Frameworks for talking about energy - mutually exclusive?

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PHYSICS COMMUNITY AND COOPERATION

Selected Contributions

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EDITORS
Derek Raine, Cheryl Hurkett & Laurence Rogers

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FRAMEWORKS FOR TALKING ABOUT ENERGY - MUTUALLY EXCLUSIVE?

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ABSTRACT

How can we use Watts' frameworks (Watts, 1988) for talking about energy to design education on the subject of energy? We showed 6 pictures also used by Watts and gave a writing assignment to 17 fifteen year olds prior to any physics education on energy. We refined the definitions of Watts' frameworks in order to solve our problems with assigning student-statements to frameworks and found the frameworks not to be mutually exclusive. Results found include the frequency of the 7 frameworks in the studied group of students, and the overlap between these frameworks. We also found that certain frameworks are involved positively and/or negatively in reaching the desired goal of secondary school learning about energy. Finally we will present some ideas on how to use the results in the design of educational materials which we hope to develop in the near future.

1. INTRODUCTION

Watts, using interviews, established 7 different frameworks for talking about energy. He did so by considering students' verbal reactions to certain pictures combined with the question to decide if the pictured situations illustrate their concept of energy and to give a reason why (Watts, 1983). He provided typical examples for each of the frameworks, in the form of citations from students.

Various later studies have used Watts' frameworks in different ways: in group discussion assignments (video recordings) (Gilbert and Pope, 1986), in interviews (Kruger, Palacio et al., 1992, Summers, Kruger et al., 1998), in writing assignments (Finegold and Trumper, 1989), analysis of TIMMS database (Liu, 2005), and in surveys through questionnaires (Kruger, Palacio et al., 1992, Swackhamer, unpublished).

As a preparation for a planned teaching experiment we chose to diagnose Dutch students' prior ideas about energy using Watts' frameworks in combination with a writing assignment. We chose a writing assignment because it's do-able for reasonable numbers of students, while it does not force students to say yes or no to sentences they would never construct themselves. This paper reports some methodological difficulties that we experienced with this chosen setup, and solutions found for those difficulties. Finally, we will also diagnose our target group of students and draw conclusions about possible teaching strategies.

Other studies based on Watts' frameworks make adjustments to the 7 frameworks described by Watts and emphasize some frameworks more and other frameworks less. Sometimes an extra 'framework' is added in which students confuse the concept of energy with another physical quantity or phenomenon.

Usually Watts' frameworks are interpreted as being mutually exclusive. Exclusivity is a desirable feature of a category system such as frameworks. It makes it easier to classify students' statements. Watts

himself makes the impression that he thinks of his frameworks as being mutually exclusive by presenting some pairs of his seven frameworks as clearly demarcated and by interpreting each of his example citations to fit into one of his frameworks and one only.

However Watts and none of the later studies have checked the seven frameworks for clear differentiation. In their original formulation by Watts it is not clear that the frameworks are necessarily mutually exclusive. Particularly for specific pairs it is very hard to regard them as exclusive.

> *"To lift a box up a hill one needs energy (body energy). This energy is acquired from food and sleep. It is generated from nutrients by burning.[. . .]"* (Student 7 on picture A)

This citation shows the idea of energy being needed, as a cause to let things happen (framework 2) and the idea of generation of energy out of stuff that is not energy, so non-conservation (framework 5)[5].

> *"Because something happens to a chemical reaction such as heating, cooling, mixing and stirring energy can be generated. This can be heat or light, but also other things such as electricity or battery acid"* (Student 16 on picture B)

In this citation and even in the same sentence we see the idea of a trigger, namely, the heating, cooling, mixing or stirring being needed to release energy that didn't exist prior to being awakened (framework 3) and the idea of generation of energy (framework 5).

Therefore we ask the question whether we are justified in requiring the frameworks to be exclusive.

We decided to interpret Watts' frameworks as non-exclusive categories for two reasons. It leaves room for us to stay close to Watts' original definitions of the 7 frameworks and we were curious about what kind of results and difficulties would arise from doing so. The limitations of the writing assignment we try to counter by using a three-valued logic: inclusion of 'undecided' as a third category.

2. How we interpreted Watts' frameworks

The next table (Table 1) shows a selection of definitions by Watts side by side to our definitions leaving out two frameworks which are not essential to our major conclusions (for the missing definitions we refer to an internal report (Logman and Kaper, 2009) which will be available from our website).

In the following, we will comment on some of the changes we made in the definitions (Table 1). From these comments it will become clear that refining the definitions has been an iterative process: in arguing about our definitions we will sometimes have to refer to results that will be substantiated later in the results section.

In defining framework 2 we focused on objects having energy and to let this energy be the cause of some activity. Doing this we stayed close to Watts. In students' products from the writing assignment we found students stating either the first or the second condition for conformation while seeming to imply the other condition, so we decided to categorize both as framework 2 as long as the statement didn't contradict the condition that was left out.

[5] See Watts' definitions as given in Table 1. This table also contains our own definitions, but we are not yet referring to those.

Watt's definition	Logman et al. definition
Framework 2: A 'depository' model of energy	
This is a model of energy that (Clemont 1978) calls a 'source of force' model. From this point of view, youngsters see some objects as having energy (and being rechargeable), some as 'needing' energy (and simply expending what they get) and yet others as neutral (and whose activities are somehow 'normal' or 'natural'). Energy, then, is a causal agent, a source of activity based or stored within certain objects. This idea of energy has a long history (Elkana 1974). The 'power' within things that enables them to act has often been called energy. If something happens, then it seems natural to look for some source that causes it.	A statement conforms to framework 2 if: • energy is regarded as a necessary cause for something to happen *and (or)* • energy is regarded as present, stored in objects†, before the relevant activity If one of these characteristics is clearly present, the other one often seems to be implied, so the "and (or)" is really meant to be an "and", the other aspect must not be contradicted! However, it's not required that both are explicitely stated. A statement contradicts framework 2 if: • something happens without energy being necessary for it.
Framework 3: Energy is an 'ingredient'	
In this framework energy is not necessarily a causal agent, but a 'reactive' one. It is a dormant ingredient within objects or situations that needs some 'trigger' to release it. Solomon (1980) notes this feature when pupils talk about food: 'pupils believe that energy is not *stored* in food, it only "gives you energy when you eat it"'. In a similar way some would argue that energy is not *stored* in coal or oil (as in framework 2) but is 'sparked off' when either is burnt. Likewise, a book lying upon a table would not have energy unless something (or someone) came along to push it off.	A statement conforms to framework 3 if: • a trigger (mixing substances, pushing a switch, lighting a fuel) is needed before the energy becomes active. A statement contradicts framework 3 if: • things happen and the necessity for a trigger is denied.
Framework 4: Energy is an 'obvious' activity	
To many, it is outward overt displays of activity that are the sole means of identifying energy. Moreover, the activities themselves are actually called energy. Movement (of any kind) is widely given as a reason for energy being involved: the energy *is* the movement itself. This often indicated, in the responses, by energy being equated with a verb, a word-of-action.	A statement conforms to framework 4 if: • an activity is equated with energy (this usually takes a verb). A statement contradicts framework 4 if: • a noun is used to identify energy, or • energy is the cause of the activity‡, or • energy is a product of activity‡.

Continued on next page...

Watt's definition	Logman et al. definition
Framework 5: Energy is a product	
In contrast, this framework carries the suggestion that energy is not an ingredient or a process (as above) but a byproduct of the situation. In some senses it was rather like a waste product as with smoke, sweat or exhaust fumes - another perspective identified by Stead (1980). Clearly energy is non-conserved, as with the other frameworks, and here it is treated as a relatively short-lived product that is generated, is active and then disappears or fades.	A statement conforms to framework 5 if: • energy (of a certain form) is the result of a certain activity. A statement contradicts framework 5 if: • an activity occurs while it's denied that (any form of) energy is involved as a product.
Framework 7: A flow-transfer model of energy	
Aarons (1965) says 'Energy is not a substance, fluid, paint or fuel which is smeared on bodies, rubbed off from one to another; we use this term to denote a construct. Numbers calculated in a certain prescribed way, that are found by theory and experiment to preserve a remarkably simple relationship in very diverse physical phenomena'. And yet Warren (1982) points out that 'energy is a fluid' *is* both an implicit and explicit suggestion behind the way in which the concept is commonly taught in schools. In this way energy is seen as being 'put in', 'given', 'transported', 'conducted' and so on.	A statement conforms to framework 7 if: • for an activity a source of energy is mentioned, and • for the same activity it is mentioned where or in what form the energy will be transferred as a result of the activity. A statement contradicts framework 7 if: • no energy source was needed for the activity, or • energy disappears after the activity.

Table 1: Watt's definitions as opposed to Logman et al. definitions. †"Objects" in the most general sense: air, fire . . . To be an object something must occupy space and have some durability, because energy must be "stored" (a state), so an object is not a process, but apart from that it can be almost everything. ‡ Being either the cause of activity or the product of an activity, energy can't be equated with the activity itself.

As most students in our study only mention the production and do not write about what happens to the energy produced after an activity ends, we decided to broaden framework 5 slightly. We added the situation in which production of energy was clearly mentioned yet nothing was written about the non-conservation of energy to this framework.

Framework 7 is designed by Watts to be a goal of education. Though not as abstractly as Aarons (1965) and Feynman (1963) want it, the idea of energy conservation is clearly included in the 'flow' terminology. When looking at how to differentiate framework 7 from the other frameworks, it occurs that both frameworks 2 and 5 are missing an aspect: adherents to framework 2 concentrate on the energy "needed" for an activity, while adherents to framework 5 concentrate on the energy as it "results" from the activity. Anyone believing **both** and believing that **both necessarily go together** for a single activity would be

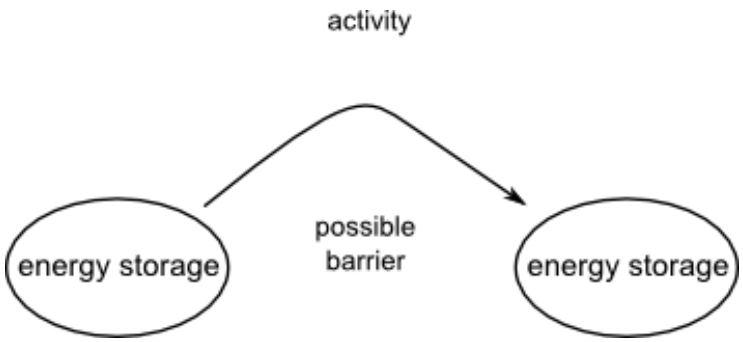

Figure 1: A general view of energy conversion within framework 7.

a believer in conservation of energy, according to us. Therefore, we took this to be the definition of framework 7.

The following statement illustrates belief in the conservation of energy (framework 7), because both the need for energy before the activity (framework 2), as well as the existence of new forms of energy resulting from the activity (framework 5) are indicated:

> *"Energy comes from the battery and goes through the wire past the switch, if it is switched on. After the switch the energy continues through the wire towards the light bulb where it creates light (energy) and heat (energy)."* (Student 17 on picture D)

3. THE RELATIONSHIPS BETWEEN OUR DEFINITIONS OF WATTS' FRAMEWORKS

Following this line of reasoning further, we saw that most of the frameworks could be interpreted as partly fitting within framework 7: the flow-transfer model of energy (see Figure 1).

In Figure 1 we see some form of energy storage as a source of energy for the activity. In some cases the activity can only start after a possible energy barrier is overcome. By the activity the energy is transferred to other objects or transformed into other forms of energy storage. Statements in framework 2 (*a 'depository' model of energy*), or in framework 5 (*energy is a product*) occupy different places in this picture (see Figure 2). Statements that mention both energy as a cause and as a product belong to both frameworks 2 and 5, and such statements are possible candidates for framework 7. In a similar way, also the other frameworks (e.g. framework 4: *energy is an 'obvious' activity*) might get a place in this picture. However, not all of them can be thought of as consistent with framework 7.

Looking at the different frameworks as supplementing each other instead of contradicting one another while fitting them into this general view of energy transfer might have some advantages. First of all it suggests ways of teaching students to reach the level of this general idea of energy transfer which can be used as an intermediate stage for students in learning the scientific concept of energy as suggested in other studies (Kaper & Goedhart, 2002a, Kaper & Goedhart, 2002b). Problems students encounter while their statements are restricted to only a part of this general view are possibly solved by assimilation of the missing parts in their view as these missing parts aren't viewed as necessarily contradicting the general view and each other any more. Another positive thing about this view is that it may help us create a new set of stages in which students move from one framework to another during the learning of the concept of

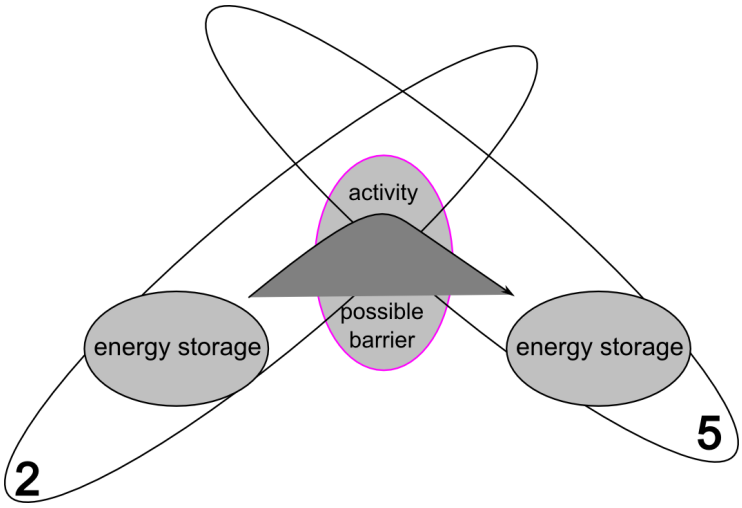

Figure 2: Framework 2 and 5 seen as part of the general view of energy transfer.

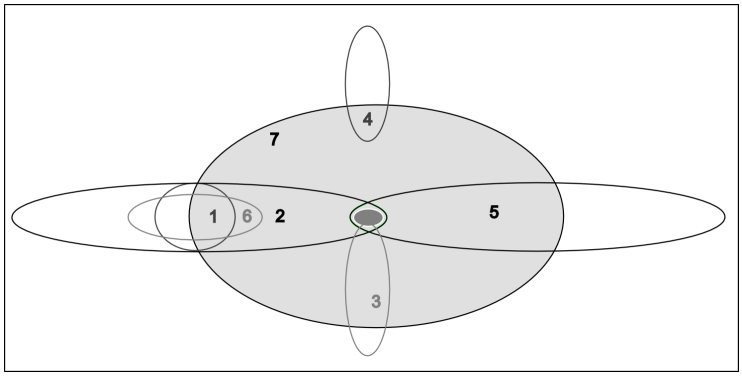

Figure 3: An overview of possible inclusion and exclusion areas of the 7 frameworks.

energy. However we have to be aware of statements that don't fit this general view as they may indicate bigger problems on the road to learning about energy and these may only be solved by accommodation.

Based on our re-definitions of Watts' frameworks, many "overlap" areas between frameworks can be expected. Figure 3 shows all the possibilities we came to expect. Detailed reasonings can be found in an internal report (Logman & Kaper, 2009).

We now picture a framework more formally as the set of statements that conforms to the framework definition. Statements by students can be represented as points in this diagram. To try and see in what ways the other frameworks relate to framework 7 we divide every framework into two parts: contradicting and not contradicting framework 7. This turns our Figure 3 into a Venn diagram. It's obvious that statements in every other framework can either contradict or not contradict framework 7.

For framework 7 (*a flow-transfer model of energy*) we drew two boundaries: the "inner" boundary contains all statements that fully conform to framework 7 (dark grey area), the "outer" boundary contains statements that neither fully conform nor contradict framework 7 (light grey). Outside of this outer boundary are statements that actively contradict framework 7 (white).

We need a source of energy (by definition this will imply framework 2) and we will need production of

energy in a certain form or location (implying framework 5) to conform to framework 7 fully. Therefore we will need conformation to framework 2 and 5 if we want to conform to framework 7. However, this is not enough. Additionally our definition for framework 7 requires that both the "needed" energy and the "produced" energy are connected by a single activity[6]. Therefore framework 7 needs to be drawn as a smaller area within the overlap of frameworks 2 and 5.

4. METHODOLOGY

Our study used a writing assignment and not an interview as Watts did. We have shown the students the six pictures also used by Watts (figure 4) and asked them to write as extensively as possible about the pictures on the subject of energy. The exact question was "to write down, picture by picture, what each has to do with energy and to do so as extensively as possible".

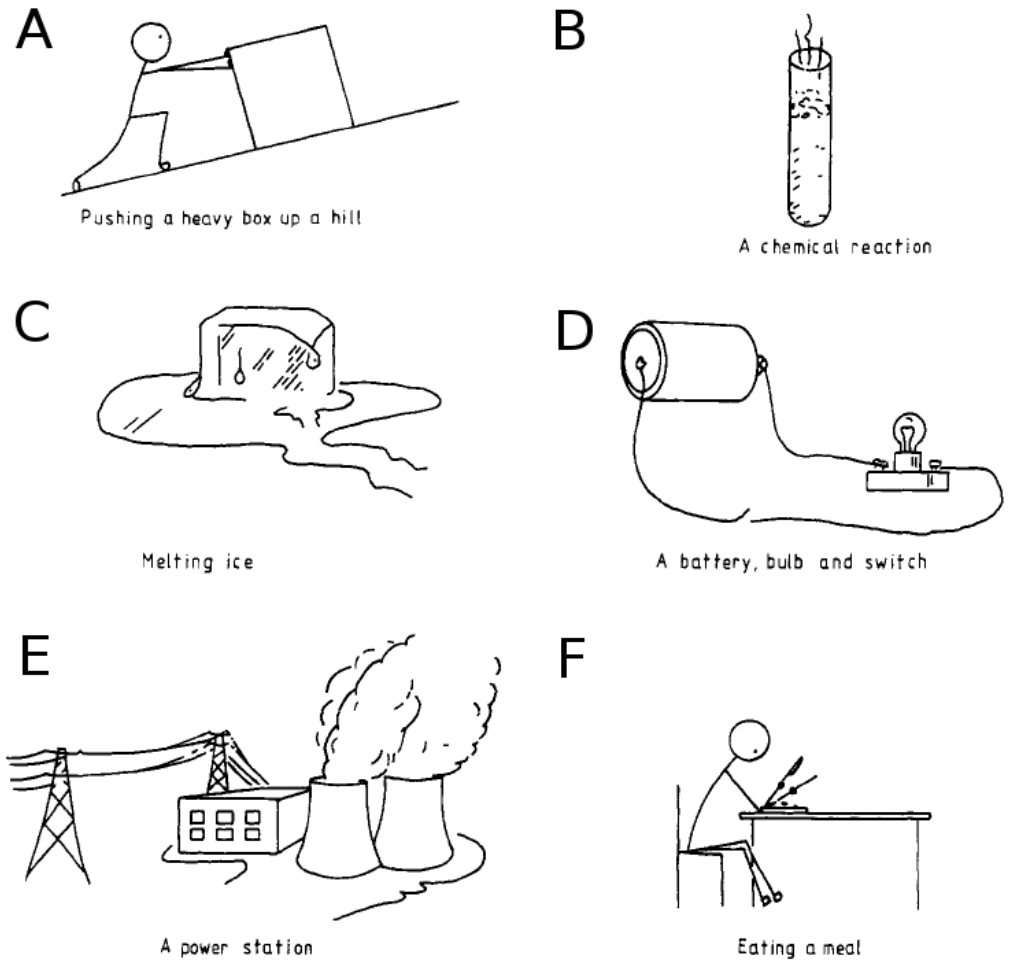

Figure 4: The 6 pictures used by Watts and by us.

[6]This feature of our definition is motivated by a wish that the work-energy theorem should somehow fit in frameowrk 7 - framework 7 being the desired end product of secondary school learning about energy

5. ANALYZING THE WRITING ASSIGNMENT

Next we tried to categorize the writings of the students into the different frameworks. We used the text written by a student concerning one picture as one statement. We assess the relation between each statement and all 7 frameworks.

The relation between a statement and a framework can be one of three things:

- "conforms": the statement contains all properties required in the framework-definition.
- "contradicts": the statement actively denies, or implies a denial of one of the properties required in the framework definition.
- "undecided": if neither of the above is true, the statement neither conforms to nor contradicts the framework. This includes the possibility of the subject not having any strong feelings for or against the beliefs of the framework.

One statement can conform to multiple frameworks, can contradict multiple frameworks and can be undecided about multiple frameworks. In categorizing all the statements by a student we want to show a student's relationship to the different frameworks at a certain stage in his learning. What does the student believe, what does the student deny to believe and about which frameworks are we undecided. We take into account that different situations may provoke different reactions by the students. A word like 'energy' may have different meanings in different situations to the student depending on the situation in which he learned about the concept of 'energy'.

Within the text written about one situation we expect consistency, otherwise our choice of "statement" would have been unwise. If it had not been consistent we then should have split the statement into smaller parts. However that did not seem necessary.

After the both of us analyzed the same 4 students we compared our results to come to a sharper consensus on how to differentiate between the possible outcomes of our analysis. In total we analyzed seventeen 15-year olds.

6. RESULTS

Having six pictures and seventeen students resulted in 102 statements to analyze. Out of these statements 4 statements didn't say anything about energy and a 5th statement could not be classified into any framework and resulted therefore in no conformation or contradiction at all (see Figure 5: white).

In 33 statements conformation was found to only one framework (see Figure 5: white): 14 of these statements concern framework 2 and the other 19 statements concern framework 5. Only framework 2 and 5 were encountered on their own.

In all 64 remaining statements conformation to two or more frameworks was found (see Figure 5: black). This means that some of the overlap areas allowed by our definitions are indeed well filled and the expectation that frameworks are not mutually exclusive is confirmed.

Looking at the results in the group of students studied we encountered some frameworks much more frequently than others (see Figure 6).

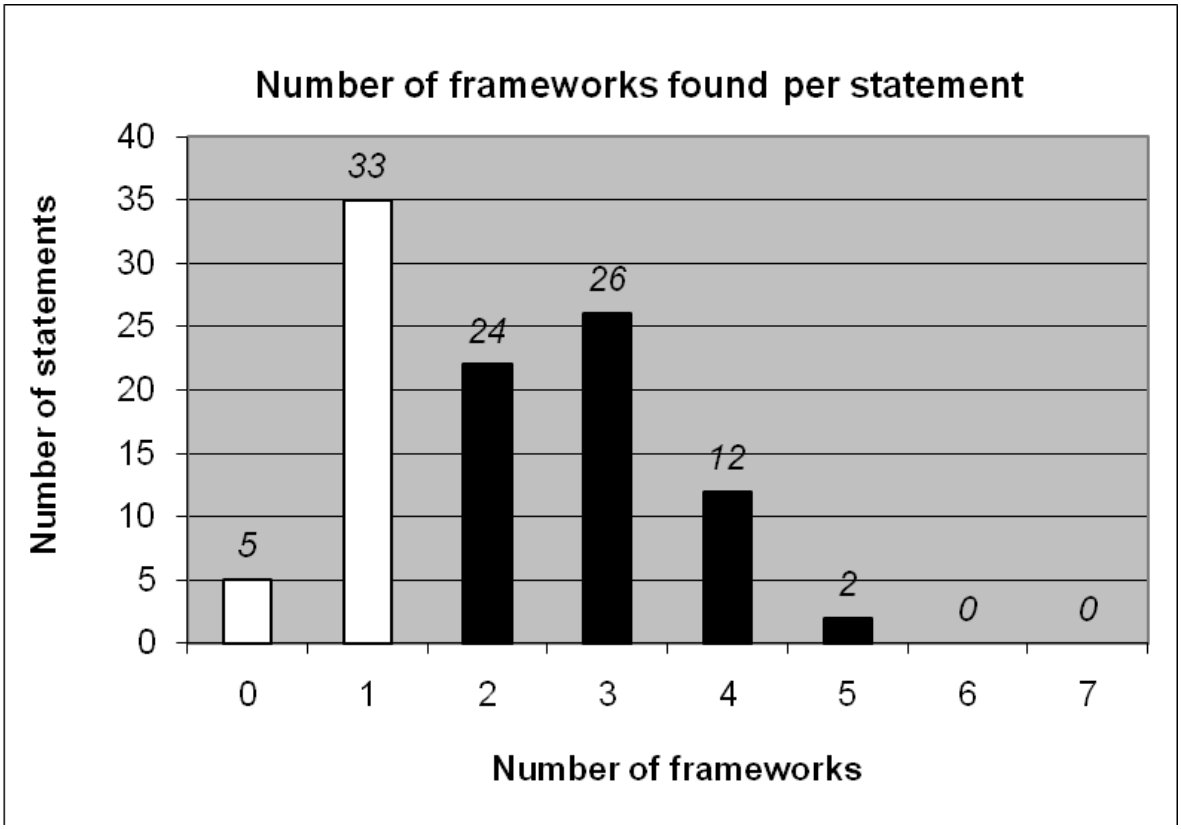

Figure 5: Number of frameworks found per statement.

We see that in the group of students studied frameworks 2, 5, and 6 are very common whereas framework 1 and 4 are contradicted in many statements. Framework 7 is confirmed or contradicted in only a few statements.

While looking for the expected overlap between frameworks 2, 5 and 7 we have found 12 statements conforming to both framework 2 and framework 5. In only one of these statements was conformation to framework 7 not found (see Figure 7). As expected, in this one statement the need for energy was for a different activity than the one which produced a certain form of energy. The dark grey area is therefore rightfully depicted smaller than the overlap of frameworks 2 and 5.

As framework 7 is the goal of our teaching, we separate all 102 statements now into the ones conforming to framework 7, contradicting framework 7, and undecided about framework 7 (the large majority). For each of these three groups of statements we show which other frameworks are involved in those statements (Figure 8).

Conforming to framework 7. When designing education, these statements by students should be the ones we are satisfied with, if indeed framework 7 is our goal. As required by our definitions, frameworks 2 and 5 are always conformed to when conforming to framework 7. Framework 4 is contradicted in all these statements which one would expect considering its definition. More interestingly, framework 1 is also contradicted by nearly all these 11 statements, while framework 6 is conformed to by 8 of these 11.

Undecided on framework 7. We have found 75 statements which were undecided on framework 7 (all 17 students showed this kind of statement). In this case either students did not state enough to place

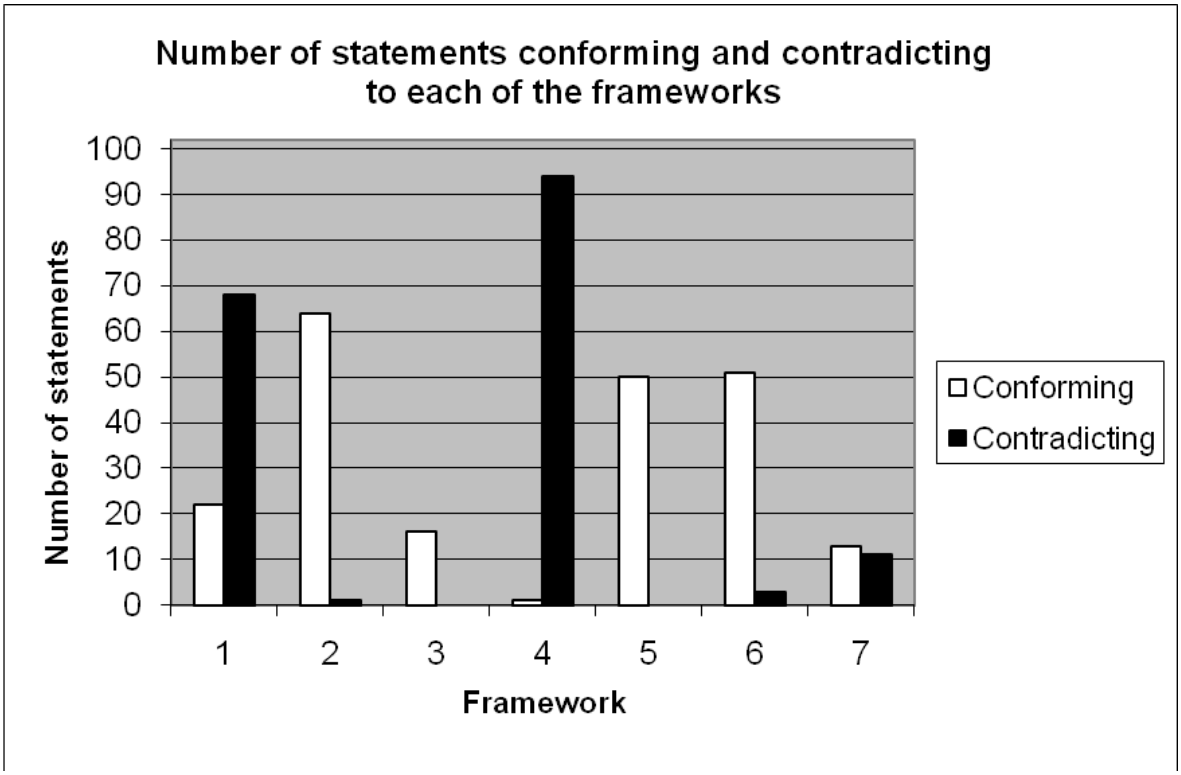

Figure 6: Number of statements conforming to and contradicting each of the frameworks.

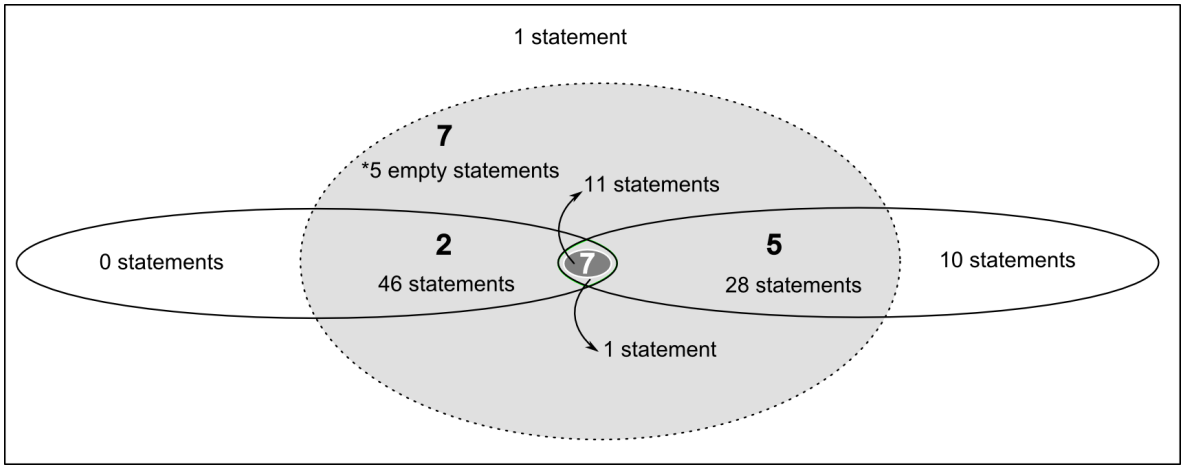

Figure 7: Number of statements conforming to the possible combinations of frameworks 2, 5 and 7.

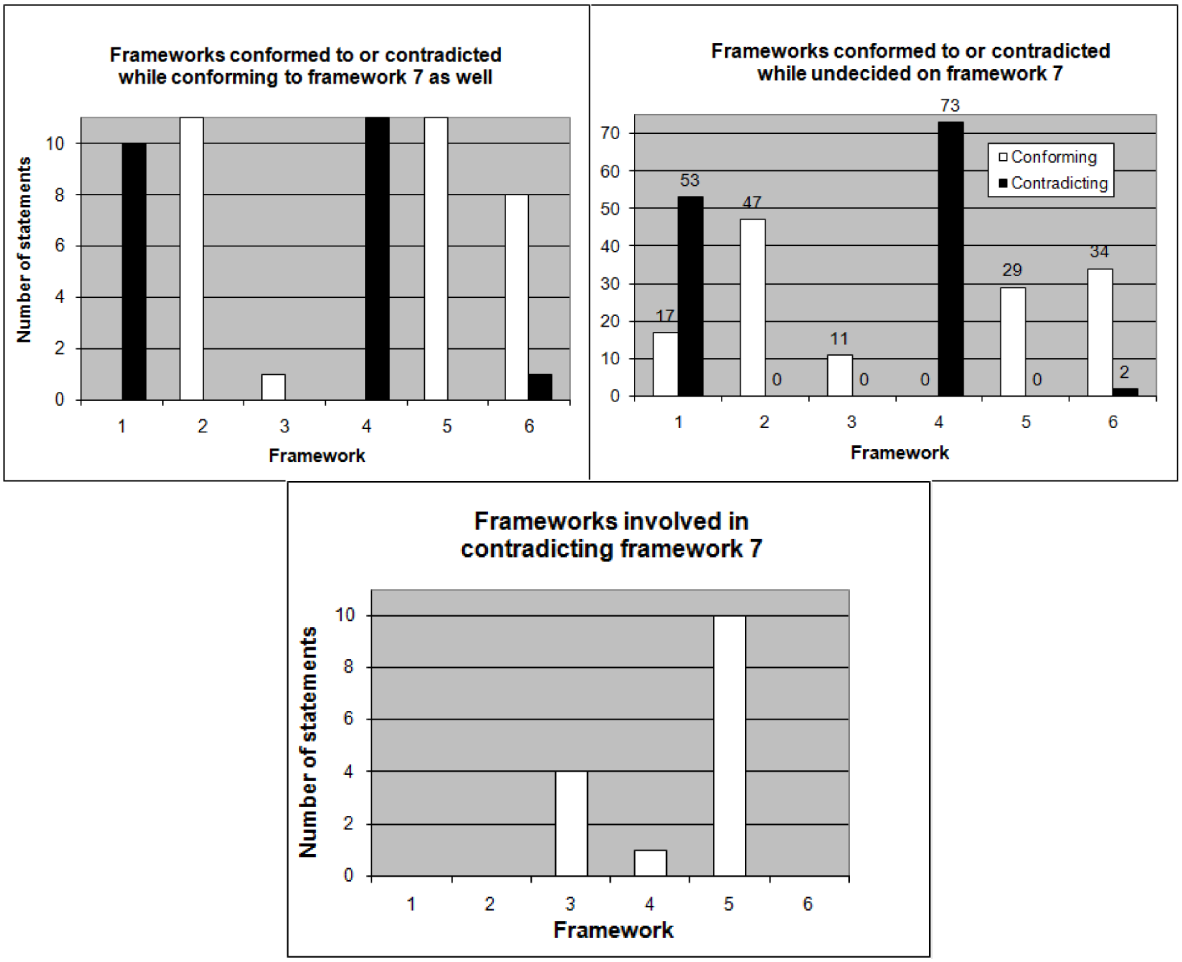

Figure 8: Relations of the other six frameworks to framework 7.

their statements into framework 7 or they did not show their rejection of framework 7. We suppose that students showing these statements may need to add knowledge to their understanding of energy (assimilation), but they probably do not need to 'unlearn' much (accommodation). If we agree on framework 4 as being contradictory to framework 7 not much work needs to be done with this group of students concerning that framework as most statements reject it already (see Figure 6). Framework 3 is optional to framework 7; and as no contradiction to framework 3 has been found not much work is needed in that area. On other overlap between frameworks and its consequences for education we refer to an internal report (Logman & Kaper, 2009). If our goal is to have students' statements agree to framework 7 we mainly need to try and persuade the students to move towards both framework 2 and 5 in which it is clear that storage of energy after an activity should get the most attention.

Contradicting framework 7. This always coincided with conformation to one of the other frameworks. The big white outer area outside all the frameworks therefore seems to be empty which in its turn means that the 7 frameworks may be collectively exhaustive. Statements contradicting framework 7 make us suppose that some accommodation is needed. We notice that framework 5 is the biggest problem for the group of students studied.

"By eating one receives new energy. The nutrients are transformed into energy." (Student

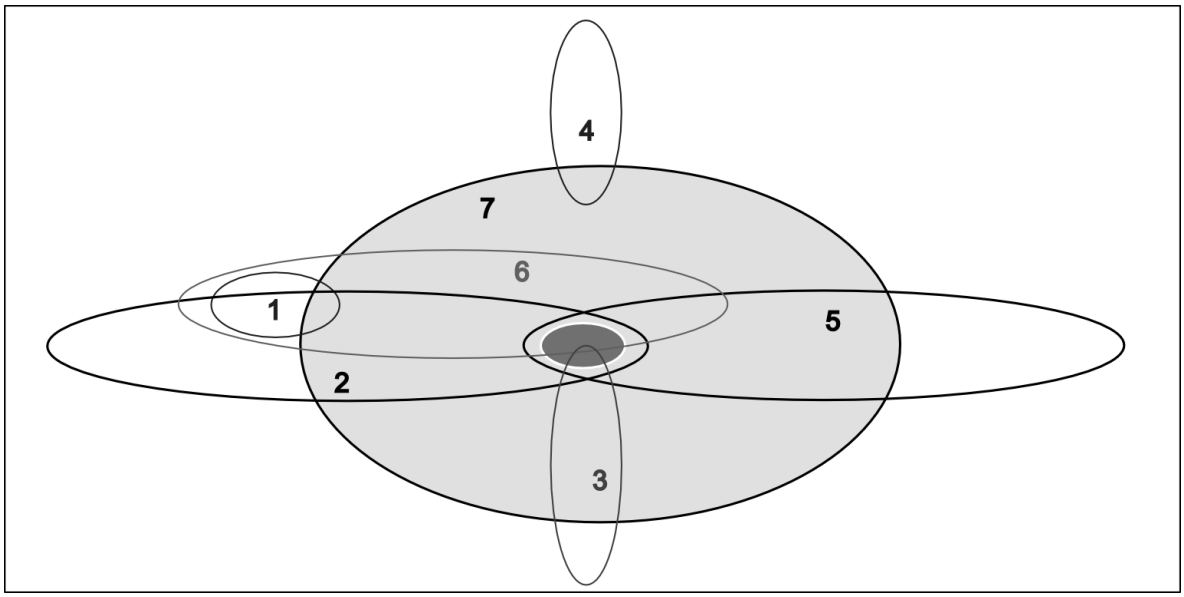

Figure 9: An overview of inclusion and exclusion areas of the 7 frameworks.

15 on picture F)

The second sentence clearly implies that the nutrients did not contain energy, but energy is produced out of them (framework 5), a clear case of non-conservation (contradicting framework 7).

In 4 of the statements framework 3 was also a problem and in only one statement was framework 4 considered to be the cause of contradiction. There was no instance where only one framework was a problem. Whereas Watts implied that all frameworks were contradictory to framework 7 it appears that for our target group of students mainly framework 5 is the culprit. The 11 statements are widespread as they were made by 8 of the 17 students. Again we conclude that energy storage after an activity should get the most attention in any education designed to counter this problem.

7. CONCLUSION

In looking at 102 statements made by 17 fifteen year olds on 6 different pictures previously used by Watts we find that the 7 frameworks established by Watts are not mutually exclusive. In fact most frameworks seem to be part of framework 7 (a flow-transfer model of energy) in a smaller or larger sense (see Figure 9: mainly frameworks 2, 3, 5, and 6). In this paper, focus has been on the overlaps between frameworks 2, 5, and 7. We refer to an internal report (Logman & Kaper, 2009) for the other relationships shown in the figure.

Our view of the overlap of each of the frameworks with framework 7 has mostly been confirmed by analyzing the students' statements. Indeed to conform to framework 7, framework 2 (*a 'depository' model of energy*) together with framework 5 (*energy is a product*) seem to be a necessary part which is an important observation for future educational design.

To reach the desired end product of secondary school learning about energy, framework 7, framework 5 is shown to be especially troublesome to our group of students, as it was often involved in contradicting 7. It is necessary to take this into account when designing education on the subject of energy.

The frameworks encountered may of course vary by student or group of students and may be used as a starting point from which their education on the subject of energy can be designed. One way may be to create small groups of students of a certain mixture to perform special tasks to do with energy. To do so one would prefer a faster way of establishing a student's set of frameworks however. Another way in which it may help education design is that it is shown that students who encounter contradictions to framework 7 may need some form of accommodation of their ideas to make a step forward, whereas students who find their views within framework 7 may only need some form of assimilation to make their next step. For instance the large group that conforms to framework 2, energy as a needed cause, needs to learn to combine their ideas with framework 5, energy as a product: needed energy and produced energy being connected through an activity.

8. DISCUSSION

The following studies are similar to ours in various degrees, which makes it useful to compare methods and results.

Kruger (Kruger, Palacio et al., 1992), using interviews, found that about 20% of primary school teachers believe in framework 1 and substantial numbers of them lacked belief in conservation of energy. They didn't expand on the 5 other frameworks.

Summers (Summers, Kruger et al., 1998), also using interviews, departed from Watts categories and decided to divide up different views into life-world view, partially scientific view and scientific view. These categories are too broad for our purpose, because they do not inform to the content of students' ideas. Summers, Kruger et al. found that energy efficiency can be readily taught to a group of primary school teachers who already grasped the concept of energy conservation.

Swackhamer (Swackhamer, unpublished) has created his own categories that are only partly inspired by Watts' frameworks. He is trying to establish an energy concept inventory to check on students' development and to identify fundamental issues to address. He also made guidelines to develop a healthy conception of energy. (e.g., avoiding forms of energy, explicit energy transfer, requiring conservation of energy).

Finegold and Trumper (Finegold & Trumper, 1989), using writing assignments mainly found frameworks 2 and 7 and have found similar distributions in Watts' frameworks as us, yet they treated them as mutually exclusive per statement. They did treat the students as adherents to multiple frameworks. However on 15 different pictures shown they found only thirty-six percent of students using 2 or more alternative frameworks. Unlike us, they found no framework 3 adherents in ninth grade but did find framework 3 adherents in grades ten to twelve. During their research they decided to subdivide framework 2 and framework 7 (where the latter was divided into flow-transfer as opposed to the scientific view). The example citations mentioned have been categorized into frameworks that we would have chosen as well, but some we would have categorized in more than just the one chosen by Finegold and Trumper (1989). They did not look for contradictions because they considered the statements to be categorized into one framework only. Like us, they come to the conclusion that frameworks 2 and 5 are needed to form framework 7. They concluded that the effect of education on energy wears off by seeing an increase in framework 7 adherents immediately after education and a following decrease in framework 7 adherents in the years after education.

Comparing the various results we can say that Finegold & Trumper (1989) agree with us that before instruction framework 2 is very frequent. Also, before instruction they found significant numbers of framework 5, though much less than we found. Education on the concept of energy has been proven to

have little lasting effect on students (Finegold & Trumper, 1989, Trumper, 1990, Kruger, Palacio et al., 1992).

Using the assumption of overlapping frameworks we have been able to establish important relationships between the different frameworks which may prove useful for future educational design. As our aim is also to look at the manouverability of the energy concept in students, it is important to find an effective way of establishing to which frameworks a student or a group of students adheres, so that a more lasting and effective education can be designed and the development of students can be tracked.

Our method has some limitations. Because we used a writing assignment we can be more certain that students used their own words and wrote their own sentences instead of reacting to ours. Therefore we can be confident in identifying students' conformation and contradiction to frameworks. On the other hand the 'undecided' category will be larger in a writing assignment, because students show us a selection of their thoughts with missing information as a result. Because sometimes we have to be undecided about a specific framework we can not establish for sure the relationship between that framework and other frameworks because we can not ask follow-up questions.

In the near future we will try to use our method with seventeen year olds and twenty-two year olds and will keep tracking the group of students studied to check persistency. We will also use our findings in a design for education on the subject of energy. In testing our results on education we will try out other methods as well such as the energy concept inventory currently being developed by Swackhamer (Swackhamer, unpublished).

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