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Image schematic justification and design based on didactic situations

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Published in:
NorDiNa: Nordic Studies in Science Education

Publication date:
2016

Document version
Publisher's PDF, also known as Version of record

Citation for published version (APA):
Bruun, J., & Christiansen, F. V. (2016). Kinaesthetic activities in physics instruction: Image schematic justification and design based on didactic situations. *NorDiNa: Nordic Studies in Science Education*, 12(1), 56-72.

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Kinaesthetic activities in physics instruction: Image schematic justification and design based on didactical situations

Abstract

One of the major difficulties in learning physics is for students to develop a conceptual understanding of the core concepts of physics. Many authors argue that students' conceptions of basic physical phenomena are rooted in image schemas, originating in fundamental kinaesthetic experiences of being. We argue that this idea should be utilised in physics instruction, that kinaesthetic activities will provide useful entry point for students' construction of physics conceptions. We discuss the nature of image schemas and focus particularly on one: effort-resistance-flow. This schema is fundamental not only in our everyday experience, but also in most of school physics. We argue that performing kinaesthetic activities can support student understanding and intuitions with respect to central physics concepts. We use the Theory of Didactical Situations to design a lesson, which targets effort-resistance-flow. In this lesson, a kinaesthetic activity takes centre stage in both adidactical (fully autonomous) and didactical (less autonomous) situations.

En af de store udfordringer studerende har med at lære fysik er at udvikle en begrebsmæssig forståelse af fysikkens centrale begreber. Mange forfattere hævder, at studerendes opfattelser af grundlæggende fysiske fænomener er forankret i billedskemaer med oprindelse i grundlæggende kinæstetiske erfaringer i verden. Hvis sådanne skemaer har en kropslig basis, bør det kunne udnyttes i fysikundervisningen. Derfor argumenterer vi for at kinæstetiske aktiviteter med omhyggelige eksperientielle og begrebsmæssige analyser, kan hjælpe studerendes grundlæggende begrebsdannelser i fysik. Vi diskuterer billedskemaers karakter og fokuserer især på ét: *effort-resistance-flow*. Vi hævder, at dette skema er grundlæggende ikke kun i vores daglige erfaring, men også i mange grene af fysikken. Vi argumenterer for, at kinæstetiske aktiviteter kan understøtte elevernes forståelse af og intuitioner om centrale fysik begreber. Vi bruger Teorien om Didaktiske Situationer til at designe en lektion, målrettet imod *effort-resistance-flow*. Både adidaktiske og didaktiske situationer er struktureret omkring en kinæstetisk aktivitet i lektionen.

INTRODUCTION

Physics teachers have long been using activities where students either directly feel or represent physical entities in instruction. Examples include using students to illustrate the principles of refraction of light, how electrons move in a circuit (e.g. Singh, 2010), or how atoms behave in a gas, fluid, or solid (e.g. McSharry & Jones, 2000). Often, these activities are seen as illustrations that make learning physics more motivating or fun. Models are often meant to *illustrate* the underlying mechanisms of a physical phenomenon rather than having students actively link their experiences to a conceptual understanding of the laws of physics.

Such activities have been described in physics education literature as participatory simulations (e.g. Collela, 2000), analogical roleplaying (e.g. Aubusson & Fogwill, 2006), drama (Ødegaard, 2003), Energy Theater™ (Scherr et al. 2013), and kinaesthetic learning activities (e.g. Begel, Garcia, & Wolfman, 2004). Common to all these activities is that students enact physical entities in order to understand scientific phenomena and concepts. Both from a cognitive and from a social aspect, kinaesthetic activities can have a positive effect on student learning and classroom environments (e.g. Aubusson & Fogwill, 2006; McSharry & Jones, 2000). Embodied experiences may play a key role when learning science. Niebert, Marsch, and Treagust (2012) show that analogies in science teaching need to be embodied in order for them to be successful. Particularly, they show that even an embodied experience does not guarantee success, if the learning demand of the student is not taken into account. This paper aims at further developing these insights into a theoretical argument based on cognitive or epistemological perspectives that justify and motivate using kinaesthetic learning activities in physics teaching at secondary and tertiary levels.

The starting point is a closer consideration of the nature of the students' preconceptions and their connection to how physics learning can be viewed from the perspective of embodied cognition. After that we show how embodied cognition allows us to consider kinaesthetic activities as viable parts of learning activities that shape student understanding of mechanics. Specifically, we argue that an image schema *effort-resistance-flow* lies at the root of many areas of physics and of students' everyday observations. We then identify three types of kinaesthetic activities two in which *effort-resistance-flow* is crucial for linking student experiences with formal physics knowledge. For a particular kinaesthetic activity, we analyse student-generated examples of such linking. As an extension of the argument, we use the Theory of Didactical Situations (Brousseau, 2002; Ruthven, Laborde, Leach, & Tiberghien, 2009) to design a lesson for teaching mechanics using a kinaesthetic activity.

STUDENT CONCEPTIONS OF PHYSICAL PHENOMENA

When studying mechanics, students are supposed to achieve a so-called Newtonian understanding of the mechanical world. A vast amount of literature has documented that traditional lecture based instruction is insufficient to achieve this goal (see e.g. Halloun & Hestenes, 1985; McDermott, 1991). Often students adopt surface approaches like rote memorization and pattern recognition, rather than developing conceptual understanding of the subject. Students exposed to traditional lecture based mechanics instruction generally do not end up with a Newtonian understanding of the mechanical world surrounding them (Crouch & Mazur, 2001).

Changing student conceptions to the desired understanding of mechanical phenomena has been addressed extensively in conceptual change research (e.g. Hestenes, 2006; Gentner & Colhoun, 2010; McDermott, 1991; Vosniadou, 2010). A common theoretical assumption in this research tradition is that students possess certain cognitive structures, schemas, which shape their actions and predictions. These schemas are triggered by a task perceived by the student and enacted in order to solve that task. Students' conceptual frameworks (Vosniadou, 1994) or ecologies (diSessa, 2002) are believed to influence, which schemas are triggered and how they are enacted in given situations. One of the central questions in conceptual change theory is whether a student's conceptual understanding is

stable across contexts, and thus theory-like, or whether different contexts are likely to trigger different schemas even if the formal knowledge is the same. It is a common finding that conceptual change does not come about easily. Even when teachers address preconceptions explicitly, students do not necessarily adopt the formally correct views in their everyday lives. It is difficult for learners to use Newtonian thinking outside a narrow context.

There is reason to question the robustness and consistency of students' misconceptions. As pointed out by diSessa (1993), the view that students have misconceptions that are stable and which must be confronted, is not only at odds with the basic idea of constructivism (that students should construct their knowledge on the basis of what they already know), but also not necessary to explain the experimental findings of the conceptual change literature. Another way of stating this point is to ask, what the epistemic status of these misconceptions is supposed to be. Are they coherent theories or are they rather ad-hoc hypotheses?

In an overview of conceptual change theories Özdemir and Clark (2007) describe two different trends in conceptual change research. The first, labelled *knowledge-as-theory* (e.g. Chi, 1992; Posner, Strike, Hewson, & Gertzog, 1982; Vosniadou, 1994), views students' conceptions as theory-like structures, which provide the students with relatively unified, robust, and coherent views rooted in persistent epistemological beliefs. From the second perspective, *knowledge-in-pieces* (e.g. Brown, 1995; Clark, 2006; diSessa, 1988, 2014), students' mental structures are seen as less coherent with "multiple quasi-independent" elements loosely connected and brought together in a more ad-hoc manner. The distinction is important because it has direct implications for instructional approaches. For instance, from the knowledge-as-theory perspective establishing "cognitive conflicts" may be aimed at in instruction, which may lead the student toward fundamental accommodative change of mental structures. From a Piagetian perspective, this is a reconstruction of the schema (Piaget, 1952). From the knowledge-in-pieces perspective, the question of cognitive development is one of refinement of existing mental structures rather than replacement of them. In our view, changes in knowledge-in-pieces happen incrementally. They resemble assimilation, the idea that the schema is fundamentally expanded but not reconstructed (Piaget, 1952), more than assimilation.

Özdemir and Clark argue that recent studies have provided empirical evidence for the knowledge-in-pieces perspective. In addition, other studies indicate problems related to the knowledge-as-theory perspective. For instance, some studies show that the same students do not use the same misconceptions consistently. Thus, Hestenes (2006) reports that nearly all students are inconsistent in applying the same concept in different situations. This finding can be understood in terms of students' conceptual profiles and their awareness of their own profiles (Mortimer, 1995). Conceptual profiles model the way students apply different ideas of a concept from experientially inferred ideas to highly abstract ideas. One of the goals for teaching is for students to "recognise different domains of each idea as well as their hierarchical framework, where some ideas explain others" (Mortimer, 1995, p. 282). In this view, different knowledge-pieces are not to be replaced, but through teaching, students should become aware of how to use them appropriately.

The premise for solving conceptual problems correctly is that the student is familiar with the general law and deductively applies it to the situation at hand and reaches a conclusion. However, if the student does not know which law to use or does not have knowledge of the general law to be used, the problem becomes one of establishing a relationship between the situation at hand, expected outcomes and an ad-hoc generated hypothesis. Then, "misconceptions" are constructed in an ad-hoc manner as responses to the encountered conceptual problem. In the situation at hand, they present themselves as likely explanations to the phenomenon or as likely strategies for solving the problem. It therefore seems unlikely that students actually entertain, for example, 'Aristotelian' theories of motion and apply them to conceptual problems. Rather, they may arrive at 'Aristotelian' notions of motion as a result of ad-hoc inferences.

The relation between student and external representation of the problem is likely important for understanding ad-hoc inferences; the way a problem is presented to the student affects how the student will work with the problem. For example, in Wason's (1966) four-card selection task, subjects are to deduce logically which cards to turn to determine the truth of a rule. Shifting the context from an abstract (numbers and colours) to a social (beer and age) context has been shown to influence subjects' ability to answer the task correctly (e.g. Fiddick, Cosmides, & Tooby, 2000). Similarly, Zhang and Norman (1994) found that external representations "change the nature of the task" (p. 119), and that they "can anchor and structure cognitive behaviour" (p. 119) This points towards a view of conceptual systems, which is rooted not only in the minds of students but also in their surroundings and in the relation between students and surroundings.

THE ROLE OF EMBODIMENT WHEN LEARNING PHYSICS

How come some students arrive at the right Newtonian conclusions while others do not? Andrea diSessa argues that understanding this question involves moving towards a systems perspective of knowledge with a multitude of mental substructures and diverse knowledge forms invoked in different situations (diSessa, 1993, pp. 148-149). Notable among these are the so-called p-prims or phenomenological primitives, which are theoretical structures that are hypothesised to be used in human conceptualisation. The term 'primitive' is used to designate that the p-prims are used with no need for further explanation and that they are atomic mental structures (diSessa, 1993, p. 112). P-prims are related to different types of phenomena familiar from everyday life, for instance phenomena pertaining to force and agency or constraint phenomena. However, they have an uneasy relationship to language, and we need to turn to the related idea of image schemas in cognitive linguistics.

Metaphor, image schemas, p-prims

Cognitive linguistics is the study of the relationships between human language and patterns of thought (Evans & Green, 2006). One of the very influential ideas in cognitive linguistics is that our embodied experiences can become encoded in language, and serve as a means for interaction. Thus, there are branches of cognitive linguistics, pioneered by George Lakoff and Mark Johnson (Lakoff, 1987, 1993; Lakoff & Johnson, 1980, 1999; Johnson, 1987), which reject a separation between body and mind and assumes a connection between individual cognition and social interaction. Recently, studies have applied ideas from cognitive linguistics in science education research (e.g. Amin, 2009; Jeppsson, Haglund, Amin, & Strömdahl, 2013; Niebert et al., 2012), and many authors have stressed the importance of metaphor and analogy in learning processes (e.g. diSessa, 1983; Gentner & Colhoun, 2010; Gentner & Gentner, 1983; Lakoff, 1987; Lakoff & Johnson, 1980; Johnson, 1987). Basically, the idea of learning by analogy is that the learner has a good understanding of the conceptual topology of a base domain and maps this conceptual structure unto a less well understood target domain (Lakoff, 1993), thereby providing conceptual structure to the target domain.

According to Lakoff (1987) and Johnson (1987) metaphors get their conceptual structure or topology through image schemas. Image schemas are pre-linguistic structures acquired through our basic bodily experiences, for instance, *part-whole*, *source-path-target*, *up-down*, and *center-periphery* (see Johnson, 1987; Lakoff, 1987). Image schemas are extremely general, and serve as phenomenological building blocks of our cognition, and the foundation for analogy and metaphor: Two conceptual domains may be seen as similar with reference to a common image schematic structure. Thus, for instance, the conceptual metaphor *life is a journey* lends its basic conceptual topology from the *source-path-target* image schema related to the experience of going from somewhere to somewhere else. This basic schema provides structure to the concept of *journey*, and is projected unto *life*.

One of our most fundamental experiences is the bodily experience of exerting effort, experiencing resistance and giving rise to flow. This basic experience gives rise to the image schema *effort-resistance-flow*. Johnson's (1987) description of force-based image schemas may be seen as aspects of

effort-resistance-flow. Similarly, Andersson (1986) used conceptual metaphor theory to introduce what he called *the experiential gestalt of causation* (EGC). For Andersson, the EGC has roots in early experiences with an agent (e.g. a child) giving energy (e.g. causing movement) to an object. More abstract patterns of causation can be assimilated into the EGC; for example, fire can be the agent, feeling of warmth the energy, and a person the object. As a person moves closer to the fire that person will experience more effect. *Effort-resistance-flow* can easily be seen as part of the topology of EGC, but we agree with Andersson that the EGC develops beyond the early kinaesthetic experiences (Andersson, 1986).

Effort-resistance-flow may also be related to Talmy's force dynamics (Talmy, 1988), which he uses to describe language construals. A central theme in Talmy's framework is the interplay between rest and movement. For example, things that are at rest can be caused to move and vice versa. The cause of the change in movement is a battle between two force entities that are opposed. Talmy shows examples of how scientists use language in this way to talk about scientific phenomena and processes, even if they know that the depiction is not strictly correct.

Effort-resistance-flow might be close to identical with the so-called "Ohm's p-prim". Ohm's p-prim is absolutely crucial in making sense of mechanical phenomena (diSessa, 1993) as well as an abundance of other physics phenomena, for example, Newton's cooling law (diSessa, 2014). diSessa even argues that Ohm's p-prim stretches beyond physics into everyday domains (diSessa, 1993, 2002). This p-prim concerns "an **agent** that is the locus of an **impetus** that acts against a **resistance** to produce some sort of **result**" (diSessa, 1993, p. 126). Thus, this p-prim surely has a bodily basis – the act of pushing material objects, experiencing resistance and causing a resulting movement (diSessa, 1993, p. 126; see also Hestenes, 2010). We agree with Jeppsson et al. (2013) that it may be fruitful to see image schemas as the underlying cognitive structures, while different manifestations integrate schemas in different ways. Combining Amin's (2009) view that conceptual metaphors could be construed as a resource for conceptual change, Sherin's (2001) work on symbolic forms, and diSessa's caution that p-prims are difficult to observe, Jeppsson et al. (2013) argue that image schemas could be classified according to the function they serve. In this way, image schemas are the source domains of conceptual metaphors when they are projected to a conceptual domain, while p-prims denote, when image schemas "are not conventionally associated with any external representational structure" (Jeppsson et al. 2013, p. 82).

It is also easy to see how *effort-resistance-flow* may lead to false conclusions about the nature of motion. For instance, a common 'misconception' is the idea that, disregarding drag, heavier objects fall faster than light objects (Hestenes, Wells, & Swackhammer, 1992). It is easy to demonstrate that this is not the case; in most everyday situations, drag does not have a big influence on the fall time. So how do many students arrive at this conclusion so easily refuted by experience? One explanation is that they are making a metaphorical mapping from bodily experience using *effort-resistance-flow*. Students know from their own bodily experience that lifting a heavy object requires more effort than lifting a lighter one, and reason conversely that the heavier object must fall faster when falling towards the earth. As shown by Niebert et al. (2012), this inference can be understood as a misalignment between direct experience and the target domain within Newtonian physics. The faulty inference might result from students drawing on the experience of lifting rather than with things that fall. The source does not correspond with the target. Niebert et al. (2012) further show that even with the correct embodied source, the teaching situation needs to take into account the learning demand of the student. Thus, if students rely on the feeling of impact of objects that fall, drawing on their experiences with things that fall may not facilitate the correct inference, whereas drawing on or creating experiences with reacting to a falling object might help.

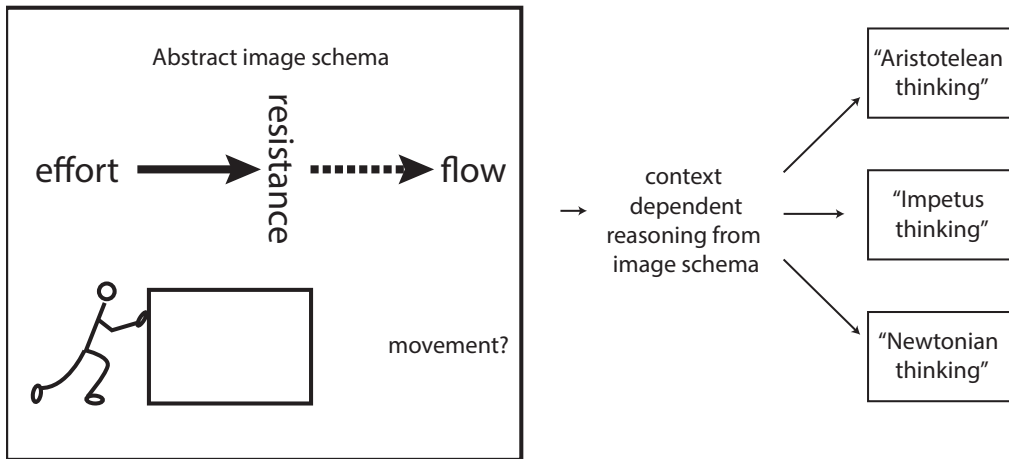


Figure 1. An illustration *effort-resistance-flow*.

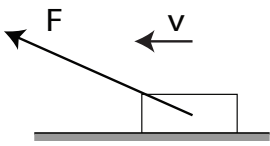
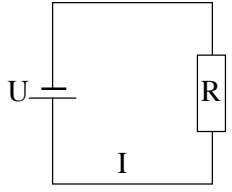
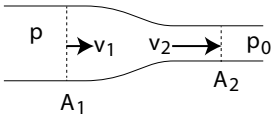
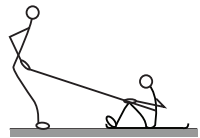
To sum up, we conceptualise *effort-resistance-flow* much like Halloun and Hestenes (1985) describe Buridan's concept of 'impetus'. However, context might change its appearance. For example, the expressed idea that motion must have a cause (Hestenes et al., 1992) can be associated with this schema, resulting in 'Aristotelian' thinking (see Figure 1). However, as diSessa (2014) shows *effort-resistance-flow* (Ohm's p-prim) can be used productively in teaching: Through a process of coordinating p-prims related to agency, effort and equilibrium, students were able to reproduce accurate descriptions of Newton's cooling law. In this process binding p-prims to correct formal concepts, and subsequent eliciting of some of the chains of reasoning were crucial. Just as Niebert et al. (2012), this shows that the task for instruction is to create learning situations, which allow phenomenological experiences to be engaged productively to build conceptions in line with formal physics.

Effort-resistance-flow as a central topology in the structure of physics

Effort-resistance-flow is not at odds with physics but lies at the heart of physics. In many physical disciplines the central physical variables either drive motion or describe it (Borutzky, 2010). Thus, contemporary energy bond graph theory as used in engineering considers effort-variables (e.g. force, voltage, hydrodynamic pressure) and flow-variables (e.g. velocity, current, volumetric flow rate). The relation of these variables signifies an "energy bond", i.e. a power transmission. Energy bond graph relies on an analogy between physics domains that was first developed by Maxwell and has been developed in the methodology of energy bond graphs (Paynter, 1961). Table 1 lists examples of effort and flow-variables along with pictures of prototypical systems.

The similarities between different physics domains have been utilised in physics instruction. For example, the Karlsruhe Physics Course (Hermann, 2000) utilises a substance-like metaphor to introduce momentum, electric charge, and amount of substance as corresponding entities across domains. Changes in these quantities with respect to time are currents, and thus force, electrical current, and volumetric flow rate are currents. They conceptualise difference in potentials as the driving forces of the current. Notice that in Table 1 force is an effort variable, and this is inconsistent with the Karlsruhe Physics Course conceptualisation of it being a current. Borutzky (2010) notes that both conceptualisations are valid, but changing conceptualisation will change the analogy between mechanics and, for example, electronics.

Table 1. Examples of variables that are used in systems modelling in engineering and proposed relation to the effort-resistance-flow image schema. In each of these systems, we can identify effort and flow variables and also resistances.

Domain	Effort (symbol [SI unit])	Flow (symbol [SI unit])	Resistance	Prototypical system
Linear mechanics	Force (F [N])	Velocity (v [m/s])	Mechanical resistance (Rasmussen, 1994)	
Electric circuits	Voltage (U [V])	Current (I [A])	Electrical resistance	
Hydrodynamics	Pressure (P [Pa])	Volumetric flow rate (Q [m³/s])	Pipe resistance (Lautrup, 2011)	
Embodied	Kinaesthetic sensation of applying effort	Kinaesthetic sensation of flow	Felt resistance	

While *effort-resistance-flow* seems like a central image schematic foundation for physics, many other image schemas may influence conceptions of physics. For example, containers (e.g. using Gauss boxes to calculate electric fields), end-of-path (ray diagrams in optics), scale (e.g. units), cycles (planetary motion), and balance (e.g. statistical mechanics) may all be relevant. What is special about *effort-resistance-flow* is that it is likely central to the sense of mechanism (diSessa, 1993) experienced by people successfully performing and learning physics, because it is tightly connected to our being able to interact with entities in the world. This fundamental insight should be utilised in teaching by devising experiments and teaching that explores the analogy between the students' basic bodily experiences and physical concepts and language. Our being in the world shapes our language and concepts via image schemas in what appears to be an evolutionary way. That is, with somewhat random variations and selection based on best fits to the current situation. Teaching with kinaesthetic activities should be able capitalise on this by designing situations in which concepts and language consistent with physics are more viable than concepts and language, which are not. Such teaching would be dependent on designed situations where explanations that are consistent with physics language and conceptions provide the best fit to the situation.

DIFFERENT TYPES OF KINAESTHETIC ACTIVITIES

Energy bond graphs exploit underlying common effort-flow structures of different areas of physics (see Borutzky, 2010). Using that line of thinking, we propose that kinaesthetic learning activities can exploit underlying image schemas in connecting human experience with different areas of physics.

In one type of activity, students use *effort-resistance-flow* as a basis for relating their experiences (source) to Newtonian mechanics (target). Since the students really are mechanical objects, there is no material difference between the two domains: Newtonian mechanics describe motion in the human domain. Utilizing the human body as an object in physics learning is not new (e.g. Bernhard, 2010; Pendrill & Williams, 2005), but the kind of activity proposed here does not necessarily involve digital sensors.

Another type of activity has students enact the mechanisms of a physics model or theory. Students enacting electrons in a circuit (Singh, 2010) may use *effort-resistance-flow* to connect the push from other students to the effect of voltage in the circuit. The working hypothesis of such activities is that it is possible to make a mechanical kinaesthetic model with the same types of relations between variables, as there would be in an electrical, thermodynamic, hydrodynamic, or quantum mechanical system. Unlike the first activity, the source domain is materially different from the target domain.

In a third type of activity, students may use other image schemas (such as *containment*) when enacting aspects of a model or theory. One could argue students in Energy Theater™ (Scherr et al., 2013) make use of, among other things, *containment* and *conduit* metaphors to embody their understanding and discussions of energy transfer processes. Again, the source and target domains are materially different, and other image schemas are in play.

In the last two types of activities, the source domain (mechanics/phenomenological experience) is different from the target domains (electrical circuits and energy transfer). Here, the embodied experiences are used to target image schemas, which are then mapped to the domain of physics by means of conceptual metaphor (Niebert & Gropengiesser, 2015)

It is important to recognise that students are not performing movements to stimulate the brain to learn better (Hannaford, 1995). Rather, they should use their experiences with enacting models to discern physics concepts. For example, if a student pulls at another student with a rope, they will both feel pressure from the rope and tension in their bodies, even if they do not identify the pull as a force in a Newtonian way. The point is to relate these bodily experiences to formal physics.

An activity relevant for teaching mechanics

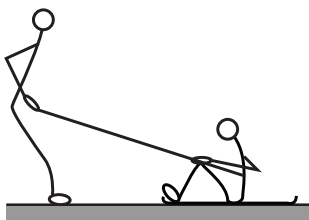


Figure 2: Drawing of the kinaesthetic experiential model discussed below. One student is sitting on a slab of plastic while being pulled by another student. In practice, some students hold on to the rope directly, while others attach it to the slab.

In this section, we provide an example of a kinaesthetic model (Bruun, 2009; Johannsen & Bruun, 2014) designed for teaching Newtonian mechanics, in particular, linear motion (see Figure 2). Furthermore, we show two examples of how student writings show evidence of them having employed *effort-resistance-flow* in the kinaesthetic activity. We distinguish between the kinaesthetic activity, which is what students perform in the didactical environment, and the kinaesthetic model, which is an idealisation of the activity useful for planning.

Below are examples from Danish first year upper secondary students, ages 15-16, with little prior knowledge of Newtonian mechanics. As part of a scientific outreach program, a class of 30 students participated in a 90-minute lesson in which they were asked to perform kinaesthetic learning activities (as described by Johannsen & Bruun, 2014). The first author of this paper and the students' regular physics teacher both taught the lesson. During the activity, students discussed and filled out a worksheet (see Appendix A for a modified version) by writing down (1) descriptions of their kinaesthetic experiences, (2) physics concepts they believed were relevant to their experience, and (3) explanations that related experiences with concepts. These sheets were collected after the lesson, and we show examples of these writings in Table 2 and 3 below. Bracketed text, [text], represents the authors' extrapolation.

Table 2. An example from a student describing the kinaesthetic experience of pulling/being pulled while sitting on a slab while holding on the rope.

KINAESTHETIC EXPERIENCE	PHYSICS CONCEPT	EXPLANATION
The more effort [forces?] the faster it went. [It became] easier [to pull]	The force goes through the string. G-force.	You have to start out running really fast because then it quickly gets easier [to pull]

The example in Table 2 clearly reflects the topology of *effort-resistance-flow*. The physical concept of (G-)forces acting through the string is imprecise, and the explanation also follows the *effort-resistance-flow* topology (the felt resistance is reduced if the flow increases quickly). It is tempting to categorise the example as an 'impetus misconception', but the explanation may be productive. Formally, the force needed on the box/sitting person to sustain a constant velocity may be taken as independent of the velocity. However, increasing the velocity would require a larger force. Taking this as a starting point, a teacher might tease out an appropriate explanation and thus help students map their experiences to the language of formal physics.

Table 3. A student's description of the kinaesthetic experience of pulling a slab.

KINAESTHETIC EXPERIENCE	PHYSICS CONCEPT	EXPLANATION
Both need to provide [effort] so [that] you can keep the balance. However, "the puller" needs to use more [effort].	Resistance force	When I pull, getting the slab going is the hardest.

Table 3 shows a case where effort is connected to balance. But the puller needs to use more effort. This example could be interpreted as a misconception, where the puller provides the most force since the puller is active while the pulled person is regarded as passive (see Hestenes et al., 1992). However, the student *may* experience more force in the vertical direction when standing compared to sitting. The rope tension has a vertical component, which points down for the student standing up and points up for the sitting student. Thus, a larger normal force acts from the floor on the standing student than on the sitting student, and this may be felt as requiring more effort. A teacher could help students generalise the descriptions to Newton's 3rd law, by focusing on the interaction between the standing and the sitting student, and downplaying the vertical interaction with the floor.

As is evident, students are not likely to miraculously derive important physics concepts simply by performing kinaesthetic learning activities. Guiding questions, validating reasoning, and timely explanations are essential elements of the teacher's toolbox when using kinaesthetic activities just as they are in any kind of teaching. The next section illustrates how the model shown in Figure 2 can be used in teaching.

FRAMING PHYSICS TEACHING BY USING KINAESTHETIC LEARNING ACTIVITIES

The Theory of Didactical Situations (TDS; Brousseau, 2002) is a design and analytical framework developed for mathematics. However, it has proven usable for a wide variety of subjects, including physics (Ruthven et al., 2009; Tiberghien et al., 2009). Ruthven et al. (2009) describe in detail, how TDS allows designers to incorporate abstract elements from grand theories of learning in teaching designs that can be realised in a classroom. Two notions were instrumental in informing TDS in its original form. The first was Bachelard's (2002) notion of the epistemological obstacle, which is "[...] the effect of a previous piece of knowledge which was interesting and successful, but which now is revealed as false or simply unadapted" (Brousseau, 2002, p. 82). The second was Piaget's (1952) notions of disequilibrium and accommodation.

TDS revolves around the concept of didactical situations where students are engaged directly in "solving a novel type of problem, refining their concepts and strategies in the light of feedback from a (material and social) milieu" (Ruthven et al., 2009, p. 330). There are three crucial elements to an didactical situation: A *task* that will have the students autonomously engaged with the knowledge to be learned. In this example, two central tasks are to explain kinaesthetic experiences in terms of formal physics (see Appendix A, task 3) and to devise a thought experiment to determine if any one of the two participants pulls more than the other (Appendix, task 4). The second component is comprised by the *conditions* under which the task will be solved. In this lesson, materials such as rope and slabs, worksheets, student groups of three, and an open setting with multiple surfaces comprise these conditions. Finally, an didactical situation will need to specify an *expected progression* towards the knowledge to be constructed. In this lesson it is for students to perform and discuss the kinaesthetic activity several times in order to map their kinaesthetic experience of *effort-resistance-flow* to a concept of force that is consistent with Newtonian mechanics.

The autonomy of the student is essential in didactical situations:

"Between the moment the student accepts the problem as if it were her own and the moment when she produces her answer, the teacher refrains from interfering and suggesting the knowledge that she wants to see appear. The student knows very well that the problem was chosen to help her acquire a new piece of knowledge, but she must also know that this knowledge is entirely justified by the internal logic of the situation and that she can construct it without appealing to didactical reasoning." (Brousseau, 2002, p. 30)

According to Brousseau (2002), didactical situations are embedded in a broader *didactical situation*, which consists of all decisions made by the teacher during the lesson - including decisions about how and when to scaffold students.

Given the emphasis on autonomy, teachers need to plan the didactical situation carefully. As an example, consider a task where students are asked pinpoint in which muscles they experience the sensation of pulling when standing and when sitting. A student standing up will likely experience this both in arms and legs, but may see this experience as one. To complete the task successfully students should be able to (1) compare standing up with sitting down, and (2) use their sensations in each case to distinguish between effort in their legs and effort in their arms. Thus, teaching must ensure that all students try out both standing and sitting. Successful mapping of a single ex-

perience of pulling to two separate sensations is likely a process of accommodation for some students. Taking this view, the preceding disequilibrium should be facilitated by a task, which asks students to consider which parts of their bodies are used in the movement (see Appendix, task 2). The mapping may later be used to analyse the kinaesthetic activity as a physical system, thus becoming of use for the students in the teaching context.

The materials (e.g. rope, handles, and slabs), the worksheets, group sizes, and even the setting (including how other students and the teacher act) comprise *didactical variables* that can be adjusted, added or removed. For this lesson, groups of three emphasise the focus on three particular roles: one standing/walking, one sitting, and one observing. This choice stages a discussion where students compare and contrast different experiences when making explanations. Another didactical variable is how and when the teacher asks questions that facilitate dialogue. The teacher might ask students to investigate different ways of performing the activity: If the knowledge to be constructed is Newton's 3rd law students might benefit from experimenting with symmetries and asymmetries. If two persons of comparable weight switch places, they should experience a comparable tension in both ends of the rope in both situations. However, if one person weighs much more than the other, that person should experience much less tension when standing than when sitting. Conversely, the lighter person will experience more tension when standing than when sitting. In fact, whether a person will find it easier to stand or sit should be dependent on difference in weight between the two participants and the angle of the rope. A teacher might facilitate student experiences with these asymmetries. One way of connecting these possible experiences to physics would then be to include spring scales as part of the didactical environment. These might be used to show that even if the force needed to pull a small person is less than that needed to pull a large person; the force needed in each end of the rope is the same. At a later time, a teacher may compare the situation with other situations, for example, the case of a large truck crashing into a small car (Hammer & Elby, 2003). The intention would then be to connect students' knowledge constructed in the situation to the truck-car situation.

Students successful in solving the task should be on the way to bridging, what we term here, the *phenomenological gap* between everyday experiences and the abstractions of formal physics. One of the tasks in the worksheet (Appendix A, task 4) is to find out if anyone of the students pulls more than the other in the activity. As mentioned, students might use spring scales to solve this task. The goal is then that correct student solutions serve as a bodily-grounded source domain for generalisation. In this way, the knowledge produced in the adidactical situation might serve the same purposes as Clement's (1993) bridging analogies.

Figure 3 shows in schematic form how a teacher can plan for bridging the phenomenological gap. Following Brousseau (2002), the knowledge to be constructed by students was originally created in a specific context, but then decontextualised, as in some formulation of Newton's 3rd law. A teacher must re-contextualise it, in this example by creating a kinaesthetic model and planning for kinaesthetic activities. Following the curved arrows going to the right in Figure 3, the teacher adds context and thus also makes the situation more concrete. The job of teaching and learning is then for students to re-decontextualise the knowledge.. While the foundations of the re-decontextualisation are laid in the adidactical situation, the full realisation happens in the broader didactical situation. In the broader scheme, the role of the teacher is to validate student answers and ultimately to help students connect the knowledge that was developed in the classroom with formal knowledge. The relation between re-contextualisation and re-decontextualisation is illustrated in Figure 3 with curved arrows going to the left.

TDS prescribes how to embed an adidactical situation in a didactical structure. First of all, the teacher distributes some of the responsibility and freedom of action to students by handing over the task and divulging the didactical environment. In this lesson, the teacher shows the equipment (ropes and slabs), and shows how to perform the activity safely without prescribing in detail how students should

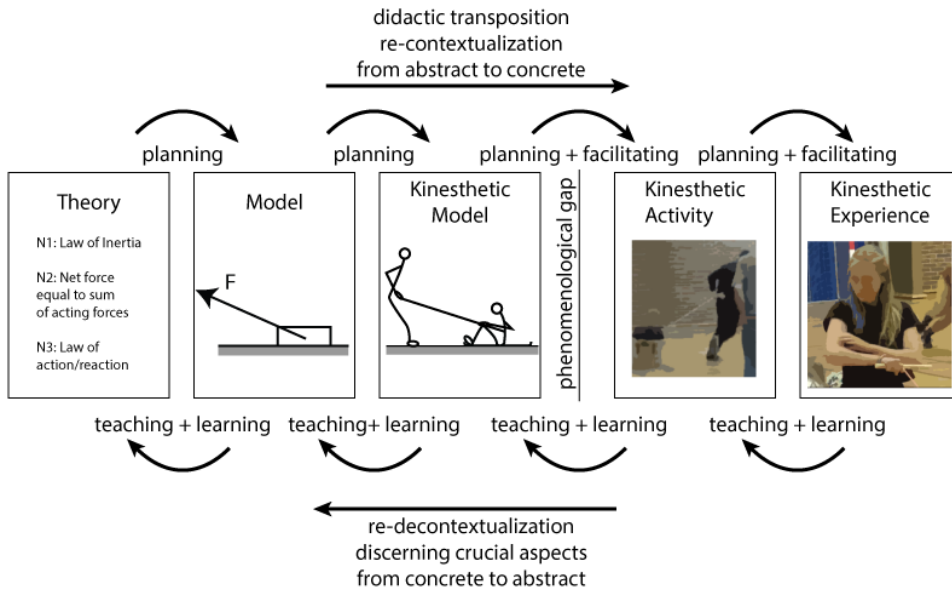


Figure 3: A model for planning and teaching with kinaesthetic models and exercises. Central to the lesson is bridging the phenomenological gap. The expressions N1, N2, and N3 signify Newton's 1st, 2nd, and 3rd law respectively.

perform the activity. In TDS, this phase is called the *devolution* (Brousseau, 2002). Students then proceed to engage with the task in *action phases* where they perform the kinaesthetic activity. They formulate their explanations verbally, in writing, and through drawings in *formulation phases*. Students validate their thinking via the feedback mechanisms in the didactical environment using other students, the teacher, or by revisiting the activity in *validation phases*. These phases are all part of the didactical situation, although the teacher can choose to interfere to make the phases more didactical. After the initial action phase, our lesson mixes the three phases to form small “ed-dies” of action-formulation-validation (e.g. performing-drawing-discussing).

The teacher helps students to contextualise the intended knowledge in the final and crucial *institutionalisation*. The idea is to connect the knowledge that has been developed during the lesson to the official knowledge. In this lesson the final phase of institutionalisation is comprised of a classroom discussion, where the teacher highlights the generalizable aspects of student experiences in the didactical environment. For example, if students had made the connection between effort and size using spring scales during the didactical situation, the teacher could introduce Newton's 3rd law as a way of formulating the knowledge obtained in the classroom. We summarise this description in Table 4.

The goal of this lesson is for students to inductively and by ways of analogy to use the kinaesthetic model to reach a higher level of abstraction than the kinaesthetic activity itself. In order to do that, teaching must be designed to bridge the phenomenological gap between physics learners' kinaesthetic experiences and abstract physics knowledge. However, as pointed out by Niebert et al. (2012), appropriate connections are not guaranteed just by having students ground understanding in embodied experience. Rather, connections between formal physics and phenomenological experiences become more likely when different didactical variables are tuned to the learning need of the students. It is for the teacher to decide how to scaffold students' bridging of the phenomenological gap by including/excluding certain, sub-tasks, and strategies for interaction. The teacher's decision will depend upon the students' social and academic abilities, on the logistical setting, and the knowledge to be constructed.

Table 4: Five phases of TDS describing a lesson that integrates the pulling model. The first column gives a short explanation for what occurs in each phase. The second column exemplifies the first for our lesson.

PHASE: SHORT EXPLANATION	EXAMPLE FROM LESSON
<i>Devolution:</i> Hand out material; unfold the didactical environment and task.	Teacher uses two students to show one way of performing the activity.
<i>Action:</i> Students perform the kinaesthetic activity and focus on the kinaesthetic sensations they experience.	Different pairs of students try standing/walking and sitting. They attend to and describe their sensations. Hypotheses about who pulls more emerge in response to task 4 (see Appendix).
<i>Formulation:</i> Put words and images to kinaesthetic experiences and come up with (physics) explanations	Students discuss where and how they experience effort in the different situations. They describe bodily sensations in terms of physics concepts. They may design experiment in response to task 4 (see Appendix).
<i>Validation:</i> Explanations are validated by revisiting the kinaesthetic activity and by student-student and teacher-student interactions.	With spring scales available, they might test their hypotheses. They may discuss whether their physics concepts are appropriate. Teacher validates and questions students' discussions and actions.
<i>Institutionalisation:</i> Teacher uses classroom dialogue to connect kinaesthetic experiences to physics.	Teacher introduces Newton's 3 rd law, while highlighting the equal tension felt in each participants arm during a single performance of the activity.

With our examples, we have mostly focused on Newton's 3rd law but a detailed analysis of the forces involved is also a possibility, but we want to emphasise that both are long-term goals, which we expect to require many didactical situations. Whatever strategy the teacher employs to reach such goals, it is by promoting performance, discussion, validation, and subsequent institutionalisation of knowledge that we expect the application of image schemas to be modified to resonate more with physics.

CONCLUDING REMARKS

We have developed an argument for using kinaesthetic activities in instruction that focuses on changing physics conceptions of students. We have argued that image schemas provide a fruitful entrance to facilitate this change, and that in particular the *effort-resistance-flow* schema is central to most school physics. We have been informed by literature to identify different types of kinaesthetic activities and we have specified how one may use the Theory of Didactical Situations (Brousseau, 2002) to design instruction that may eventually lead to conceptual change.

We hold that it makes little sense to label student understandings as right or wrong. In our view, (image) schemas as enacted by students have served them well (mostly) in their lives so far, a point made also by Linder (1993). To initiate change in student conceptual ecologies (diSessa, 2002) there must be a designed situation that selects for understandings consistent with formal physics.

The image schema *effort-resistance-flow* is likely an ideal starting point for learning physics, as most school physics can be encompassed by the schematic structure as demonstrated by energy bond graph theory. A central aim of instruction from this perspective is that students become aware of how

their intuitive experience of *effort-resistance-flow* situations may be conceptualised and used to work with and explain physics phenomena. If image schemas are indeed central to human development of conceptual understandings, the idea that instruction might target them through kinaesthetic activities should be explored further.

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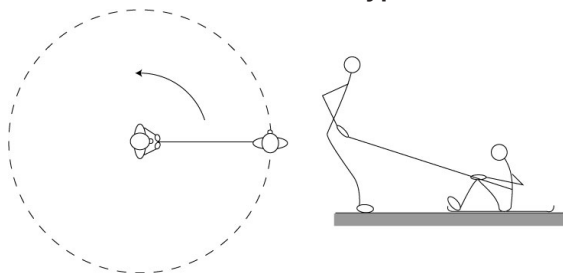
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APPENDIX A: WORKSHEET FOR STUDENTS

The worksheet has been modified here in two ways compared to the worksheet handed out to students. First, it has been translated to English from Danish. Second, the original worksheet included a second activity with a circular movement. We have excluded this activity for the purposes of clarity. The lesson included Task 4, but it was administered orally.

Feel the force in two different types of movement



Purpose. In this exercise you'll perform two kinaesthetic activities that represent physical systems. The idea is to apply the correct physics terms to your bodily experiences and to use these terms to design an experiment.

Task 1: Do the activities for the first time. You'll need something to sit on, a rope and two handles. One of you pulls. Another is pulled. The third person observes. Make sure to switch, so all three of you get to try all roles. It is part of this task to find out how you do the activity. One possibility is that you both hold the rope, or that you tie the rope to, for example, the person being pulled. *Remember! Take care of each other! If you run too fast, you may get hurt!*

Task 2: Describe the movements. Describe the movement in detail from the beginning to the end. Where can you feel being pulled? What does the pulling person do? What can you observe? Try to describe the *bodily observation* (what you can feel) with words. If necessary, run the exercises again and vary the amount you pull, or how fast you run. Are there differences? *Bodily observations* can be, for example, the experience of faster and faster movement, the experience that the floor is uneven, or the experience of a tight rope.

Task 3: The Table. Make a table as shown below with a row for each physical observation you made. For each observation, write which physics concept you would use to describe it. In the explanation column, elaborate how you would use this concept to describe the bodily observation. The task is to be precise. Try to use as few physics concepts as possible for each bodily observation

Bodily observation	Physics concept	Explanation

Task 4: The thought experiment. Would you say that one of the persons is pulling more than the other? Design an experiment to test your claim. You do not need to perform the experiment right now, but you should describe it with enough detail so that someone could perform it.