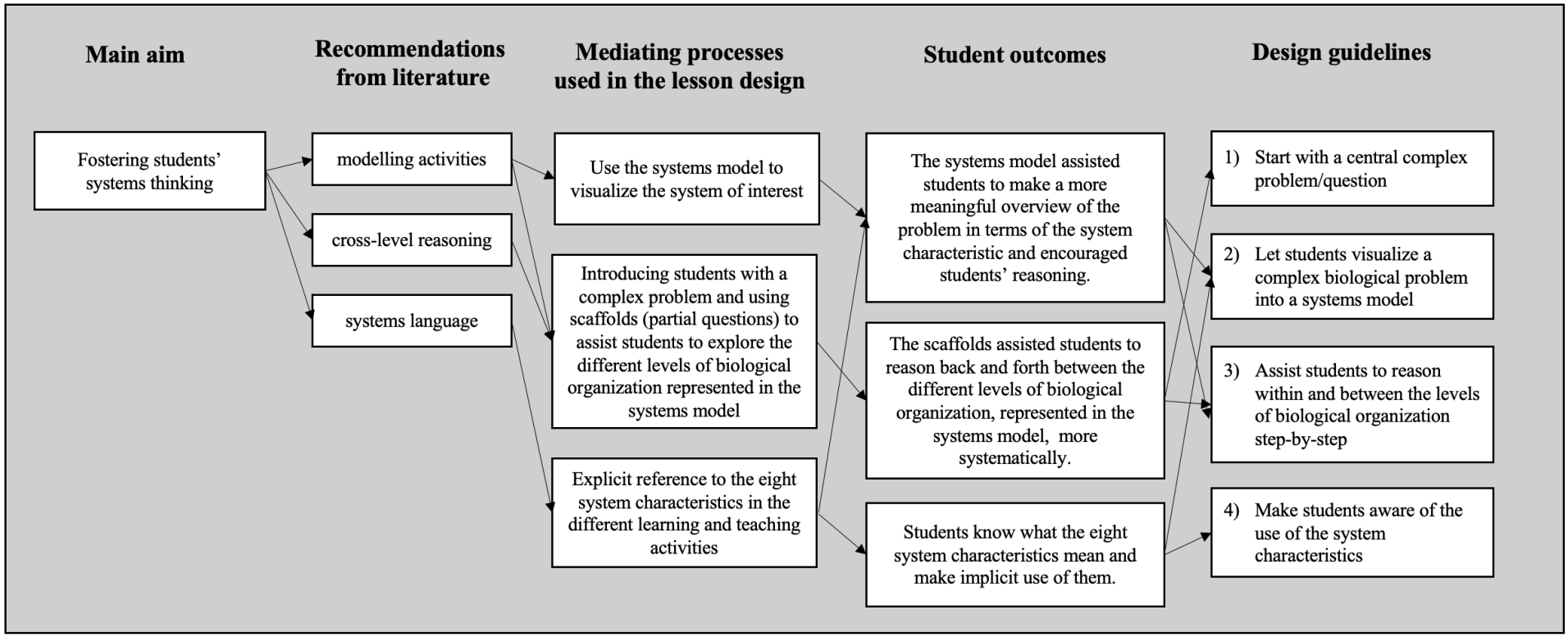
Supplemental Material

CBE—Life Sciences Education

Gilissen *et al*.

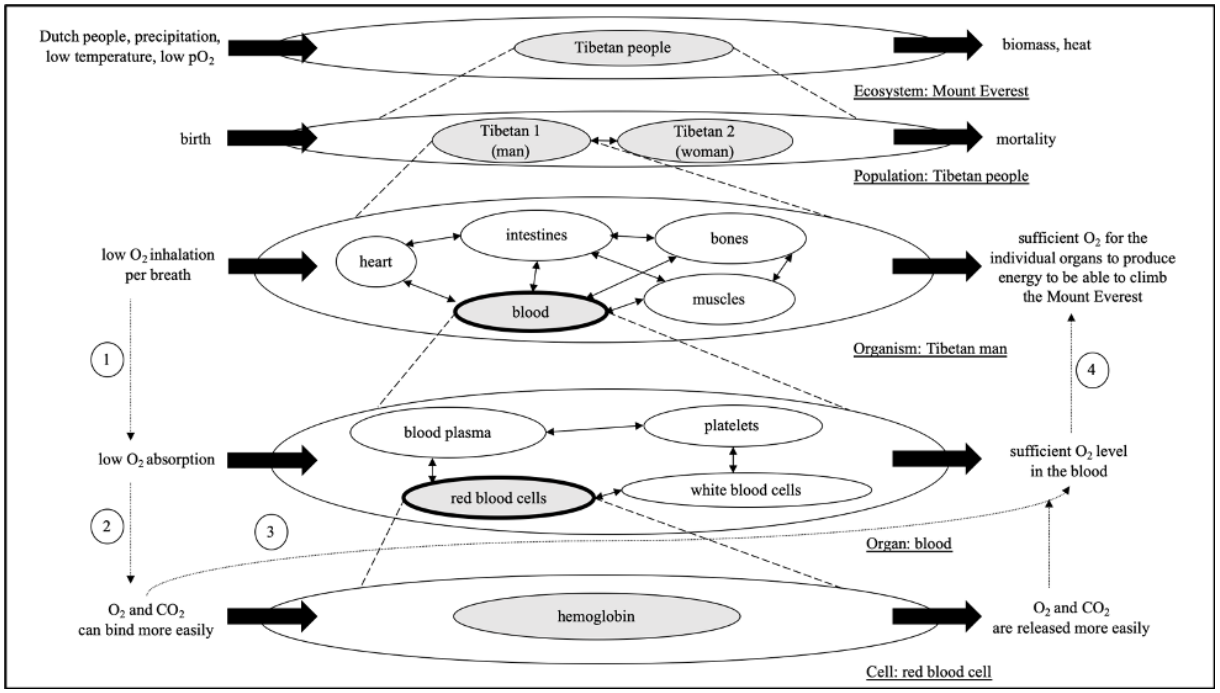
Appendix 1. A conjecture map (Sandoval, 2014) of this research which shows how the recommendations from literature are translated into mediating processes in the lesson design and which design guidelines could be formulated based on the student outcomes.



Appendix 2. The guiding questions are related to the eight system characteristics and can be used by students as a cognitive tool to investigate the characteristics of a specific system.

System characteristic	Guiding question
Boundary	Where can you draw a systems boundary? What belongs to the system, and what belongs to its environment?
Hierarchy	In which subsystems (and as a part of which larger system) can you divide the system? And to which levels of organization do these (sub)systems belong?
Components	Which components does the system consist of? What is the function of the individual components within the system?
Interactions	What are the relations between the different system components?
Input and output	What (energy, information or matter) enters the system? And what leaves the system?
Feedback	Which feedback loops are present in the system components? • Does the feedback lead to opposing changes within the system? → negative feedback • Does the feedback lead to enhancing changes within the system? → positive feedback
Dynamics	Which regular changes occur in the input and output? In what way do changes take place within the system over time (hours, days, months, years)?
Emergence	How does the different components together result in emergent behavior?

Appendix 3. Visualization of the Tibetan problem into the systems model. This model represents is the *hierarchy* of the problem. We zoom in step by step from the ecosystem level to the cellular level. Each level is visualized in terms of an *input and output* (exchange of matter, energy or information with the environment), *components* of the subsystem, and their *interactions* (visualized with arrows, but in this case not described). The numbers 1 to 4 illustrate the reasoning steps from the organism level to the cellular level back to the organism level. It declares how Tibetan people are able to live in an environment with a low pO_2. In this figure we zoomed in on the component blood, but it is also possible to zoom in on the muscles, because these also have an adjustment on cellular level (Huerta-Sánchez et al., 2014).



Appendix 4. Visualization of the Oostvaardersplassen problem into the systems model. The numbers 1 to 6 illustrate the effects of the measure 'additional feeding' on the ecosystem, population and organism level. In the short term, additional feeding leads to less starvation mortality of red deer, but to prevent this in the longer term, more additional feeding must take place to feed all the red deer.