Research Summary

Motion and Forces
Using bridging analogies to teach about balanced forces
Students should be taught about: using force arrows in diagrams, adding forces in one dimension, balanced and unbalanced forces.
Science (Physics) – KS3

Statement of issue

There is a long history of research establishing that forces and motion are an inherently difficult area to teach in science (Brown & Clement, 1989; Driver et al., 1994; Kruger et al., 1990; Tao & Gunstone, 2000). Misconceptions based on motion frameworks are primarily reported in the literature (Demirci, 2005; Nie et al., 2019).

There are three main misconceptions: (i) if an object is moving there is a force acting on it in the direction of movement, (ii) sustaining motion requires a continued force, (iii) if an object is not moving no forces are acting on it (Gilbert & Watts, 1983). We will focus on the last misconception as this has been repeatedly highlighted in the literature (for example, Demirci, 2005; Nie et al., 2019) that students commonly believe that an absence of motion means that forces are absent.

Main findings from the research

To tackle this misconception research suggests using bridging analogies (Brown & Clement, 1989; Bryce & MacMillan, 2005; Minstrell, 1982).

What are bridging analogies in science education?
An analogy, drawing on Driver and Bell's (1986) model, comprises two parts: the target and base. The target is the situation to be explained by the analogy. The base is the better understood analogous situation. The teacher and student draw attention to the relations between elements in the base and elements in the target (unless the relation is considered obvious). The individual perceives these elements as characteristics or relationships, and they are similar across both the base and the target.

Think of an analogy as the mapping of knowledge from one topic (the base) onto another (the target; Gentner, 1983). For example, in the lesson plan, we are mapping the knowledge about upward force, by engaging with the analogies the students gain direct experience of upward force (i.e. the "feeling of" a book held up by a hand, book suspended from a spring, spring being pushed down by a hand). In the final analogy, this relation of experience is replaced with pliable wood demonstrating the cause of the upward force. Research shows the more shared relations, the more useful the analogy (Gentner, 1989).

What is an anchoring concept?…is an "intuitive knowledge structure that is in rough agreement with accepted physical theory" (Clement et al., 1989, p. 555). One way to identify students' anchoring concepts is to use an anchoring example; this offers the students a problem situation to demonstrate their knowledge. Ideally, students will confidently give a correct response to the problem thereby demonstrating their anchoring concept that can be used. Be careful to distinguish between memorised answers and intuitive knowledge, as memorised answers cannot be used as anchoring concepts. Brown and Clement (1989) combined anchoring intuitions and analogical reasoning (using individual experiments and class discussions), to tackle misconceptions. They found that secondary students who experienced anchoring and analogy performed statistically significantly better than those with no analogy/anchoring.

Identifying the problem:

There are no clear developmental age-related differences (Erickson & Hobbs, 1978) for common misconceptions held in forces. Instead, the same misconception – that of an absence of motion means that forces are absent – are more clearly communicated by older than younger students (SjØberg & Lie, 1981). Research suggests that the counterintuitive development of abstract ideas about forces in conjunction with students' everyday experiences is central to students' difficulties (Heywood & Parker, 2001). Making bridging analogies an appropriate response to the misconception, as bridging analogies offer students affordances to their everyday experiences.

Bridging Analogies

Minstrell (1982) explored the impact bridging analogies had on the reasoning of 27 physics students. As a teacher Minstrell had repeatedly found his students struggled with the topic of forces when objects were stationary, therefore using Arons (1981) work he devised a series of bridging analogies to support students understanding. The analogies he demonstrated were the book (1st)was placed on the table, (2nd) on an outstretched hand of a student, (3rd) on the hand again, adding more books to the hand, (4th) hanging from a spring, and (5th) on the table, then a beam of light was reflected at a low angle of the tabletop to the wall, he stood on and off the table causing a depression, shown by the movement of the reflected light. Finally, the book was placed (6th) on the table again. For each analogy, students were asked to draw the forces acting on the book. After each analogy, Minstrell polled students on their understanding of forces. These polls show that as the number of analogies increased so did the number of students understood in balanced forces. For example, in the first poll conducted at (1st) 52% of students believed *only* in downward force, and by the last poll conducted at (6th) 93% of students believed in *balanced* forces. Therefore, demonstrating the success of sequentially linked bridging analogies.

Brown and Clement (1989) designed an experiment to tackle the same misconception – that absence of motion means that forces are absent. They did this by adapting a popular science textbook at the time, 21 students who had taken no physics classes took part and were either given the control explanation or experimental explanation of balanced forces. The experimental explanation made a connecting sequence of bridging analogies – based on a hand pressing down on a coiled spring, then moving to a wooden board being pressed down by hand between two supports, to a hand pressing on a desk to a book placed on a desk. The analogies were built from an anchoring point of student experience: a hand pressing down on a spring. The control explanation stated that Newton's third law applied to the book on the table situation and that therefore the table is exerting an upward force. They found a statistically significantly better understanding as tested using paper and pencil test about forces for those receiving the sequential analogies approach in the experimental condition.

Bryce and MacMillian's (2005) work builds on Minstrell's (1982) and Brown and Clement's (1989) research, and they explored the effectiveness of bridging analogies for 21, Year 10 students. They found that bridging analogies were more effective in tackling the misconception than didactic teaching for some students. A similar approach to sequential bridging analogies was adopted, with an anchoring concept centred on a book (1) on a desk, (2) held by a hand, (3) suspended from a spring, (4) spring being pushed by a hand (then balance a book on the spring), (5) on a bendy table. However, where Bryce and MacMillian's work differs, students were encouraged to carry out the analogies themselves. The teacher's role here is critical as they make clear to the students the relations between the anchor and the target, for example in (5) the bendy table, commenting "this looks rather like a table". By the end of the analogical sequence, 86% of students considered that the book and the table's forces were equal. Neither this study nor Brown and Clement's (1989) study achieve 100% of students understanding balanced forces. Bryce and MacMillian state that this approach's success relies on students engaging with the analogies and thinking through their meanings.

The key message from the research is that:

- There must be a usable anchoring conception.
- The analogical connection between an anchoring example and the target situation may need to be developed explicitly through processes such as intermediate analogies.
- It may be necessary to engage the student in the process of analogical reasoning in an interactive teaching environment, rather than simply presenting the analogy in a text or lecture.

Therefore, a lesson was produced to incorporate bridging analogies into teaching balanced forces.

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