International Society of the Learning Sciences

Domain-Inherent Metaphors in Educational Practice: A Single Case Study

Charlotte H. Müller, Martina A. Rau
chmueller@ethz.ch, martina.rau@gess.ethz.ch
Dept. of Humanities, Social and Political Sciences, ETH Zürich, Switzerland

Abstract: Scientists as well as students make sense of new information by relating it to prior experiences. For imperceptible concepts, doing so often involves constructing metaphors. As a result, disciplinary discourse contains a wide range of domain-inherent metaphors that date back to their initial discovery. Therefore, students need to learn these domain-inherent metaphors on their way to becoming scientists. However, it is unclear what characterizes these domain-inherent metaphors when teachers use them during instruction. Using chemistry as an example, we offer a detailed analysis of the domain-inherent metaphors that a high school teacher employed during his lessons both in speech and gesture. To guide future research, we theorize on potential positive or negative effects on students' learning.

Introduction

Philosophers of science theorize that metaphors are an important aspect of scientific discourse and theory building (Hesse, 1965; Mahootian, 2015). Metaphors allow scientists to relate new discoveries to prior, often bodily experiences and hence support sense making. Therefore, these metaphors make their way into expert discourse, such as in nomenclature and terminology, but also gesture (Hesse, 1965; Jäkel, 2003; Mahootian, 2015). For example, the activation "barrier" of a chemical "reaction" denotes the "increase" in energy when chemical "bonds" "break." All terms in quotation marks constitute so called domain-inherent metaphors, meaning that they (i) are inherent to expert discourse (Müller & Rau, 2025) and (ii) possess a second meaning that describes a sensorimotor or social experience (Steen et al., 2011). This metaphor use is often implicit as the metaphorical term has historical roots that became conventionalized. For example, even experts may be unaware of how Edward Frankland's bodily experience (who coined the term chemical "bond," Frankland (1866)) shaped today's scientific language.

Domain-inherent metaphors yield both learning opportunities and potential ground for misconceptions. Even though these metaphors are highly conventionalized, the source domains that once helped the scientist make sense of the concept might help students to learn about the concept. For example, potentially it helps a student to think about the chemical "bond" in terms of a physical connection between atoms to make sense of molecular structure. Simultaneously, over-reliance on these metaphors may lead to misconceptions, for example when students believe chemical bonds to be rigid and physical (Boo, 1998).

In addition, like scientists, students make sense of new information by grounding it in prior bodily experiences. When new information is highly abstract, imperceptible, or potentially even non-physical, students tend to struggle more to find something that they can relate the information to (Johnstone, 1991). Therefore, they may aim to grasp at any grounding opportunity that comes their way, including domain-inherent metaphors.

In a recent systematic review, we examined research on metaphorical mappings in chemistry specifically (Müller & Rau, 2025). We found that research so far has focused on instructional analogies; that is, metaphorical mappings designed for instructional purposes. However, domain-inherent metaphors used in chemistry classrooms remain underexplored, even though they are a central component of expert discourse. We consider investigation of domain-inherent metaphors a first step towards understanding their effects on student learning.

To start filling this gap, we present a single case study of one teacher. Specifically, we analyzed all metaphorical mappings describing imperceptible concepts that the teacher expressed in language and gesture.

Conceptual framework

Our work takes an embodied, constructivist stance towards cognition and specifically, we discuss our findings through the lens of conceptual metaphor theory (CMT, Jäkel, 2003; Kövecses, 2020; Lakoff & Johnson, 1980). In the following, we first elaborate on this theoretical stance. Second, we situate the study in existing science education research on conceptual metaphors and gesture.

Embodied cognition theories assume that cognition arises from human existence in and interaction with the world (Shapiro, 2019). For science learning, this means that children first make sense of the world by observing and interacting. For example, they may develop the theory that the earth must be flat because whenever they look outside, the earth seems quite flat (Vosniadou & Brewer, 1992). They then bring these initial embodied

 © ISLS

conceptions to the science classroom, where they sometimes conflict with the scientific conceptions that the students are supposed to adopt, for example, that the world is round.

One mechanism relevant to this context is conceptual metaphor construction. We define conceptual metaphors as a set of cross-domain mappings between a more familiar source domain and a less familiar target domain (Jäkel, 2003). Importantly, this mapping is not only relevant for students who learn new information, but also for scientists who make sense of yet unexplained phenomena. For the latter, the metaphorical mapping serves an explanatory as well as sense making function. For example, Aristotle already found that sound propagates like (water) waves. This metaphor enabled scientists to explore when the wave metaphor works and when it fails. The metaphor stayed in scientific terminology (e.g., "sound waves," Hesse, 1965). Finally, learners may express these mappings not only in language but also in gesture as simulated (metaphorical) action (Cienki, 2016; Hostetter & Alibali, 2019).

In chemistry education specifically, research has mainly focused on instructional analogies and has to a large extent neglected domain-inherent metaphors (Müller & Rau, 2025). The limited extant research on chemistry-inherent metaphors found that experts use more conceptual metaphors in general and more empathetic metaphors in particular than novices when solving problems related to entropy (Jeppsson et al., 2013, 2015). Therefore, this research indicated that indeed, metaphors are a cognitive resource for experts. Similarly, Dreyfus and colleagues analyzed one professor and one student discussing negative energy (Dreyfus et al., 2015). They found that energy was often conceptualized as location or substance, often within the same utterance. Thus, research on chemistry-inherent metaphors is limited to two concepts, energy and entropy, and to the higher education context.

We aim to understand the role of implicit, often unacknowledged domain-inherent metaphorical discourse in education, using chemistry as an example domain. This work will serve as basis for future research to understand how instructors may support students in learning of and with domain-inherent metaphors. We ask:

1. What metaphorical language and gesture does a chemistry teacher use when talking about imperceptible chemical concepts?
2. What role does this teacher attribute to certain metaphors?

While RQ1 aims at collecting metaphorical language and gesture generally, RQ2 regards the role that these metaphors played in the discourse and whether the teacher used the metaphors intentionally; that is, whether he was aware of the metaphorical language and accompanied gesture production. Furthermore, we aimed to understand whether he was surprised by our findings of RQ1, or whether he was fully aware of his metaphor use. Here, we present a single case of one teacher. This case study is part of a bigger analysis of multiple high school teachers. With this contribution, we present an initial fine-grained analysis.

Methods

Participant

We describe the case of Daniel (pseudonym), who we observed during a total of 7 lessons (307 minutes) in three different classes spanning different high school levels. Daniel is a 40-year-old man who has been teaching chemistry for over 10 years at a Swiss high school, after having earned a master's degree in chemistry. He never pursued profession other than teaching. Therefore, we can confidently consider him a chemistry expert as well as a teaching expert in the sense that he actively participates in both discourses. During these lessons, Daniel focused on the concepts of energy, reaction velocity, and dye chemistry. He taught in his native language German.

Procedure

The study consisted of three parts. In the first meeting, we explained the study procedure and answered his questions. Further, he completed a demographics questionnaire and consented to the study procedures.

Second, we observed seven 45-minute lessons on three non-consecutive days. When videotaping, we recorded only Daniel's and not his students' voices. We edited the videos so that no students were visible.

Finally, after completing the analyses, we conducted a follow-up interview with Daniel. Here, we first asked him to explain a specific concept to see whether the metaphors in speech and gesture were robust over time. Second, we presented him with illustrative segments from the recordings and asked him to describe the metaphors that he used. Third, we described our own interpretation and discussed with him whether he agreed or not.

Analysis

We analyzed metaphorical language and gesture in the video material in three main steps: data preparation, the analysis of speech, and finally, the analysis of gesture. Two people coded the data: a chemist (first author) and a

 © ISLS

research assistant studying comparative linguistics and biochemistry. Therefore, both coders had expertise in high-school level chemistry. We discussed and resolved disagreements continuously for both the speech and gesture analyses. We first isolated sentences in the transcripts that mentioned an imperceptible chemical concept. In these sentences, we coded all words or phrases that related to the imperceptible concept. This included terminology, but also verbs associated with the concept as well as adjectives and pronouns.

To answer RQ1, we used the metaphor identification procedure (MIPVU, Steen et al., 2011) to identify words or phrases related to metaphors. Importantly, the MIPVU does not claim to identify the role of these metaphors or whether they are a cognitive resource or a stylistic choice. Instead, it is a linguistic procedure that allowed us to identify metaphors systematically and largely objectively. In the following, we will use the notation "TARGET CONCEPT is SOURCE DOMAIN" to indicate metaphors that map the source domain to the target concept. To identify the source domain, we gathered the basic (or most sensorimotor or emotional) meaning from the German dictionary "Digitales Wörterbuch der deutschen Sprache" (DWDS).

For every metaphorical word, we identified accompanying metaphorical gestures based on the metaphor identification guidelines for gesture (MIG-G, Cienki, 2016). Therefore, we defined a gesture as the dynamic phase of movement and tension in the hand occurring after either a relaxed position of the hands or from a post-gesture hold. Without sound, we first described the movement of the hands (e.g. hands positioned on chest-height, slightly cupped, as if loosely holding something). With sound, we then analyzed whether the gesture was referential. For referential gestures, we differentiated between enacting (e.g., throwing an imaginary ball), embodying (e.g., the fists representing balls), holding/touching (e.g., the hands holding an imaginary ball), and tracing gestures (i.e., the index finger tracing an imaginary trajectory). This allowed us to identify the physical referent of that gesture (e.g., in the examples above, a ball). If the physical referent differed from the contextual topic (e.g., an atom), we coded the gesture as metaphorical (e.g. "ATOM is BALL").

We grouped the resulting set of individual metaphors to metaphor concepts according to systematic metaphor analysis (Schmitt, 2015). Two metaphors belonged to the same metaphor concept if they drew on the same source domain to explain a certain target concept. For example, the metaphor concept "ENERGY is (SPECIFIC) LOCATION" contained both the metaphor "CHANGE IN ENERGY is LOCATION CHANGE" and "SPECIFIC ENERGY is SPECIFIC HEIGHT" as they both made use of the source domain LOCATION. This allowed us to understand metaphor use beyond individual metaphors. A metaphor concept that consisted of many metaphors pointed to a source domain that served to describe a certain target concept frequently.

Finally, to address RQ2, we analyzed the follow-up interview. Specifically, we noted which metaphors from the classroom data the teacher employed again in the interview, potential disagreements with our interpretation, as well as whether he was aware of the metaphors that he used. This allowed us to validate our findings, and correct misunderstandings. Most importantly, it allowed us to interpret the functions of the metaphor as perceived by the teacher.

Results and discussion

We coded a total of 557 words or gestures as metaphorical, corresponding to an average of 1.8 metaphors per minute of data. We found 120 different metaphors across speech and gesture corresponding to 37 metaphor concepts. However, many of the metaphor concepts only contained a single metaphor. Therefore, they are rather weak compared to other metaphor concepts. Table 1 summarizes the metaphor concepts that encompassed at least three metaphors.

Table 1
List of Metaphor Concepts Consisting of at Least Three Metaphors

Metaphor concept	Example metaphor	# metaphors
ENERGY is (SPECIFIC) LOCATION	CHANGE IN ENERGY is LOCATION CHANGE	19
ENERGY is SUBSTANCE	ENERGY TRANSFER TO A is A EATS SUBSTANCE	7
MOLECULE is OBJECT	MOLECULE is PROPERTY	7
CHEMICAL BOND is PHYSICAL LINK	INTERMOLECULAR FORCES are GLUE	6
ENERGY is LIQUID	ENERGY TRANSFER is FLOWING	5
SCIENTIFIC INSIGHT is PHYSICAL KNOTTING	THEORY is PHYSICAL OBJECT	5
LIGHT is OBJECT	LIGHT is OBJECT THAT CAN BE BENT	4
ATOMS are PEOPLE	CHEMICAL COMPOUND are PEOPLE IN RELATIONSHIPS	4
MOLECULES are LIVING BEINGS	REACTANT is PARTICIPANT	4
ATOM is OBJECT	ATOM is BALL	3

Regarding RQ1, we found that Daniel employed many metaphors in his teaching. This finding is consistent with CMT, which proposes that metaphorical language is rather the norm than the exception, especially

 © ISLS

in language describing imperceptible concepts (Jäkel, 2003). Further, two metaphor concepts consisting of the most metaphors were "ENERGY is SUBSTANCE" and "ENERGY is LOCATION." These metaphor concepts have been comprehensively discussed in physics education (see Amin (2020) for an overview). They are further consistent with CMT in that they draw on image schemas (Lakoff & Johnson, 1999). Image schemas are "recurring, dynamic pattern[s] of our perceptual interactions and motor programs that give coherence and structure to our experience" (Lakoff & Johnson, 1980, p. xiv). In this case, Daniel employed the image schemas LOCATION and SUBSTANCE. In short, we found that Daniel drew on common sensorimotor experiences when discussing energy. These findings reproduce prior research in the context of a Swiss chemistry classroom and support the claims of CMT that metaphor use is extensive when discussing imperceptible concepts. In the following, we highlight two representative reflections by Daniel on his use of metaphor.

One metaphor that Daniel introduced intentionally was the "ENERGY is LIQUID" (as opposed to the commonly used SUBSTANCE) metaphor. In the interview, he explained that he wanted to move away from the idea that ENERGY needed to be "added" to a chemical system to start a reaction like a SUBSTANCE would be "added". He thought this would falsely suggest that there must always be a person present who manually does this adding of energy. Therefore, he changed his language intentionally to ENERGY "flowing" in and out of the chemical system. However, when confronted with our findings that he still used several metaphors conceptualizing ENERGY as a SUBSTANCE in his teaching, he voiced surprise and the goal to be more careful in the future. However, based on CMT, one might argue that refraining from using the "ENERGY is SUBSTANCE" metaphor is (i) likely not possible because it is highly engrained in expert discourse and consequently likely also in his own thinking, and (ii) potentially not beneficial to students because they need to learn about and adopt expert discourse sooner or later.

The second reflection that we want to highlight is related to the metaphor "REACTION is LOCATION CHANGE." This metaphor belongs to the metaphor concept "ENERGY is LOCATION" and is employed, for example, when chemists talk about the change in energy throughout a reaction in terms of a movement across a landscape. Daniel was not surprised that he used this metaphor, but he was not aware of a set of gestures that he used alongside the metaphor. For example, he often moved his hands along a path in the air when describing the progress of a reaction. When reflecting on these gestures during the follow-up interview, he connected the metaphor to teaching materials in the classroom. His reflection thereby complemented our analysis, as we only focused on language and gesture but not materials. He explained that as chemical reactions are traditionally written from left to right, he would further be careful to arrange substances that he would use during a lesson from left to right. He therefore pointed towards how the writing conventions of reactions from left to right, from reactant to product, constituted a metaphor. Previous work has similarly identified metaphors in visual representations, for example in diagrams (e.g., an energy level diagram reproducing the ENERGY is LOCATION metaphor, Amin, 2020).

We found that he was aware of many metaphors in speech although he was not aware that he used some of them. However, he was not aware of the metaphorical gestures he produced along with the metaphors in speech.

Conclusion

We found that indeed, the language and gesture high school teacher Daniel used during teaching was rich in metaphors. We further found that he was aware and careful about some of these metaphors, and unaware of others. For the most part, he was not aware that he produced gestures accompanying these metaphors.

We theorize that the use of 1.8 metaphors per minute of teaching will impact student understanding. For example, these metaphors may ground students' sense-making processes as they try to understand new information. However, it is possible that without additional scaffolding, they may over-rely on the metaphors and generate misconceptions. Examining differences between metaphors used by teachers and students may point towards a knowledge gap that teachers must address (Niebert & Gropengiesser, 2015). Here, we offered a first step towards a comprehensive collection of metaphors in educational discourse that the students need to understand.

While we were able to describe the role of these metaphors as perceived by Daniel, our analysis does not provide further information of what cognitive mechanisms led to his use of metaphors. Future work should investigate to what extent students adopt these metaphors easily and whether they truly think about the target concepts in terms of the source domains. If they do, teachers should introduce these domain-inherent metaphors more explicitly, including their limitations. Furthermore, this would point towards designing instructional analogies aligned with these domain-inherent metaphors (Amin et al., 2012). Finally, we did not discuss speech and gesture separately in this short paper. Further disentanglement of which metaphors occur in speech only and which are supported by gesture may yield in further insights. With this contribution, we offer a first corpus in the specific context of German-speaking Switzerland, from which future research can draw metaphors from.

 © ISLS

References

Amin, T. G. (2020). Chapter 3. Coordinating metaphors in science, learning and instruction: The case of energy. In A. Beger & T. H. Smith (Eds.), *Figurative thought and language* (Vol. 6, pp. 73–110). John Benjamins Publishing Company. https://doi.org/10.1075/ftl.6.03ami

Amin, T. G., Jeppsson, F., Haglund, J., & Strömdahl, H. (2012). Arrow of time: Metaphorical construals of entropy and the second law of thermodynamics. *Science Education*, *96*(5), 818–848.

Boo, H. K. (1998). Students' understandings of chemical bonds and the energetics of chemical reactions. *Journal of Research in Science Teaching*, *35*(5), 569–581. https://doi.org/10.1002/(SICI)1098-2736(199805)35:5%3C569::AID-TEA6%3E3.0.CO;2-N

Cienki, A. (2016). Analysing metaphor in gesture: A set of metaphor identification guidelines for gesture (MIG-G). In *The Routledge handbook of metaphor and language* (pp. 149–165).

Dreyfus, B. W., Gupta, A., & Redish, E. F. (2015). Applying conceptual blending to model coordinated use of multiple ontological metaphors. *International Journal of Science Education*, *37*(5–6), 812–838. https://doi.org/10.1080/09500693.2015.1025306

Frankland, E. (1866). XXXIX.—Contributions to the notation of organic and inorganic compounds. *J. Chem. Soc.*, *19*(0), 372–395. https://doi.org/10.1039/JS8661900372

Hesse, M. B. (1965). *Models and analogies in science*.

Hostetter, A. B., & Alibali, M. W. (2019). Gesture as simulated action: Revisiting the framework. *Psychonomic Bulletin & Review*, *26*(3), 721–752. https://doi.org/10.3758/s13423-018-1548-0

Jäkel, O. (2003). *Wie Metaphern Wissen schaffen: Die kognitive Metapherntheorie und ihre Anwendung in Modell-Analysen der Diskursbereiche Geistestätigkeit, Wirtschaft, Wissenschaft und Religion* (Verbesserte, aktualisierte und erweiterte Neuauflage). Verlag Dr. Kovač.

Jeppsson, F., Haglund, J., & Amin, T. G. (2015). Varying Use of Conceptual Metaphors across Levels of Expertise in Thermodynamics. *International Journal of Science Education*, *37*(5–6), 780–805. https://doi.org/10.1080/09500693.2015.1025247

Jeppsson, F., Haglund, J., Amin, T. G., & Strömdahl, H. (2013). Exploring the Use of Conceptual Metaphors in Solving Problems on Entropy. *Journal of the Learning Sciences*, *22*(1), 70–120. https://doi.org/10.1080/10508406.2012.691926

Johnstone, A. H. (1991). Why is science difficult to learn? Things are seldom what they seem. *Journal of Computer Assisted Learning*, *7*(2), 75–83. https://doi.org/10.1111/j.1365-2729.1991.tb00230.x

Kövecses, Z. (2020). *Extended conceptual metaphor theory*. Cambridge University Press.

Lakoff, G., & Johnson, M. (1980). *Metaphors we live by*. University of Chicago Press.

Lakoff, G., & Johnson, M. (1999). *Philosophy in the flesh*. Basic Books.

Mahootian, F. (2015). Metaphor in chemistry: An examination of chemical metaphor. In E. Scerri & L. McIntyre (Eds.), *Philosophy of Chemistry* (Vol. 306, pp. 121–139). Springer Netherlands. https://doi.org/10.1007/978-94-017-9364-3_9

Müller, C. H., & Rau, M. A. (2025). Instructional Analogies Dominate, Domain-Inherent Metaphors Are Overlooked: A Systematic Review of Metaphorical Mappings in Chemistry Education. *Journal of Chemical Education*, *102*(7), 2576–2591. https://doi.org/10.1021/acs.jchemed.4c01537

Niebert, K., & Gropengiesser, H. (2015). Understanding starts in the mesocosm: Conceptual metaphor as a framework for external representations in science teaching. *International Journal of Science Education*, *37*(5–6), 903–933. https://doi.org/10.1080/09500693.2015.1025310

Schmitt, R. (2015). Systematic Metaphor Analysis as a Method of Qualitative Research. *The Qualitative Report*. https://doi.org/10.46743/2160-3715/2005.1854

Shapiro, L. (2019). *Embodied Cognition* (2nd ed.). Routledge. https://doi.org/10.4324/9781315180380

Steen, G., Dorst, A. G., & Herrmann, J. B. (Eds.). (2011). *A method for linguistic metaphor identification: From MIP to MIPVU*. Benjamins.

Vosniadou, S., & Brewer, W. F. (1992). Mental models of the earth: A study of conceptual change in childhood. *Cognitive Psychology*, *24*(4), 535–585. https://doi.org/10.1016/0010-0285(92)90018-W