**Coding manual**

**Category 1: Transactive Communication**

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| 1. **Transactive Communication I: Self-References** | |
| Underlying Idea/Key Question | To what extent do students explain the reasoning behind their ideas/the progress they make on a conceptual level? |
| Positive Indicators and Anchor Examples from our Investigation (Quotes are Translated from German) | * “I would put the term ‘MO’ diagram there because…” * “That’s similar to the nitrogen molecule, so it fits here.” * “We’ve already seen paramagnetic behavior with oxygen.” * “We put all terms that have to do with orbital interference in this corner.” |
| Negative Indicators and Anchor Examples from our Investigation (Quotes are Translated from German) | * Students express ideas without justifying them. * “That was part of the videos, so it will be important.” (No justification on the conceptual level!) * “If that’s okay with everyone, I would just write down the Wikipedia definition now.” * “Do you want to have interference connected to binding? I think that’s actually pretty self-explanatory.” |
| 3-point Likert scale | * 3: (Almost) all ideas/progress made are justified or illustrated. * 2: Some ideas/progress made are justified or illustrated. * 1: (Almost) no ideas/progress made are justified or illustrated. |
| Notes | We focus not on the correctness of the content of the ideas put forward, but on whether the students justify/illustrate them. This can also happen when asked by other group members. It is important that the person who made the statement justifies it. (Otherwise: Item 1.3) Statements such as “there is still space in the top left corner” do not constitute a substantive conceptual (!) justification. |

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| 1. **Transactive Communication II: Low-Level Transactivity** | |
| Underlying Idea/Key Question | To what extent do the students utter low-level transactive speech acts? |
| Positive Indicators and Anchor Examples from our Investigation (Quotes are Translated from German) | **Ensuring/Paraphrasing**   * “So, you mean that…?” * “Did I understand correctly that…?” * “So, binding molecular orbitals are created by constructive interference of atomic orbitals?” * “Yes, exactly, that was the one with the amplitudes. When trough meets trough and peak meets peak, there is an amplification and the other way round we have an equalization and then it is weakened.”   **Inquiring**   * “If the overlap integral is positive, this stands for constructive interference.” “What do you mean by 'constructive interference'?” * “We should add the bond order there.” – “Why the bond order?” * “Can you perhaps explain that again with non-bonding and symmetry?” * “Someone else here had effective bonds. What did you mean by that again?” * “I wanted to ask what exactly binding means in this context. I don't quite understand it.” |
| 3-point Likert scale | * 3: The students express many low-level transactive speech acts. * 2: The students express some low-level transactive speech acts. * 1: The students express almost no low-level transactive speech acts. |
| Notes | When performing low-transactive speech acts, students do not add their own ideas, but ensure that thoughts from group members have been correctly understood.  **Ensuring/Paraphrasing**  Group members   * ... repeat what others have said in their own words, * ... repeat previous ideas of group members or summarize them in their own words, * ... refer to statements to ensure that they have understood them correctly, * ... summarize (interim) results of the work process.   **Inquiring**   * Group members ask comprehension questions aimed at a more detailed explanation or at missing/more detailed information. * When asking questions, students do not contribute new ideas. |

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| 1. **Transactive Communication III: High-Level Transactivity** | |
| Underlying Idea/Key Question | To what extent do the students utter high-level transactive speech acts? |
| Positive Indicators and Anchor Examples from our Investigation (Quotes are Translated from German) | **Expanding**   * “We could also include the interference.” * “That makes sense! The fact is that …” * “Or we could take electron distribution as a new word and add that and then combine this concept with it.”   **Scrutinizing**   * "Do you really think constructive interference belongs here?" * "I don't think we should write it like that." * "But I don't know if we should combine MO diagram with AO, because it's called MO, so I would only combine it with MO."   **Contrasting**   * "Then we write '...' on this arrow" - "I would rather write '...' on it." * "Then let's write '...' on the arrow." - "But then we'd have to turn it around so that it makes sense." * "How do we do that now? We can do it this way or that way. But it's better this way, because otherwise we'd have to split the sentence up and that doesn't work quite as well."   **Concluding/Consolidating**   * "And if we write your idea on the arrow, we can add my suggestion to it." * "You two have just talked about Hund's rule and Pauli's principle. You can see them both clearly on the MO diagram, so let's link them together." |
| 3-point Likert scale | * 3: The students express many high-level transactive speech acts. * 2: The students express some high-level transactive speech acts. * 1: The students express almost no high-level transactive speech acts. |
| Notes | When performing high-transactive speech acts, students develop their group members’ ideas by adding their own thoughts or (re-) formulating previous ideas with a new justification or example.  **Expanding**  Group members   * ... take up ideas from others and develop them further with their own ideas. * ... supplement statements made by others with additional or similar new ideas. * ... elaborate on a statement made by a group member so that it becomes more detailed and precise.   **Scrutinizing**  Group members   * ... ask comprehension questions aimed at a more in-depth explanation or at missing/more detailed information, * ... express objections to an idea, * ... criticize ideas with reasons. * Key words: "but", "nevertheless"   **Contrasting**  Group members   * ... compare two or more opposing opinions and weigh them up against each other, * ... present an alternative thought, which is weighed up against the idea of a group member or a jointly developed idea. * Key words: "on the one hand/on the other hand"   **Concluding/Consolidating**  Group members   * ... develop a common idea from two or more different opinions, * ... propose a compromise to solve a problem, * ... work out a commonality between two statements so that the concept map becomes more interconnected. |

**Category 3: Problem-Solving Activities**

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| 1. **Problem-Solving Activities I: Common Understanding of the Task Before Beginning to Work** | |
| Underlying Idea/Key Question | To what extent do the students discuss their understanding of the task before starting to work on it? |
| Positive Indicators and Anchor Examples from our Investigation (Quotes are Translated from German) | * "Let's read the assignment before we start." * "What are we supposed to do here?" * "I understand that we have to transfer our terms first." * "We also have to label all the arrows afterwards, don't we?" * "Has everyone read the task? Okay, then let's get started." * Students read the task out loud. |
| 3-point Likert scale | * 3: The students discuss their understanding of the task or the task definition before they start working. * 2: It is clear that the students read the task before they start working. They talk about it briefly, but do not discuss how they have understood the assignment. * 1: The students start working on the task straight away without consulting each other first. |
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| 1. **Problem-Solving Activities II: Common Understanding of the Task After Beginning to Work** | |
| Underlying Idea/Key Question | To what extent do the students discuss their understanding of the task while working on it? |
| Positive Indicators and Anchor Examples from our Investigation (Quotes are Translated from German) | * "What are we supposed to do here now?" * "My understanding is that we're supposed to transfer our terms first." * "Hang on... What exactly should we do again?" * "We also have to label all the arrows afterwards, don't we?" * "Now we've entered the terms... What do we do next? * "We'll just do the presentation as a group, don't worry" - "I understood that one person would be drawn by lot." |
| 3-point Likert scale | * 3: The students discuss their understanding of the task or the task definition while working on it. * 2: It is clear that the students read the task while working on it. They talk about it briefly, but do not discuss how they have understood the assignment. * 1: The students do not talk about the task while working on it. |
| 1. **Problem-Solving Activities III: Strategize Before Beginning to Work** | |
| Underlying Idea/Key Question | To what extent do the students structure their work process or discuss their strategic approach before they start working on the task? |
| Positive Indicators and Anchor Examples from our Investigation (Quotes are Translated from German) | * The students structure their work steps. * "Let's first transfer and sort all the terms before we write anything on the arrows." * "Shall we put our collections of terms next to each other first?" * "We have a total of 90 minutes. We should consider that so that we can still discuss." * "If we can think of any more terms to add, we can do that at the end." |
| 3-point Likert scale | * 3: The students plan each work phase in advance. For each (sub)phase, the group discusses how to proceed before starting to work. * 2: The students plan individual stages of the work process in advance. There are phases that are not addressed. * 1: The students do not talk about their strategic approach before they start working. |
| Notes | Merely addressing a sub-phase (e.g., "We have arranged all the terms. Let's cluster them next") also counts here. |
| 1. **Problem-Solving Activities IV: Strategize After Beginning to Work** | |
| Underlying Idea/Key Question | To what extent do the students structure their work process or discuss their strategic approach while they are working on the task? |
| Positive Indicators and Anchor Examples from our Investigation (Quotes are Translated from German) | * "Wait, we discussed that differently earlier." * "Just a second. We're still in the process of arranging the terms. The other one will come in step 3." * "Okay. Then let's start labeling the propositions next." * "If we want to label all the arrows, we won't have time to color in the terms." * "What's our next step?" * "Does what we've just done make any sense at all?" * "Okay, then we can sort out the grammar issue later and focus on writing now." * "We'll see how we arrange it in the end. We have to finish all the relations now." |
| 3-point Likert scale | * 3: Students monitor their work process carefully. If necessary, they react accordingly. * 2: Students do not monitor their work process carefully. They do not respond to difficulties they notice   OR  they notice them too late to respond  OR  they have to compromise elsewhere to respond.   * 1: Students do not monitor their work process. |
| Notes | The fact that the students monitor their work process becomes particularly clear when they discuss their strategic approach. It is important that the ongoing process is reflected here.  Time management does not fall under the aspect of problem-solving activities, but is one of the resource-related learning strategies. |
| 1. **Problem-Solving Activities V: Reflection on Work Process/Strategy** | |
| Underlying Idea/Key Question | To what extent do the students reflect on their work process or the strategy they’ve chosen? |
| Positive Indicators and Anchor Examples from our Investigation (Quotes are Translated from German) | * "That worked really well!" * "Actually, we could have discussed more ..." * "We really dawdled around..." * "I think it's impressive when you discuss the terms and realize how interconnected they are." |
| 3-point Likert scale | * 3: The students reflect on the process of creating the map/glossary in detail and in a (self-)critical way. * 2: Students reflect on the creation process briefly and concisely together   OR  stop their reflection due to time constraints.   * 1: Students do not reflect on the work process after completing the map/glossary. |
| Notes | This can take place both at the end (overall reflection) and during (intermediate reflection) the work process. |
| 1. **Problem-Solving Activities VI: Reflection on Product** | |
| Underlying Idea/Key Question | To what extent do the students reflect on the product they created, i. e. their glossary or concept map? |
| Positive Indicators and Anchor Examples from our Investigation (Quotes are Translated from German) | * "Beautiful. I like the concept map like this!" * "I'm not entirely satisfied. There are still some connections missing..." * "Yes, it looks much better. I think the right-hand side is well organized. It's easy to see what belongs where. It's much clearer that way." * "It's not really clear to me." * "A bit grey - do we want to paint the map in color?" * "Everyone knows what is meant." * "We're still missing 3 terms" (level 2) |
| 3-point Likert scale | * 3: The students reflect on the map/ glossary in detail and in a (self-) critical way. * 2: The students reflect on the product briefly and concisely together   OR  stop the reflection due to time constraints.   * 1: The students do not reflect on their product after completion. |
| Notes | This can take place both at the end (overall reflection) and during (intermediate reflection) the work process. |
| 1. **Problem-Solving Activities VII: Consequences for Future Learning** | |
| Underlying Idea/Key Question | To what extent do the students derive consequences for future learning processes from their reflections? |
| Positive Indicators and Anchor Examples from our Investigation (Quotes are Translated from German) | Level 2:   * "Next time, let's not waste so much time choosing colors." * "Next time we should make sure we explain the missing terms. * "I really need to look at the videos again before the presentation."   Level 3:   * "Concept maps are not for me." * "If I create a concept map again, it will definitely not be with this software." * "I would create concept maps the same way again." * "I will definitely study with the concept map again before the exam." * "Maybe we should have discussed on the aesthetics beforehand. We'll have to think about that next time." * "I definitely need to look at molecular orbital theory again before the exam." |
| 3-point Likert scale | * 3: The students derive consequences for future action. In doing so, they also refer to topics other than the concept map or the glossary on molecular orbital theory. * 2: Students derive consequences for their future actions. * 1: Students do not derive any consequences for their future actions. |
| Notes | It must become clear that the students draw the consequences directly from the work process.  This item is the only one that cannot be generalized to all collaborative processes, as it is content-specific. |