify the where, the what, the how, or relational aspects of the mathematical object. ‘Where’ refers to spatial aspects such as location or direction, ‘what’ gives information of the kind of the object, ‘how’ concerns the style of a mathematical object or activity, relations are specified when the gesture represents relations within an object or between objects in addition to what is explicated in speech. The specification reflects a potential non-verbal influence on the interpretation of an utterance within social interaction.

- Gestures are performed on three referential levels: Level 1 is considered the level of the concrete, when the gesture refers directly to something that is already fixed. On this level, the gesture functions as an index in that its meaning solely derives from the meaning of what it refers to. On level 2, the level of the potential, gestures are embedded into an existing inscription. That is, something that is not fixed that way is made visible within an existing representation. The interpretation of gestures on level 2 demands for the material and/or contextual background of an inscription. The gestures in the gesture space, which is the space in the air roughly between the shoulders and the hips (McNeill, 1992, p. 86), are performed on level 3. They are free in the sense that they are detached from any inscription. Their disengagement from the concrete reveals a state of conceptualization of a mathematical idea.

Mathematical knowledge is considered to be constructed by individuals in social interaction, not arbitrarily but constrained by our bodily experience as humans in the world (Núñez, Edwards, & Matos, 1999, p. 53). While social-constructivism concerns the social-communicative aspects of learning, embodied cognition adds how individual aspects are shared as being based on bodily experience. It grounds the assumption that in social interaction, not only explicit and conventionalized modes of expression like speech are considered for the interpretation of an utterance, but also implicit ones such as gestures. It is due to our shared bodily experience as humans in the physical world that these implicit embodied modes of expression can be processed similarly by distinct individuals. Hence, the social-constructivist and the embodied approach do not oppose each other: While gestures may embody knowledge that is not consciously accessible, they may contribute to the social interaction implicitly. Reconstructing the epistemic processes within social interaction thus requires considering both implicit and explicit modes of expression.

Furthermore, embodied cognition theory states that bodily behaviour influences the way we think, grounding fundamental mathematical concepts in everyday experience through metaphorical thinking (Lakoff & Núñez, 2000). By expressing something in terms of something else, an entire conceptual environment can be understood via a more accessible or more illustrative domain. The domain referred to is called source domain and conveys how the relationships in the target domain shall be understood.

The social epistemic process was described by an epistemic action model that has been developed by Bikner-Ahsbahs (2006) based on the interpretation of speech acts. It encompasses the three social epistemic actions of (a) gathering single mathematical entities like examples or associations, (b) connecting a finite number of them, and (c) seeing structures such as generalities or patterns (GCSt-model). The latter takes place when a new entity is built or a known entity is re-built in a new context.

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speakers with wider possibilities to organize thought in ways suitable for linguistic expression” (Kita, 2000, p. 180).

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by an utterance, but also that gestures can have direct impact on the accomplishment of epistemic actions. They can prepare, support, and also realize epistemic actions in different ways which I call epistemic functions. This paper deals with two epistemic functions that I consider to support reasoning actions.

Within the frame of the GCSt-model (Bikner-Ahsbahs, 2006), reasoning actions are a specific kind of connecting actions: Two or more aspects of a mathematical object or idea are linked in order to justify or explain a hypothesis, or the rejection of a hypothesis. This paper focuses on these kinds of connecting actions, providing first suggestions on how gestures may take part in supporting students’ reasoning as epistemic connecting action.

METHODS

Three pairs of high-achieving students of grade 10 solve three tasks each. The tasks have been constructed to prompt fruitful epistemic processes by initiating epistemic actions. The three tasks deal with different mathematical topics and each provides a different variety of representations to work with in the course of solving the task. The epistemic functions presented in this paper concern a geometric-algebraic task and a task on logical reasoning using the idea of mathematical induction. This choice has been made due to the diversity of mathematical topics and representations provided by the tasks.

The Geometric-Algebraic Task deals with the parabola as geometrical locus. In the course of the task, three different representations are provided to the students: First, they have to construct a folding diagram according to the following instructions. On a given sheet, a point M is marked. They are now asked to (i) mark any point on the lower edge of the sheet, (ii) fold the paper such that the chosen point comes to lie upon the point M, (iii) draw a perpendicular to the lower edge of the sheet running through the point chosen on it, (iv) mark the intersection point of this perpendicular and the folding line with a red cross, (v) keep on proceeding like this by choosing new points on the lower border until they recognize a curve. This process leads to a folding diagram of the envelope curve of a parabola, the folding lines being tangents to the curve and the intersection points being points on the parabola. Figure 1a shows a possible outcome of this process.

Then, a GeoGebra file is introduced that represents a similar situation within a coordinate system. Here, the point corresponding to the one chosen on the lower border is called “P” and can be dragged to the left and to the right. Through dragging, a trace is produced by the points on the curve (Figure 1b). Finally, a printout capturing one possible situation from the GeoGebra environment is given to the students (Figure 1c). A first subtask consists of making conjectures about what can be seen in the folding diagram. Thereupon the folding diagram shall be compared to the GeoGebra diagram before a conjecture about the type of the function shall be stated and justified.

The Task on Logical Reasoning was formulated as a word problem:

An undefined number of persons sit in a circle. Everybody wears a hat. Everybody sees every hat except one’s own. Everybody knows that at least one hat is marked. Every five minutes, a bell rings. Everybody who knows that his own hat is marked shall raise his hand with the ring of the bell as soon as he knows. The challenge consists in concluding from the number of hats one sees whether one’s own hat is marked or not.

No further representations of the situation have been provided. For the base case of seeing zero marked hats
it follows immediately that one's own hat is marked from the condition of knowing that there is at least one marked hat. The induction step can be induced from the reaction of the other persons by reconstructing how many marked hats they see, and then concluding on whether one's own hat is marked from the behaviour of the other’s at the n\textsuperscript{th} ring of the bell. Solving the task thus makes use of the idea of mathematical induction and distinguishing cases concerning the reactions of the other consultants at the n\textsuperscript{th} ring of the bell.

The two tasks differ not only in the mathematical topic they deal with but also in the role of representations provided to the students. The rich semiotic variety of the geometric-algebraic environment is suggested to prompt the students to use gestures when reasoning on the kind of function. However, the more important question is how gestures may support the reasoning actions when solving this task. The lack of such representations in the task on logical reasoning raises the question whether gestures are used at all, and if so, what these gestures refer to and whether and in which ways they support reasoning as the main mathematical activity of the task.

Data and analysis
The learning processes have been videotaped from three perspectives: One camera filmed from the front to capture the gestures of the students. A second camera was directed to the inscriptions in front of the table. A third perspective was used to record the student’s use of GeoGebra visible on a computer screen. Based on these video recordings, transcripts have been written, considering verbal utterances as well as non-verbal actions (see Figure 2 for the transcription key).

For answering the research question stated in this paper, those connecting actions become relevant in which the students justify or explain their conjectures. To reconstruct the role of gestures therein, the gestures are analysed within the semiotic bundle, taking into account also possible metaphorical meaning, grounded in the bodily experience with the physical world.

**HOW GESTURES CAN TAKE PART IN REASONING SITUATIONS**

In the following section, two examples will be reconstructed. These present the two epistemic functions contrasting and giving visual access to the structure of a reasoning action as ways in which gestures can support reasoning actions.

**Supporting counter argumentation by contrasting to another representation**
The two students Mike and Tim work on the task in which the \textit{parabola} is explored and experienced as geometrical locus. They have already constructed the folding diagram and traced the curve in the GeoGebra environment. Preceding the following scene, Mike and Tim have identified the curve to be an exponential function “with some factor in front of it” (235). Prompted by an interviewer, the students are asked...
to make statements about the values of the function represented by the curve for \( x = 0 \) and \( x = -1 \). This is when they realise that “it can’t be that it is an exponential function” (284; See Figure 2 for the GeoGebra diagram as visible on the screen at that moment.), explicating the reason in speech and gesture (Figure 1 for transcription key):

284 /Mike: it can’t be that it is an exponential function’ (looks at Tim)
285 Tim: right.
286 Mike: because, uhm
287 /Tim: then it [would be] (points towards the screen) smaller there
288 /Mike: [elsewise the number would be smaller and smaller (points at the screen from right up to left down) (.)] the left side normally

Mike’s reasoning of the refutation of the curve representing an exponential function consists of three utterances: In line 284, he refutes the conjecture about the type of the function. At this point, the basis of the conclusion he draws after considering the concrete values does not become explicit. In lines 286 and 288 he justifies his conclusion. Although Tim already confirms Mike’s statement in line 285, Mike gives an explanation using a counterargument. He starts with “because” (286) but hesitates. This makes Tim start an approach, imprecisely referring to that “it would be smaller there” (287). This mentioning ‘something being smaller’ in combination with the pointing towards the screen suggests that he has in mind the same reason that in turn is expressed by Mike (288).

From Mike’s verbal utterance alone, the reasoning is not complete: He uses an undefined reference (“the number”) and leaves out aspects that are specified in gesture: The iconic reference to the shape of the curve of an exponential function is combined with the indexical reference to the screen. Through this, two main functions are fulfilled: The gesture allows “the number” to be interpreted as a y-value and the direction of decrease to be from right to left, adding an aspect that is needed to interpret the argument to its full account. Shaping the interpretation frame of the entire utterance, the gesture specifies the where, the what, and the how as style of the shape of the curve potentially embedded into the GeoGebra diagram on level 2 in front of the screen. The performance on level 2 superimposes the actual case visible on the screen with the one to exclude as ephemerally shaped in gesture. This depiction of the hypothetical case to be refuted, the shape of the curve of an exponential function, makes apparent the difference in the styles of the two shapes. The curve has been traced in its full extent before and its symmetry is knowledge that is shared between the students. The depiction of the gesture thus represents only that part in which both representations do not fit together, hinting at a difference that is specified and with that, illustrates the counter argument given in speech.

**Giving visual access to the structure of the reasoning action**

Rosa and Lisa resolve the task on logical reasoning. They already hypothesized how to behave after the \( n^{th} \) ring of the bell, depending on the number of hats they see and the behaviour of the other consultants. They checked their strategy for some concrete cases and in conclusion, decided it to be valid. In the following excerpt, they investigate whether there may exist another strategy by assuming the case that all consultants wear a marked hat, considering the generic example of five consultants sitting in the circle and consequently seeing \( n=4 \) marked hats:

297 Rosa: the at the fourth ring they still see- (writes: ”4th ring: no”) (4sec) none ,oh- (scratches out ”no”), there I have always written nobody (writes ”nobody”) (...) (writes ”⇒”) ,that means there have to ,be- (briefly raises
Rosa concludes on the number of marked hats in the game ("that means there have to be [more than four]"), based on the fact that nobody signals at the fourth ring of the bell ("at the fourth ring they still see none"). While this is interpreted as a connecting reasoning action that can be reconstructed from the verbal utterance, Rosa's accompanying gesture metaphorically represents the connection of premise and conclusion as tracing a path from the back forth in an upwards arc by turning the wrist forward once. In this gesture-speech interplay, components of a metaphorical mapping based on the image schema of source-path-goal (Edwards, 2010, pp. 233–234) can be identified: Within this mapping, the "goal" corresponds to the conclusion. The movement of the hand on level 3 metaphorically represents the "path" within the gesture space and embodies what could verbally be expressed by the word "then". The gesture summarizes that the conclusion "there have to be [more than four]" is derived from the condition that nobody signals. It helps understanding how Rosa 'packaged' her utterance into source, path and goal. The metaphorical meaning does not develop within the social interaction such that the gesture is not considered to explicate situated meaning by specifying aspects of a mathematical object. Moreover, it is deeply embodied in the everyday concept of deducing a conclusion from a given premise, not necessarily related to a mathematical topic. The gesture itself implicitly realizes a connection of premise and conclusion and with this, supports the verbal connecting action of logical inference by illustrating it in a more general way. The visual access it provides does not refer to a mathematical object but to the structure of reasoning on a meta-level. This way, it may help to keep the discourse on track by sharing the organization of thought underlying the argument.

SUMMARY AND DISCUSSION

The two epistemic functions of gestures presented in this paper show how gestures may support reasoning as specific kind of connecting action in different ways:

Contrasting-gestures shape a representation of a mathematical object which is reasoned about in comparison to another representation. In this way, the gesture can specify aspects to exclude one of the two possibilities. The contrasting-gesture complements speech and inscription in an explicit manner. Without the gesture, it would be left unclear why the verbal utterance justifies the conclusion. Using a gesture this way to support a counter argument becomes possible by the graphical representation of the mathematical object on which is reasoned and the knowledge about it as has been developed within the social interaction.

Gestures can also embody the action of connecting premise and conclusion within an act of reasoning and thereby give visual access to the structure of a reasoning action. In this case, the metaphorical character of the gesture is completely detached from the concrete content of the task. The structuring-gesture provides an implicit support by not enriching the utterance semantically, but on a meta-level. Using a gesture this way may support the collective act of reasoning as it indicates the logical structure within an argument and may help to keep track. It makes traceable how the argument was organized as logical inference.

Being characterized by a deictic use of gesture and a close and direct relationship to speech and current inscription, contrasting can be considered a situated function. On the other side, the metaphorical use of gesture while structuring the verbal discourse has an implicit meta-relation to speech such that the function may be rather a universal one.

This raises the question whether there may be typical ways of using gestures with respect to different types of reasoning actions and about the role of these gestures in learning and in teaching. With regard to the mathematics classroom, Arzarello and Sabena suggest that gestures may foster students' argumentation skills by structuring mathematical arguments (Arzarello & Sabena, 2014, pp. 99–100), similar to what I have presented in this paper. While they adopt an individual approach, the examples presented here indicate how it may also benefit reasoning actions from a social perspective: Adding gestural expression provides visual access to the argument such that it becomes received and processed also in a visual modality, making the understanding of the utterance (and so also of an argument given) more comprehensive.

To test and refine this hypothesis, further individual research on the role of gestures in social reasoning actions is needed, conducted against a more elaborated theoretical background. The epistemic func-
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Tions of gestures presented in this paper can provide a basis for such an investigation due to their diverse groundings in graphical aspects of reasoning on the one hand, and the logical structure of discourse as metaphorically embodied aspect on the other hand. Furthermore, the presented findings suggest to be aware of the potential of gestures for and in social processes of argumentation.

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