“OKAY, YES IT’S TRUE” – DOING DISCOVERING WORK IN A TANGIBLE-USER-INTERFACE-MEDIATED JOINT PROBLEM SOLVING PHYSICS ACTIVITY

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Abstract

This paper is a single case analysis of an occurrence of discovery work accomplished by two university students who are jointly engaged in a tangible-user-interface-mediated physics problem solving activity. The latter is a computer simulation of a biker’s applied force and work done to the bike in a changeable landscape. Participants are asked to solve several tasks to eventually find out which factors influence the dependent variables “Force on Pedal” and “Work”. By relying on an ethnomethodological conversation analytic framework to conduct a moment-by-moment video based analysis, we highlight how two students accomplish the interactional work of discovering that a specific factor influences one of the target variables. Also, our analysis points to the need of adapting the described activity to support the triggering of episodes in which participants engage in joint reflections and discoveries.

Keywords: discovering, tangible user interface, joint activity, conversation analysis.

1 INTRODUCTION

The here presented study is a single case analysis, i.e. we look closely at an episode of a multimodally embodied conversation “in order to track in detail the various devices and strategies used by participants to accomplish a particular action” [1 p10]. To do so, we rely on an ethnomethodological conversation analytic (EM/CA) framework and conduct a moment-by-moment video based analysis. More precisely, we shall study in-depth how two university students interactionally accomplish discovering a specific matter while they are jointly engaged in a tangible-user-interface-mediated physics problem solving activity. The latter is a computer simulation of a biker’s applied force and work done to the bike while driving over different road surfaces, climbing diverse hillsides, travelling over various distances, and while changing pedal and wheel gears. Participants are asked to solve several tasks to eventually find out which factors influence the dependent variables “Force on Pedal” and “Work”. To evaluate the prototype of this bicycle scenario and to gain insight into the situated organisation of joint problem solving processes, we videotaped three small groups of students while they were interacting among themselves and with the tangible-user-interface (TUI). For the purpose of this paper, we shall draw on a single episode to highlight how two students accomplish the interactional work of discovering that a specific factor influences the force applied on the pedal. So, the present study seeks to contribute to a better understanding of “how discoveries are produced within a context of joint activity” [2 p32] while evaluating the prototype of the developed bicycle scenario. Indeed, our analysis also points to the need of adapting the TUI-mediated activity to support the triggering of episodes in which participants engage in joint reflections and discoveries.

2 THEORETICAL AND METHODOLOGICAL ISSUES

2.1 Investigating joint problem solving in an EM/CA based approach

To study the details of action as they are sequentially arranged moment-by-moment by the participants, within the very context of their situated activity, we rely on an EM/CA inspired approach [3, 4, 5]. Ethnomethodology (EM) focuses on “the methods by which observable actions are produced” and seeks “to investigate how social activities are accomplished” by the participants [6 p20]. Conversation analysis (CA) draws from EM “a concern for understanding how order” is “achieved in social interaction”; it has developed a sophisticated “empirically based methodology based on microanalytic studies” [1 p5] which centres on concepts such as turn-taking, sequencing, repair and preference organization. According to CA, communication is sequentially organized. Sequences are
ordered series of turns through which participants accomplish and coordinate an interactional activity. The relevance of any turn is to be understood from its occurrence in a series of turns. The latter are unfolding in time, i.e. they refer to what has been said (done) before and raises expectations about relevant next turns. The most common type of sequences are dyadic adjacency pairs uttered by two different speakers producing one turn each. For example, a question (first pair part) creates a conditional relevance for an answer (second pair part), likewise a summon (calling for the attention of the other participant) ‘requires’ a next turn in which the addressed interaction partner indicates that he/she has heard and is able to respond [7 p15].

Accordingly, we shall reveal “the sequential organization of a discovery-in-process” [8 p213] in the following analysis. This means that we do not conceive here of discovery as a psychological phenomenon referring to a private event taking place in the realm of the mental but as “discovering work” [8, 9]. The latter can be understood as a witnessable process during which participants display to one another that “something new enters the world held in common” by them and we see “how the matter so treated transitions from a dawning possibility […] to an established thing” [9].

To capture participants’ interactions among them and with the TUI with great accuracy and detail, we recorded the activity from different perspectives. The recording equipment was composed of four fixed cameras and a separate sound recorder. The resulting sound and video data streams were connected within one space to generate an ‘expanded-around view’ of the ongoing event (fig. 1); elsewhere, we termed this apparatus ‘joint screen’ [10]. For reasons of convenience and to ensure that the chosen frame grabs are not too small to recognize relevant details, we chose here to rely on images from either one or two camera perspectives to support our analysis.

2.2 The TUI-mediated bicycle problem solving activity

Shared interfaces such as multi-touch tables and tangible systems mediate and support collaboration by allowing co-located participants to simultaneously interact with digital information [11, 12]. While multi-touch tabletop interfaces are operated using finger touches, tangible tabletop interfaces make use of tangible widgets to interact with the system. Here, the latter consist of a physical handle (a graspable object participants manipulate to interact with the system) and a corona (a visual feedback element). This tangibility potentially facilitates the participants’ interaction with the system by building on everyday experiences of the physical environment, by enabling bi-manual control and by providing a “[t]ight coupling of control of the physical object and the manipulation of its digital representation” [13 p368].

In our case, the instantiation of the scenarios on TUI makes use of the software frameworks TULIP (Tangible User Interface Library) and COPSE (COllaborative Problem Solving Environment) [14, 15]. The latter provides a series of building blocks that can be combined in a variety of ways in order to model and instantiate complex phenomena and related problems on tangible tabletop interfaces. In the COPSE framework, a scenario is defined by relying on three key concepts: (1) widgets; (2) equations defining the underlying model, and (3) scenes specifying the background images shown on the tabletop. The three building blocks are linked through variables. Widgets manipulate variables, whereas scenes react on trigger conditions bound to variables. If the trigger holds true, the
corresponding scene is shown to the participants. Multiple scenes can work in accord to orchestrate rich visual feedback to further comprehension of the complex problem.

Thus, the scenarios correspond to a simulation where users “can adjust various parameters” to which “an underlying computational model responds by displaying the result of the user’s input”; their implementation goes along with the idea that through repeated manipulations participants “can arrive at an understanding of the model” [16]. The idea of modelling a biker’s needed force and energy was initiated in the context of the ReEngae Erasmus+ project1 by a group of five teachers, who assembled the underlying equations of the applied force on pedal and work done on the bike while riding over two different road surfaces (sand, road), climbing more or less steep hillsides (0%, 10%, 20%), travelling over various distances (1-30 km), and while changing pedal (1-3) and wheel (1-7) gears. All these variables are associated with widgets and the participants can change their values by turning the corresponding round-shaped objects. On the occasion of our data construction with adult students, we reworked both graphical and task design of the initial version of the prototype (fig. 2). The coronas of the two widgets with square-shaped handles display the feedback with regard to the force applied on pedal and the work done on the bike when the participants push down the red button. The remaining widget in the upper left corner is used to switch between the different phases and steps of the activity and to display them textually.

During the problem solving activity, the participants go through three phases. In the first one, participants are given the possibility to explore the functioning of the widgets and their impact on the scene. In the second one, they have to solve tasks with increasing difficulty where they are asked to set the independent variables (gears, inclination, distance, ground) so that they attain the given target values of the dependent variables (Force, Work). In the final phase the participants are asked two test questions with regard to what factors do not influence the force on pedal and the work done on the bicycle respectively. The extract we will analyse, is taken from the period where the participants cope with the first test question.

From these explanations, it becomes clear that this kind of software simulations (as any other) can be considered as “mock-ups”. This term is taken from Garfinkel & Sacks and refers to “an account of an observable state of affairs” that on the one hand “provides for an accurate representation of some relationships and some features in the observable situation” but on the other hand “makes specifically and deliberately false provision for some of the essential features of that situation” [17 p363, italics in the original]. The ‘experiments’ the participants are doing to work on the tasks are even “mock-ups” in a double sense. First, the participants are asked “to rediscover well-established scientific facts” and, second, they are “doing so in a simplified and idealized ‘microworld’” [8 p214]. When designing simulation-based learning environments this is somewhat tricky. Indeed, it may be difficult to discern whether students learn something about the physical laws or “rediscover the meaning or affordances that were designed into the software artifact as a model of physics” [18 p240].

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1 The ERASMUS+ project ReEngage (2015-2017) unites schools, teachers and institutions to focus on issues around preventing school dropout. Secondary schools are supported in implementing new teaching and learning practices which promote students’ numerous cognitive abilities. One of the practices offered to the teachers is the use of tangible tabletop interfaces for creating joint problem solving scenarios based on structural equations. Teachers are supported in implementing collaborative learning scenarios through training sessions, a web platform and a user guide. (see http://www.reengage-learning.eu)
3 ANALYSIS

3.1 Introducing the analysed episode

To understand what is going on in the selected episode, we must first explain in detail the functioning of the red button widget and lay out what happened just before the analysed extract. The red button widget allows to check whether the variables (inclination, ground, distance, gears) are set up to meet the conditions set by the task. When participants push down the red button, they get the feedback in the coronas of the force on pedal and energy widgets in the form of the ensuing values. Furthermore, the red button’s corona appears either as a green belt (and a green tick in the task display) if the parameters are correctly adjusted (fig. 3), or as a grey belt if this is not yet the case (see e.g. fig. 7).

The idea of the developers was that participants would first set up the different parameters and then push the button to check the impact of their input. However, they rapidly used the button in the following way: one participant permanently held down the red disc so that they instantly got the feedback after they adjusted something. The two students in question here also adopted this way of proceeding after seven minutes.

Previous to the analysed episode the two students (Leia and Luke) start working on the first test question “What object(s) does/do not influence the force on pedal?”. Providing the correct answer to this question is done through removing the object in question which is the distance object here. However, Leia and Luke agree on taking away the inclination, distance and ground object and do so. Consequently, the coronas of both the energy and force widget display the message “object missing” since two objects (inclination and ground), have been removed. This is a design flaw of the prototype; while this software behaviour may be appropriate for the exploration and the task phase, it is not suitable for the test phase where participants are explicitly asked to remove objects. Thereafter, they remove single objects but – although the red button is held – they receive no feedback from the system with regard to the correctness of their trials. So, there appears to be a momentary malfunctioning of the system here. Finally, the two students conclude by themselves that inclination, ground and distance are the factors that do not influence the force on pedal. They, however, do not appear to be particularly convinced as we shall see in the first out of six following excerpts.

3.2 Casting doubt

Excerpt 1

1  LUKE  #†kann een zréck/
         can one go back
         †touches TO -->
         fig  #fig. 4
2  (2.1) *† (0.3) † (0.2)
       --*>(0.2)
       -->†turns TO -->
       leia  *moves left hand (via GO) to RB & touches it -->
       *moves right hand to IO, touches it and turns it slightly with no
effect
       on TUI
3  LEIA  #†ech hu gemengt et kéint een och #[hei*
         how I thought one could also here
         -->*
         luke  -->†
         tui  #†Task 6
4  LUKE  ![et* geet zréck
         it goes back
         *moves left hand to GO & touches it
        -->
        leia  *keeps her hand on RB -->

Participants’ talk and embodied actions have been transcribed (with minor modifications) according to the ICOR conventions for talk and to the conventions for multimodal transcription (see the note on transcript conventions at the end of the paper) [19, 20]. Since the two students spoke Luxembourgish (bold), an English translation is provided in the transcript below the original talk.
When we join the scene both participants are gazing at the task object (TO) and Luke is touching it (fig. 4). So far, they have used the task object to move between the different instructions in the task phase but not yet in the test phase. In terms of sequence organisation we have a question (line 1) which as a first pair part creates a conditional relevance on the next turn, namely an answer. Instead, we witness a rather long silence of 2.6 seconds (line 2) during which Leia moves her left hand to the red button (RB) and her right hand to the inclination object (IO). She then provides an account for the official absence [21 p101] of her answer by uttering “how I thought one could also here” (line 3) meaning that in her opinion it was still possible to have instant visual access to the results of their manipulations of the tangible objects while holding down the RB (as they did in the previous phase). Luke does not reply to her and turns back the task object causing the system to jump back to the previous step (task 6). This TUI-generated feedback provides an answer for his question which he verbalizes in line 4 (“it goes back”).

To fully understand what is happening here, we have to take a close look at the embodied conduct of the two participants. By delaying turning the task object, Luke casts doubt on the previously established fragile consensus (see 3.1); and by moving her hands to the RB and the inclination object (IO) Leia demonstrates an understanding of Luke’s doubt (fig. 5). So, they mutually agree on doubting and make this accountable to one another. Furthermore, they jointly lay the foundations for dispelling the doubt by displaying their mutual understanding of how to do it. Luke intends to and does go back to a previous step where it is possible to hold the RB down and to instantly see the feedback of their manipulations. And Leia - by touching and turning slightly the IO - proposes a candidate for an object that potentially influences the force on pedal.
3.3 Getting ready

Excerpt 2

4 LUC
↑[et* geet sréck
it goes back
↑moves left hand to GO & touches it

--> lyn (0.1)

5 LUC kuck emol eng Kéier↑†
take a look

-->↑†

lyn † (0.5)
↑points to RB with left hand -->

7 luc †♀ (0.5)
↑points to RB with left hand -->

8 LUC #dré*↑ck*
push

-->♀
↑retracts his hand to GO and touches it -->

fig #fig. 6
lyn *↑releases RB* & (0.1)

8 luc *↑releases RB* & (0.1)
↑moves right hand to DO and touches it -->

9 lyn *↑releases RB* & (0.1)

10 LUC okteet↑#
okay

-->↑† #fig. 7

The next step basically consists in Luke instructing Leia to hold down the button so that they can start trialling. In line 6 Luke summons Leia to focus. Following his left-hand movement (line 4-6) we can imply that he is about to handle the ground object to engage in the co-operation of the above described instant checking procedure (see 3.1). The latter demands to keep the red button pressed and, so far, Leia is only touching it. Consequently, Luke redirects his hand movement to point to the red button (line 7-8) and verbally instructs Leia to push it (line 8). After briefly removing her hand she firmly presses the button leading the TUI to display the grey corona around the RB and the current values in both the energy and the force coronas (line 9). Concurrently, Luke gets his two hands on the ground and distance objects (GO, DO) respectively (lines 8-10). In line 10 all hands are on the relevant objects to proceed (fig. 7) and Luke validates with an “okay”. So, they have gotten ready and can move on to the next step.

3.4 Trialling

Excerpt 3

11 leia ↑♀ (0.1) & (0.5) ♀ (0.5) ♀ (0.3) & (0.4) ↑ (1.2)
↑♀ turns IO ↑ releases IO -->

luke -->↑lifts & puts GO&DO on TUI ↑

↑turns GO&DO -->

fig #fig. 8

12 LUKE dréin na=eng=Kéier ♀ drun
turn it once more

-->♀ touches & turns IO -->

Due to an error in the formulas the values are much too high and go far beyond the strengths of a human being. In a more recent version this error has been corrected.
Now, Leia turns ‘her’ object (IO) and Luke nearly instantly follows by lifting ‘his’ two objects (GO, DO) off the table (line 11). So, they follow a systematic procedure of isolating one variable (inclination), eliminating the remaining ones (ground, distance) and changing the former to see its effect on the target variable (force). However, as a result of the removal of two objects the depiction of the ground disappears and both force and energy coronas display “object missing”. Consequently, Luke puts back the ground and the distance object and immediately afterward Leia releases the inclination object. In a sense, all objects and displays are restored and a new try-out can be initiated. This is done by Luke who turns the ground and the distance objects. The distance widget works and its alteration affects the depicted energy value (not relevant for answering the test question), but the ground, probably for some technical reason, fails to shift for the moment. So, Luke instructs Leia to turn the inclination object which she starts doing right way.

3.5 Noticing

At the beginning of line 13 (after Luc’s instruction) the ground finally changes its appearance from sand to road surface but the inclination remains at 0% (fig. 9). Both participants keep on turning their objects. It is the inclination\(^4\) that reacts first and raises from 0% to 10% leading to almost a triplication of the force on pedal (fig. 10). The ground surface tightly follows by switching (back) to sand (fig. 11). This also entails an augmentation of the force on pedal but a far less significant one. By

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\(^4\) The corresponding widget appears to work smoother.
simultaneously declaring “dach” (yes it does) in line 14 respectively “ah dach” (oh yes it does) in line 15, the participants jointly interpret the substantial increase in the value of the force on pedal as an information that falsifies their previous jointly established hypothesis (‘inclination, ground and distance do not influence the force on pedal’) and they notice that the inclination does indeed influence the target variable in question here.

Although both participants act in concord, Lyn’s conduct differs in noteworthy ways. Her turn is prefaced by the change-of-state token “oh” indicating that she “has undergone some kind of change in […] her locally current state of knowledge” [22 p299]. While uttering “ah dach” she is pointing to the force widget, thus making the source of her noticing explicit. Furthermore, through the wording of her utterance (“this one does”), which includes a deictic expression, she singles out the inclination factor with regard to the two other (ground, distance). The referent of “this one” is identified through her embodied conduct by pointing with her hand to the inclination object and touching it (lines 16-17). At the end of her turn she starts turning the IO, and so initiates the next step where she is going to verify her newly won insight.

3.6 Verifying

Excerpt 5

<table>
<thead>
<tr>
<th>Line</th>
<th>Participant</th>
<th>Utterance</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>LUKE</td>
<td>↑dach</td>
<td>yes it does</td>
</tr>
<tr>
<td></td>
<td></td>
<td>↑keeps hands on GO&amp;DO, turns only DO affecting E alone --&gt;1.23</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>LEIA</td>
<td>den heite $schonn</td>
<td>this one does</td>
</tr>
<tr>
<td></td>
<td></td>
<td>--&gt;$turns IO --&gt;</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>LEIA</td>
<td>tui</td>
<td>$G:sand;$I:0;$F:1039;$R:298</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$okkef</td>
<td>okay</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$points to IO with right index --&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>fig</td>
<td>#fig. 12</td>
</tr>
<tr>
<td>19</td>
<td>LEIA</td>
<td>t‘ass $jo $t‘ass wouer</td>
<td>it’s yes it’s true</td>
</tr>
<tr>
<td></td>
<td></td>
<td>--&gt;$</td>
<td></td>
</tr>
</tbody>
</table>

Leia now proceeds to check out their jointly asserted insight by turning the inclination object. Her handling causes the inclination to revert to 0% and the energy value to decrease in accordance (line 18). Luke is cooperating in this verification procedure by not interfering with Leia’s action. He only manipulates the distance object which (he appears to be aware of) has no effect on the energy value. By pointing with her index (fig. 12), Leia instantiates the inclination object as the relevant referent here. Her simultaneous verbal utterance “okay” accomplishes the following work: the result of the verification procedure is accepted and consequently that topic is closed. Moreover, “okay” is used pivotally here [23] and functions as a “linking device” [24] to the next topic, or, rather to its extension or elaboration.

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5 The Luxembourgish word “dach” (like the German “doch”) is used to give an opposing answer to a statement that is expressed in a negative form.
3.7 Elaborating

Excerpt 6

<table>
<thead>
<tr>
<th>LEIA</th>
<th>okkee</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>19</td>
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<tr>
<td></td>
<td>20</td>
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<td>26</td>
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<td></td>
<td>27</td>
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<tr>
<td></td>
<td>28</td>
</tr>
</tbody>
</table>

In this last excerpt of the selected extract Leia claims that she “experienced a flash or click of comprehension” [25 p152]. Moreover, she provides an account of her understanding by extending her insight. By casting her verbal utterance “it’s yes it’s true” as a remembering she links the finding gained within a specific setting - an activity mediated through a software-based simulation (of an idealised physical world) - to something outside, possibly a past experience of climbing up a hill with a bike.

Note that the meaning of her verbal utterance is only understandable if one considers her complex hand gesture. Viewed from above (fig. 13), it draws a line reminiscent of an upward slope and, viewed from front, it performs an upward zigzagging movement (fig. 14). Both movement views are imbued with the meaning of “steepness” which is not contained in the verbal utterance alone. Furthermore, Leia’s gaze informs us that her multimodally embodied elaboration is addressed to Luke. The latter verbally acknowledges Leia’s elaboration in line 26 and 28.

[Figure 13.]

[Figure 14.]
4 SUMMARY AND CONCLUSIONS

Through our turn by turn analysis of the multimodally embodied conduct of two adult students engaged in a TUI-mediated joint problem solving activity, we reconstructed how they interactionally accomplish doing a discovery in situ. While constantly displaying a joint orientation to their task, they are doing a multimodally embodied work of noticing, of directing the other's attention, of seeking and of securing mutual understanding [8]. Finally, a new insight is introduced in their shared world. More specifically, they do this in six steps: in response to collaboratively raised doubt (step 1), they get ready (step 2), establish and follow a trialling procedure (step 3), notice that one variable is influencing the target variable (step 4), verify their finding (step 5), and finally one participant extends the jointly displayed understanding by referring to an experience outside their current setting (step 6). So, we find here the three-part sequence of proposal (step 1), assessment (steps 3-5), and uptake (step 6) as pointed out by Koschmann and Zemel [2 p42]. They further specify that it is “what comes between the proposal and the uptake that makes the participants' conduct recognizably a discovery” [2 p43]. In our example, we see inserted between the proposal and the uptake “recognizable forms of discovering work” [2 p. 44], e.g. we see trials conducted and interpreted by the participants. Note that here the proposal of a candidate object (step 1) is accomplished ‘discretely’ through Leia’s embodied conduct.

Indeed, participants' actions are not organized solely in talk but “through the simultaneous use of multiple semiotic resources with quite different properties” [26 p1]. This became particularly relevant in the first and the last excerpt of the analysed episode. In the first one, doubt is expressed through an inter-elaboration of Luke’s uttered question and his halting hand movement. The so cast doubt is co-elaborated through Leia’s hand movements mobilizing the relevant artefacts (including the candidate object) for the next step, whereas her verbal utterance does a different work, namely accounting for her delayed response. In the last excerpt, Leia produces her understanding as an embodied matter. Indeed, her overt display of understanding can only fully be grasped if one considers both the contributions of her verbal utterance and her hand movement as construing the meaning of steepness. So, our findings points to the significance of considering multimodally embodied conduct in analysing joint problem-solving activities.

Our case study also raises some challenges for designing TUI-mediated joint problem activities. Notice that prior to the participants casting doubt, the system did not react ‘properly’ due to a design slip (“objects missing”) and a malfunctioning (delayed response time of the ground widget). Thus, in a sense, the doing-a-discovery-episode was triggered by a breach in the system. Hence, it is worthwhile to further investigate what kind of TUI-mediated breaching behaviours may trigger moments of uncertainty with ensuing coping procedures that allow to gain new insights with regard to a topic matter. The findings of these studies can then inform developers to consciously integrate breaches into the TUI-mediated activities to provide for starting points for participants to engage in joint reflections and discoveries.

ACKNOWLEDGEMENTS

We would like to thank Luke, Leia and the other students for participating in the study; Josef Camilleri, Christopher Cassar, Florian Islamaj, Oiane Martínez López and Irene Soria López for the initiation of the bicycle simulation idea within the context of a ReEngage training event organised in January 2016 in Madrid; and Timothy Koschmann for his valuable advice on discovering matters.

NOTE ON TRANSCRIPTION CONVENTIONS

LEIA/LUKE participant speaking
leia/luke participant doing the embodied action when she/he is not the speaker.
tui behaviour of tangible user interface
/ rising intonation; = latching; [ overlapping talk
(0.6) timed pause (A precise timing of the pauses and the synchronization of talk and embodied action were rendered possible thanks to the transcription software TranScripter [27].)

Gestures and descriptions of embodied actions are delimited between two identical symbols (one symbol per participant) and are synchronized with correspondent stretches of talk.
, , and delimit respectively a first, second or third gesture done by Leia
† and ‡ delimit respectively a first or second gesture done by Luke
◊ indicates the values of the TUI at that moment
*--> described embodied action continues across lines until the same symbol is reached -->*.

Circles and arrows highlight relevant details on the screen shots.

Abbreviations used in the transcript: TO task object; IO inclination object; GO ground object; DO distance object; RB red button; E energy corona; F force corona.

REFERENCES


