Evolution Education Resource: Metaconceptual Learning Activities for Promoting Metacognitive Awareness and Self-Regulation of Intuitive Thinking in Evolution Education

Students' intuitive thinking (e.g., teleological, respectively, goal-directed thinking) often proves helpful in different contexts, such as everyday life, but can be an obstacle to learning about evolution (Figure 1). Thus, enhancing students' evolutionary understanding is often challenging, with intuitive conceptions of evolution still existing after instruction. Consequently, it is necessary to explicitly address students' intuitive conceptions to support students in developing an appropriate understanding of evolution. Currently, available learning materials that teachers can use in evolution teaching are numerous. However, they almost exclusively focus on subject-specific knowledge, and if they address students' conceptions, they do so only marginally or attempt to change/eliminate students' conceptions. However, eliminating intuitive conceptions is neither possible nor preferable because they are resistant to change and valuable in many contexts other than evolution (González Galli et al., 2020; Perez et al., 2022; Shtulman & Harrington, 2016). No appropriate materials are published at the moment that respect the context-dependency of intuitive conceptions and enable students to regulate their conceptions in a context-dependent manner, i.e., using them in contexts where they are productive but inhibiting them in contexts where they are hindering.

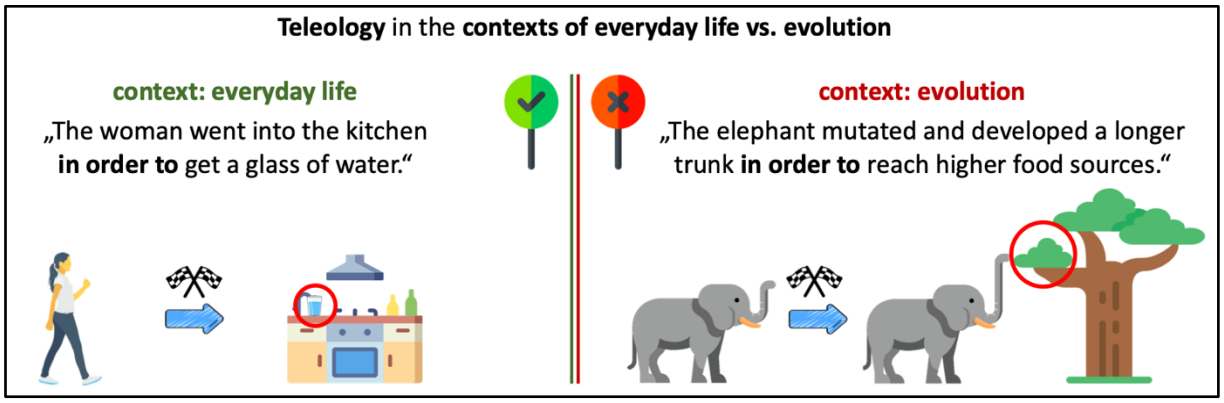

Figure 1. Teleology may be appropriate in the context of everyday life but inappropriate in the context of evolution.
Note. Figure development by the author. Individual parts of the figure are from Flaticon.com

Thus, we developed two novel metaconceptual learning activities focusing on intuitive conceptions and their context-dependency that biology teachers can implement at the upper secondary level. The learning goal is to make students metacognitively aware of their intuitive conceptions and enable them to self-regulate these in the context of evolution, thereby enhancing conceptual understanding. According to national standards, students should learn to construct sound scientific explanations of evolutionary changes, e.g., by referring to scientific concepts such as variation, heritability, and differential survival/reproduction (Gregory, 2009; NGSS, 2013). However, this goal can only be reached when students learn to self-regulate their intuitive conceptions.

Two metaconceptual activities will be outlined here: (a) a self-assessment of one's conceptions and (b) instruction on the context-dependency of conceptions (for the learning materials, see appendix). Regarding (a), students receive a list of seven scientific concepts of natural selection (e.g., variation, inheritance, differential survival/reproduction) and a list of three intuitive ways of thinking (teleology [i.e., goal-directed, purposeful understanding of evolution], anthropomorphism [understanding that species modify their characteristic intentionally

during evolution], and essentialism [understanding that species change as a whole from generation to generation because of neglecting or underestimating intraspecific variation]). Exemplary phrases and key terms are provided in the lists for each scientific and intuitive conception to support the self-assessment. The students are asked to examine their own previously given explanation of evolutionary changes by color-coding in their explanation and checking off in the lists intuitive and scientific conceptions used (Figure 2). This way, students become metacognitively aware of their conceptions. To become able to self-regulate their conceptions, students receive instruction on the context dependency of conceptions in activity (b). For example, they receive information on why intuitive thinking (e.g., teleology) may be appropriate in everyday life but not in the context of evolution and are asked to discuss this context-dependency of teleological thinking by contrasting statements in both contexts. Further context-differentiations relate to different scientific contexts and different social contexts. Individual tasks, activities with a partner, and class discussions alternate, making the activities diversified and interactive.

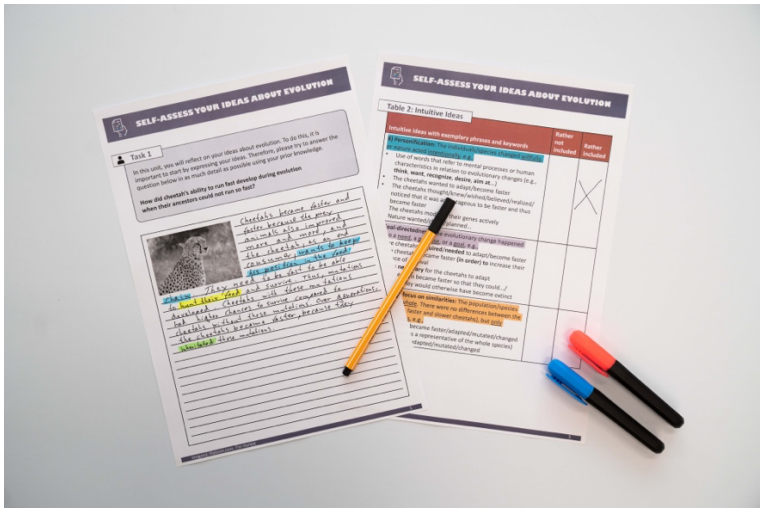

Figure 1. In the self-assessment activity, students self-assess their prior evolutionary explanations by color-coding intuitive and scientific conceptions used.

The metaconceptual activities have been developed with feedback from students and teachers and have been refined repeatedly based on empirical findings from our research group (Bannefeld, 2018; Hartelt & Martens, 2024a; Schilling, 2020; van Stappen, 2020). In particular, we have tested the comprehensibility, age-appropriateness, and effectiveness of the two activities in think-aloud interviews and a randomized experimental intervention study with *N* = 730 students (approved by the institutional review board of the local university, number 23/2021). In the experimental intervention study with a pre-post-follow-up-test-design (Hartelt & Martens, 2024a), both metaconceptual activities ((a) and (b)) have been systematically varied in a 2x2 factorial design. This design allowed measuring the individual and combined effects of the two metaconceptual activities on students' conceptual understanding of evolution. Students who participated in one or both metaconceptual activities used less intuitive conceptions and more scientific conceptions afterward to explain evolutionary changes than students who received only instruction on subject-specific knowledge with no focus on their intuitive conceptions. We also found positive long-term effects of the metaconceptual activities on students' conceptual understanding in the follow-up test (for more detailed analyses, e.g., on the individual effects of both metaconceptual activities on students' conceptual understanding, metacognition, and self-efficacy, see Hartelt & Martens, 2024a, b).

For the learning materials of the metaconceptual activities, please contact Tim Hartelt (hartelt[at]uni-kassel.de).

References

Bannefeld, F. (2018). *Schülervorstellungen und naturwissenschaftliche Erklärungen im Kontext von Evolution – Entwicklung und Erprobung eines Selbsteinschätzungsinstruments* [Student conceptions and scientific explanations in the context of evolution – Development and testing of a self-assessment instrument; Unpublished master's thesis]. University of Münster.

González Galli, L. M., Peréz, G., & Gómez Galindo, A. A. (2020). The self-regulation of teleological thinking in natural selection learning. *Evolution: Education and Outreach*, *13*, Article 6.

Gregory, T. R. (2009). Understanding natural selection: Essential concepts and common misconceptions. *Evolution: Education and Outreach*, *2*, 156–175.

Hartelt, T., & Martens, H. (2024a). *Influence of self-assessment and conditional metaconceptual knowledge on students' self-regulation of intuitive and scientific conceptions of evolution* [in press]. Journal of Research in Science Teaching.

Hartelt, T., & Martens, H. (2024b). *Metaconceptual instruction on intuitive conceptions – Do self-assessment and conditional metaconceptual knowledge influence students' self-efficacy and cognitive load?* [submitted].

Hartelt, T., Martens, H., & Minkley, N. (2022). Teachers' ability to diagnose and deal with alternative student conceptions of evolution. *Science Education*, *106*(3), 708–738.

NGSS Lead States (2013). *Next Generation Science Standards: For states, by states*. The National Academies Press.

Perez, G., Gómez Galindo, A. A., & González Galli, L. (2022). Metacognitive regulation of essentialism in the teaching of evolution. *Interdisciplinary Journal of Environmental and Science Education*, *18*(4), Article e2295.

Schilling, J. V. (2020). *Konzeptuelles Wissen und Schülervorstellungen zur Evolution – Selbsteinschätzung und Pilotierung eines Selbsteinschätzungsfragebogens für die Sekundarstufe II* [Conceptual knowledge and student conceptions about evolution – Development and testing of a self-assessment instrument for upper secondary classes; Unpublished master's thesis]. University of Münster.

Shtulman, A., & Harrington, K. (2016). Tensions between science and intuition across the lifespan. *Topics in Cognitive Science*, *8*(1), 118–137.

van Stappen, H. S. (2020). *Metakognition im Biologieunterricht. Förderung des konzeptuellen Wissens über Evolution durch konditionales Wissen* [Metacognition in biology classes. Enhancing conceptual knowledge about evolution by fostering conditional knowledge; Unpublished master's thesis]. University of Münster.