

Supporting Students’ Mechanistic Reasoning Through Black-Box Pedagogy
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OVERVIEW: A learning unit focusing on mechanistic knowledge gaps, i.e., black boxes, supported students in moving from broad causal claims toward mechanistic explanations, asking more productive unpacking questions, and reflecting on when explanatory gaps should be unpacked or retained.

KEYWORDS: Science Teaching | Science Learning | Nature of Science | STEM Education

AUDIENCE: Instructional Designers | K-12 Teachers | Curriculum Developers

KEY POINTS

- Discussing black boxes supported students’ shift from causal claims to mechanistic explanations.
- Discussing black boxes focused students on asking questions about hidden mechanisms.
- An explicit discourse about black boxes allowed students to justify both unpacking and retention of black boxes by considering criteria of explanation depth and science communication.

INTRODUCTION Mechanistic reasoning is central to science learning, supporting students' sensemaking of phenomena. In science, constructing such explanations often requires unpacking “black boxes”: identifying hidden entities that produce phenomena. Yet even detailed explanations depend on some parts remaining black-boxed. This means students need support in noticing black boxes, asking productive questions about them, and deciding which to unpack. In this study, we examined a learning unit that explicitly discusses black boxes, highlighting their presence in explanations. We asked: (1) How does this emphasis affect students’ construction of mechanistic explanations? (2) How does it affect students’ questions about black boxes? (3) How does it support students’ awareness of black boxes and considerations involved in retaining or unpacking them?

FINDINGS Comparing student responses to a pre- and post-question about the cause-and-effect relationship concerning cancer revealed a move toward more mechanistic explanations. Initially, students primarily described the correlation between a cancerous agent and cancer, but after the intervention, they referenced underlying entities and processes like DNA damage and abnormal protein production. This change aligns with findings from the learning unit, indicating that students were increasingly focusing on black boxes. Throughout the unit, students were repeatedly asked to identify black boxes and ask questions about them. While students were initially confused by the “black box” term, as the unit progressed they asked more questions directed at

unpacking identified black boxes. Together, these findings suggest that explicitly discussing black boxes supported students in moving from causal descriptions toward mechanistic reasoning. Furthermore, In a follow-up poster task, a small group of students were asked to justify the unpacking and retention of black boxes when creating informational posters of disease. This examination revealed that students were able to discuss and justify both unpacking and retention of black boxes, tying both to relevant criteria of explanation depth and science communication.

TAKEAWAYS This study suggests that explicitly discussing black boxes can effectively help students engage more productively with mechanistic reasoning. Explicitly naming "black boxes" provides students with a shared vocabulary to recognize and verbalize areas where mechanistic understanding is incomplete. This allows students to formulate mechanistic questions and focus on unpacking information. This vocabulary was also found to be transferable across contexts, as students were able to discuss black boxes and their place in the construction of novel explanations. This also means that students can learn to make sophisticated choices about explanation criteria, balancing the need for mechanistic details with the need for clarity and communicative focus. Ultimately, these results imply that science instruction should integrate the teaching of metacognitive tools that help students construct explanations, reflect on their structure and connect this to the nature of explanations in science.