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Metamodelling Messages Conveyed in Five Statistical Mechanical Textbooks from 1936 to 2001

Abstract

Modelling is a significant aspect of doing physics and it is important how this activity is taught. This paper

focuses on the explicit or implicit messages about modelling conveyed to the student in the treatments of

phase transitions in statistical mechanics textbooks at beginning graduate level. Five textbooks from the 1930s

to the present are analysed with respect to their messages about the following issues: What is a good model?

What is the purpose of modelling? What does it mean to understand a natural phenomenon? It is argued that

these texts give the student quite different perceptions of these issues and thus what of it means to do physics.

Introduction

Modelling is undeniably an important aspect of physics research because it is often through models that

physical phenomena can be grasped and made theoretically accessible. A (scientific) model, which here will

be taken to be a simplified representation of a real object, situation, or process, allows us to explain or predict

the behaviour of the target system, i.e. the segment of reality we wish to come to grips with. In the last few

decades, eductional researchers have argued that modelling and models should hold a similarly prominent

position in science teaching. Justi and Gilbert (2003), for instance, invoke three general purposes for science

education advocated by Hodson (1992) to advance what they see as the specific purposes of teaching models

and modelling: The students should know the models that are the central products of science; they should

create and test their own models; and they should 'come to appreciate the role of models in the accreditation

and dissemination of the products of scientific enquiry.' (Justi & Gilbert, 2003, p. 1369) The latter of these

purposes follows from the view that students should understand the central processes of science combined

with the fact that modelling is a crucial scientific activity.

The knowledge (or understanding) that the student should acquire according to the third purpose is

sometimes called metamodelling knowledge (the terms 'epistemologies of models' and 'metaconceptual

knowledge about models' are also used; see Schwarz, 2002), which is defined as 'knowledge about the nature

and purpose of scientific models.' (Schwarz & White, 2005, p.166). This definition is congruent with the aspects of students' conceptualization examined in Grosslight, Unger. Jay and Smith (1991), who studied ideas about 'what models are for, how and by whom they are made, under what conditions (if any) they should be changed, whether or not there can be multiple models for the same thing, and what models actually represent.' (Grosslight, et al. 1991, p. 799)

Metamodelling knowledge is important in itself because of the prominent position of models in we want students at all educational levels to learn. In addition, some argue that this knowledge is important for another reason, because without metamodelling knowledge, 'students cannot fully understand the nature of science, and their ability to use and develop scientific models will be impeded.' (Schwarz & White, 2005, p. 166) Thus the students' ideas about modelling may influence how they will do modelling, which is important not only if they become practitioners in research or applications, but also in education because teachers need skills to conduct modelling activities in their classes (Justi & Gilbert, 2002b, p. 1274).

There has been a host of educational research concerning metamodelling knowledge; most papers have sought to describe and measure either students' (Grosslight et al., 1991; Treagust, Chittleborough & Mamiala, 2002) or teachers' (Justi & Gilbert, 2002a; Justi & Gilbert, 2002b; Justi & Gilbert, 2003; Justi & van Driel, 2005; Smit & Finegold, 1995; van Driel & Verloop, 1999) metamodelling knowledge and understanding of models and modelling. The pioneering study by Grosslight et al. (1991) found that there are three levels in the understanding of the nature of models: At level 1, models are seen either as toys or as replicas of the real-world objects or actions and if they are incomplete it is because the producers wish it so. At level 2, the models are thought to be constructed with a specific, explicit purpose and they do not have correspond exactly to the real-world thing and some aspects of reality could be neglected, simplified or enhanced. The focus is still on the model and the real-world thing rather than the ideas portrayed in the model. At level 3, the modelling is thought of as a tool for developing and testing ideas, not as attempt to get a copy of reality. The

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modelling process is cyclic and role of the modeller is active: constructing several models, determining which design fits the purpose of the model the best, and testing the models in order to develop and examining ideas. The middle and high school students Grosslight et al. interviewed showed an increasing percentage of students at level 2 with increasing age, but none showed an understanding the level 3; in contrast, all the participating experts were at level 3. In another study, Etkina, Warren and Gentile (2006) mention four ideas that professional physicists share: "a model is *a simplified version* of an object or process under study; a scientist creating the model decides what features to neglect;" (Etkina et al., 2006, p. 34), "a model can be *descriptive* or *explanatory*; explanatory models are based on analogies – relating the object or process to a more familiar object or process;" (Etkina et al., 2006, p. 34), "a model needs to have *predictive* power;"(Etkina et al., 2006, p. 34) "a model's predictive power has *limitations*." (Etkina et al., 2006, p. 34)

Much research has used categories identical or similar to those of Grosslight et al. (1991) or Etkina et al. (2006) to give a broad picture of the metamodelling knowledge of students and teachers. While acknowledging that this is a relevant picture, the present paper argues that there are other important aspects of metamodelling knowledge involved in physics education as well. The above categories cannot, for instance, be used if we want to understand the students' ideas about model selection criteria or about how models are used in the framework of theory building. The four ideas of Etkina et al. (2006) are too general to be able to function as guiding principles for the modelling activity. For instance, they do not tell us whether *all* simplified versions of objects or process qualify as acceptable models. If not, what are the criteria that determine whether a model is acceptable? Furthermore, what limitations to predictive power are we willing to accept? The purpose of the present paper is to examine the messages that the students receive about modelling that will allow them to choose between specific models. Moreover, their ideas about the purpose of modelling regulate how they engage in modelling, so this is an issue as well.

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Just like in previous research, it is relevant to understand each side of the triangle: 1. the students' understanding of models and modelling, 2. the sources for this understanding (often textbooks or teachers) and 3. the means for improvement of the students understanding. The objective of the present study is to gain some insight into the second leg of the triangle of this *problématique* by analyzing textbooks and show that they do in fact convey very different messages about these issues:

1. What constitutes a good model of a system, including the role of experimental facts and of the fundamental theories (such as classical mechanics or quantum mechanics) that are used in the construction of the model?

2. How is the phenomenology theory organized?

3. What does it mean to explain a physical phenomenon? Here explanation is used in the sense of causal explanation of Gilbert, Boulter and Rutherford (2000), i.e. why does the phenomenon behave as it does? Such an explanation is provided on the basis of the basic constituents of the system and from their behaviour the system's behaviour is determined.

4. Is there any notion of universality involved?

Method

Students' formation of ideas about physics is a complex matter because several components of the teaching process influence the outcome. The students receive messages about models and modelling not only from the textbooks, but from other sources as well, above all their teachers. However, textbooks are clearly a factor of central importance, and science education is to a large extent based upon textbooks presentations of the subject matter (Stinner, 1995). Indeed, the chosen textbook influences how and what students learn (Alexander & Kulikowich, 1994) and how and what teachers teach (Alexander & Kulikowich, 1994; Harrison, 2001). According to Harrison (2001), anecdotal evidence shows that in general teachers teach in ways that are compatible with the textbook; moreover, he reaches a conclusion (with the proviso that more

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research is needed) that "there are links between the way [physics] textbooks use models and the way teachers teach with models," (Harrison, p. 428). Even though the textbook is not the only factor influencing the students' knowledge of physics, it is a crucial factor, both *per se* and because of its effect on the teacher's behaviour. Since it is not possible in a first approximation to analyse the entire complex of factors involved in the knowledge acquisition of models and modelling, it is reasonable to restrict attention to one single, significant factor. As a way of charting some of the ways textbooks can present models and modelling and the messages they convey about this activity, this paper compares textbooks. The aim of the paper is to use the different presentations of modelling in these textbooks selected as an opportunity to span different conceptions of modelling in physics that are conveyed to the readers of the books. This is achieved by comparing and contrasting two modern textbooks with three older ones.

Most of the messages sent by the textbooks about the four metamodelling issues above are expressed explicitly, either as statements that pertains to physics in general or comments about the status or role of a particular model or a group of models that are easily extendable to all of physics. However, the textbooks also convey more implicit or underwritten messages from the way models and modelling are dealt with. For instance, if only realistic models are used to in a chapter on a particular subject, it sends the implicit message that only realistic models are relevant for the theory of the subject. If the readers pick up such messages, they are they are relevant for the present analysis even though they implicit.

We cannot be sure that a student reading the textbook will receive the same messages as a professional physicist. Hence, an analysis of textbooks from the latter's perspective – which is what is given here – will not necessarily reveal what the learner actually receives from reading the same books and the student may not be able to identify the same differences between the texts. However, the audience for the textbooks are students at the late tertiary level and they may be expected to perceive the messages more readily than students at previous levels. Moreover, the present analysis focuses on the explicit messages and the more tangible of the

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implicit messages (rather than the more subtle nuances) which it is more likely the students will perceive.

Finally, according to the contemporary view of science reading, science reading is 'directed at constructing

meaning' (Rivard & Yore, 1992, p. 3) in a complex process involving the student's knowledge, sensory

experience and the text. According to Valencia and Pearson (1987) this so-called interactive constructive view

'emphasizes the active role of readers as they use print clues to "construct" a model of the text's meaning.' (in

Rivard and Yore, 1992) Thus, the cognitive processes associated with reading are seen as an attempt on the

part of the students to construct meaning. How that is done is complex process: 'Instead, it suggests that at all

levels of sophistication, from kindergarten to research scientist, readers use available resources (e.g., text,

prior knowledge, environmental clues, and potential helpers) to make sense of text.' (Valencia and Pearson in

Rivard and Yore, 1992) It is natural to assume that in their struggle to make sense of the textbooks, the

students may pick up the messages in their attempt to construct meaning of the text.

Needless to say, students encounter modelling in many physics courses, not least in those on

Newtonian mechanics, classical electrodynamics, or quantum mechanics. Statistical mechanics have been

chosen here because the modelling aspect is particularly acute in this discipline; it is possible that other

physics disciplines in the standard physics curriculum could have been chosen with equivalent results, but this

will not be explored here. The models of statistical mechanics by definition involve a large number of

particles which must necessarily be treated in a simplified way. This means that idealizations, abstractions

and/or approximations are fundamental features of the trade and all textbooks of statistical mechanics convey,

implicitly or explicitly, messages about modelling issues. Since this is not least the case with phase transitions

– such as the everyday phenomenon of H_2O changing from a liquid state to a vapour state involved in the

boiling of water as well as the less well known transition from a magnetic to a non-magnetic state that appears

when a regular bar magnet is heated – this paper focuses on the treatment of this subject in the various

textbooks.

The choice of analysing five textbooks is a pragmatic one determined by a wish to strike a reasonable

balance between spanning as many different characteristic messages concerning the issues stated above as

possible, but at the same time without going into too much detail. The individual book was selected according

to the following criteria: each should contain a chapter on phase transitions, be somewhat articulate about

modelling issues, be representative for a class of textbooks and not be too idiosyncratic in its approach. The

books are at the beginning graduate level (or perhaps advanced undergraduate). The three classical textbooks

are Fowler (1936), Huang (1963), and Pathria (1972), while the two moderns are Wilde and Singh (1998) and

Salinas (2001). The three former textbooks appear to be *the* textbooks of the decades of the publication;

Huang (1963) is still used, whereas a new version of Pathria (1972) appeared in 1996. Due to their recent

publication dates, Wilde and Singh (1998) and Salinas (2001) have not yet achieved status of classics, but

have received very favourable reviews. At the same time, the views of the books are not idiosyncratic and

each of the books could have been replaced by one other (and in most cases by several others) contemporary

textbook(s) conveying the same views.

The textbooks cover nearly 70 years, from 1936 to 2001. During this period, the approaches of

physicists to the modelling of phase transitions have changed considerable several times. Since Ralph

Fowler's book of 1936, phase transitions have been treated in most textbooks on statistical mechanics and the

books have reflected these turns. The question addressed here is neither when and why these changes occurred

nor whether the presentations in the textbooks reflects the views of contemporary research physicists; rather,

the paper uses these presentations as an occasion to describe different ways of dealing with modelling in the

teaching of physics students.

Previous Findings about Textbooks and Modelling

Previous analyses of textbooks have uncovered problematic aspects of science textbooks. In his analysis of

the teaching of acidity in textbooks at 'A' level, post 16 years old, Oversby concludes that status of the

models as models 'is grossly underplayed' (Oversby, 2000, p. 249); that the relation of the models to the

phenomena is 'frequently implicit and is sometimes not stated'; (Oversby, 2000, p. 249); and that neither the

explanatory power of the models is discussed, nor their explanatory weaknesses. From these shortcomings,

Oversby concludes:

> Consequently, students using the textbooks have no rationale for independent selection of a model for a particular purpose. Without further guidance they must either accept the author's choice for the examples given, or proceed to construct their own rules for selection in novel contexts. In such circumstances, it is inevitable that errors in analogical reasoning will be made.' (Oversby, 2000, p. 249).

Justi (2000) summarizes her and Gilbert's analysis of Brazilian and English textbooks for 14 to 16-year-old

students on the atom and a Brazilian textbook on chemical kinetics: The textbooks do not 'present scientific

knowledge as consisting of provisional models which are developed and "valid" in specific contexts.' (Justi,

2000, p. 215); how each model attains consensus status is not described; and the theoretical background of the

models is not discussed. As we shall see, the textbooks discussed in this paper, do not fall into any of these

traps, except for Justi's issue about the achievement status which is neglected in most of the textbooks.

In her study of the teaching of light in science education, Margaret Rutherford had another finding

about physics textbooks, namely that at school and early tertiary level, 'students are not expected to engage

with the current ideas and models used by "real" physicists in explaining light and electromagnetic

phenomena, but to be content with simplified models and descriptive explanations.' (Rutherford, 2000, p.

269) The textbooks presented here also differ also in this respect, because the models used are in fact the

scientific models of the physics research community.

Model and Theory

Before getting to the textbooks, the general features of modelling in statistical mechanics will be

briefly reviewed. In physics, the modelling process can be seen as an interplay between the model,

experimental results and the fundamental theory underlying the model (typically quantum mechanics or

classical mechanics). I will distinguish between to different types of theory. The first type, called foundational

theory, refers to the theoretical framework which lays the foundation of the model and is used to describe the behaviour of the microscopic constituents. Typically, this type of theory will be quantum mechanics or classical mechanics. The second type, which I will call phenomenological theory, is the insight into a particular system gained by the experiences with a model or a system of models. In short, the manipulation of the model(s) gives some ideas about the workings of the real system in question.

In statistical mechanics, the modelling of macroscopic phenomena follows this "recipe:"

1) The microscopic constituents (for example atomic nuclei or electrons) which are used to "build" a macroscopic phenomenon are chosen.

2) Based on quantum mechanics (in some cases classical mechanics suffices), the microscopic behaviour and energies of the constituents are determined.

3) The formalism of statistical mechanics is used to determine, at least in principle, the thermal quantities that the modeller wants to find.

If these steps can be performed the model is said to be solved. It is widely acknowledged that microscopic modelling of macroscopic phenomena involves the above steps, but how the two first steps are performed differs considerably in the textbooks (as well as in the research literature). This is due to the fact that for most aggregates of such microscopic building blocks of interest it is impossible mathematically to perform the last step, suggesting that extensive simplifications are necessary. This is not least the case with phase transitions. There are a host of different meanings attached to the term model; in this paper it will be used exclusive in the sense microscopic model and a model will be taken to be the microscopic constituents chosen in step one above and the kind of mechanics they obey.

The modelling of magnetism can illustrate these steps. A magnet (strictly speaking a *ferro*magnet) such as the well-known red and black bar magnets from high school consists of atoms that in turn are built of nuclei and electrons. The magnetism is due to the revolution of the electrons around each nuclei and the

electrons rotation around their own axis. The latter is called the electron spin (or just spin) and can only be

described completely in terms of quantum mechanics, but it can be intuitively understood in a classical

analogy as the rotation of a charged sphere, which gives rise to a magnetic dipole. The classical analogy to the

revolution around the nucleus is a circuit. These two electronic motions create a magnetic dipole moment and

a magnetic field which causes the magnetization. Detailed studies, both experimentally and theoretically,

show that the magnetic properties are mainly due to electron spin. Consequently, most models focus on the

electron spin and neglect the revolution of the electrons.

Insert figure 1 about here

Consider a lattice such as the two dimensional square lattice of figure 1a – this corresponds to the

lattice of a crystal. To each site of the lattice we attach an electron with a spin; in accordance with the

classical analogy, each spin is represented by an arrow pointing in the direction of the magnetic dipole – see

figure 1b. Quantum mechanics tells us both how that these spins are represented spin operators and how they

interact. The so-called Heisenberg model is based on this knowledge (and a few mild simplifications), while

the so-called Ising model[1] can be seen as a simplification of this model. The first assumption of the Ising

model is that these spins, rather than being given by the standard spin operators of quantum mechanics, are

restricted to point in two directions: up or down – this is illustrated in figure 1c. This assumption in effect

implies that the spin of the model does *not* behave as it should from a quantum mechanical point of view. This

distortion is conscious and has the consequence that the model is seen as a considerable simplification of real

magnets. The model rests on an additional, less crude, assumption, namely that only nearest-neighbour spin

interact and the interaction energy of such a pair of nearest neighbours is J if they are parallel and -J if they

are anti-parallel. J is taken to be positive for ferromagnets. Whether one uses the Heisenberg model or the

Ising model, by applying the formalism of statistical mechanics, the way is open to determining the thermal

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[1] From a historical point of view the name the Lenz-Ising model is a more fortunate than the Ising model (see Brush (1967) and Niss (2005)), but since the latter is used by virtual all physicists, it has been chosen here.

behaviour of the model. A real magnet is (typically) magnetic at room temperature. If the temperature is

raised, the magnet will gradually become less and less magnetic and at the so-called Curie temperature it is no

longer magnetic at all. The magnet thus goes from a magnetic phase to a nonmagnetic phase; consequently,

the Curie temperature is called the phase transition temperature.

Despite the fact that the Ising model is gross simplification of the Heisenberg model, the former is in

fact the most used in both the textbooks and in physics research not least because it is much easier to

determine the properties of this model. In order to distinguish realistic models like the Heisenberg from the

much more simplified models like the Ising model, let us call the former realistic models and the latter

caricature models, because of the similarity between such models and caricature cartoons, which tries to

capture the depicted object in a few strokes. According to Frigg and Hartmann (2006) "Caricature models

isolate a small number of salient characteristics of a system and distort them into an extreme case." Of course

a more refined classification could be made, but this crude one captures an essential difference used among

physicists.

The Caricature View—Fowler (1936)

Ralph Fowler's textbook of 1936 is not the first systematic expositions of statistical mechanics (the

first edition of the book appeared in 1929, a year after the first textbook on statistical mechanics), but it is the

first to include a chapter on phase transitions (under the heading cooperative phenomena[2]). In this chapter,

Fowler applies statistical mechanics to three specific phase transitions.[3] Each of these three phenomena are

described separately and Fowler does not give a unified description of their shared properties; they are simply

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[2] For some time, it was customary to call phase transitions by the name cooperative phenomena, to underscore the fact that such phenomena can only be described in terms of a host of cooperating units, rather than as a sum of single non-interacting units. This is therefore a question of terminology, rather than a fundamental difference.
[3] They are: (i) the so-called order-disorder transition in alloys, described above; (ii) a transition in certain solids where the atoms or molecules go from a vibrational state to a vibrational and rotational state upon heating; and (iii) the deposition of metal vapor on a glass or another metal which only occurs below a critical temperature.

treated as disparate phenomena that are only connected by the fact that they all involve the cooperation of several units.

Fowler's exposition of all three phase transitions follows the same recipe – as an example we will look at the so-called order-disorder transition in binary alloys. X-ray experiments reveal, he notes, that such alloys, which are composed of two types of atoms, undergo a change at a certain critical temperature from a totally ordered arrangement of the two types of atoms at absolute zero to a disordered one where the atoms are randomly distributed at high temperatures. It turns out that the heating process just described leaves the structure of the crystal lattice (almost) unchanged, so the degree of order is a geometrical property depending only on the distribution of the two types of atoms in the sites of the lattice. This means that the models of alloys can focus on this atom configuration and neglect the crystal structure. This is a significant simplification, but it may be necessary to drop it 'in more refined treatments'. (Fowler, 1936, p. 791) Fowler then turns to two models based on this idea. The difference between these models is the way the energy associated with the order is taken into account, but neither model is based on quantum mechanical considerations about this energy and both should be considered to be caricature models. The first model is based on a rather crude assumption about the energy associated with the order and the assumption implies that one atom can "feel" all the other atoms, so it is in effect an assumption of long range interactions between the atoms. The second model is needed, writes Fowler, because this assumption is 'more than doubtful': It is more natural to expect that the atoms in the lattice act on each other with short range forces or even that only the interactions between nearest neighbours are of any real importance.' (Fowler, 1936, p. 797) Fowler does not support this objection with theoretical arguments, but simply appeals to the common sense of the reader: it is natural to assume that the interaction between atoms is short range. At any rate, the latter model is built on this more reasonable assumption.[4]

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[4] In order to examine the model, some approximations are necessary, but they are insignificant for an understanding of the idea of Fowler's argument.

In addition to this thorough discussion of the models' assumptions, Fowler determines their thermal properties. After a discussion of the difficulties of making suitable experiments for alloys, these properties are compared with experimental data. He writes about the result of one these comparisons: 'The agreement on the whole is fair,' but his overall conclusion is more negative: 'Making all allowances however, it is not fair to claim more than that existing theory [the two models] is a decent first approximation' (Fowler, 1936, p. 809). He blames the omission of effects, such as the neglect of lattice vibrations, for this discrepancy.

In the alloy case, as well as in the two other cases treated by him, Fowler takes the student to the modeller's workshop and he shows how to build a model from experimental facts. The following steps are involved in this process: first some reasonable fundamental assumptions are made (for example that lattice vibrations can be neglected). On this ground, the modeller builds one or several models and maybe compares the models with each other. Then the model is confronted with experiments and an explanation of possible discrepancies is attempted. In neither of these steps does Fowler appeal to theoretical arguments; rather, all arguments are of the sort, "it is natural to assume," etc. The foundational theory does not play a role in this development of the model, so the chapter conveys the impression to the student that it is irrelevant whether the model is founded on this theory. Fowler's book thus conveys a particular view to the students, at least in the chapter on phase transition; this view is not, however, explicitly stated, but because the same scheme, which conveys the same message is used in all three examples of the chapter, it is very likely that the student will actually receive the message. According to this view physics is about understanding isolated physical phenomena through simple models tailor made to the system in question and experiments determine whether a model is relevant or not rather than a fundamental theory. Thus Fowler subscribes to a caricature view of modelling. He does not attempt to give a general description of phase transitions, he discusses particular models representing specific phenomena; these models are simply meant to capture the essential of the system, but not more generic properties of phase transitions.

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Physics as unified theory – Huang (1963)

In the first decades after the publication of Fowler's book, the statistical mechanical treatment of phase transitions developed considerably both in terms of the methods involved and the approach taken. One of the first textbooks to take these developments into account is Kerson Huang's of 1963. The spirit of this book is that one should seek a general single unified description of physical phenomena. This should include statistical mechanics, according to the preface of the book:

> The purpose of the book is to teach statistical mechanics as an integral part of theoretical physics, a discipline that aims to describe all natural phenomena on the basis of a single unifying theory. This theory, at present, is quantum mechanics. (Huang, 1963, p. vii)

This attitude is reflected in Huang's chapter on phase transitions, which tries to establish the connection between quantum mechanics and phase transitions. The explicit purpose of the chapter is to show that the phenomenon of phase transition is a possible consequence of molecular interactions. These interactions can, at least in principle, be deduced from quantum mechanics, emphasising Huang's wish to connect this theory and the natural phenomenon in this case phase transitions, with the help of statistical mechanics. In addition, Huang has the more specific aim to study the relationship between general characteristics of models and the different types of phase transitions; this could be called the mathematical mechanism of phase transitions. So, in contrast to Fowler's description of specific models designed to do particular tasks, Huang wants to put phase transitions into a grand scheme.

In his attempt to fulfil these purposes, Huang examines only a classical system with some mild restrictions on the interaction. This system is a model in the above sense of this term, even though he does not use this word. This model which is also used in the discussion of the mathematical mechanism plays an important role in Huang's description and it is the only model appearing in the chapter on phase transitions. Models also enters at another level, as we shall see, namely in order to illustrate the mathematical mechanism, but these models are of a much simpler kind. This illustration appears not in the chapter on phase transitions, but in the following chapter.

The bulk of the phase transition chapter is concerned with technical discussions of whether the formalism of statistical mechanics behaves as we would expect if is to be a valid theory of phase transitions (Huang shows, for instance, that the pressure is non-negative). In order to carry out the involved proofs, he relies on a particular model, namely a classical system of N molecules confined to a volume V. These molecules can be seen as hard spheres interacting through a potential; the details of this potential are not given explicitly,[5] but the potential is thought to be, to a good approximation, the intermolecular potential of ordinary matter, so it is a quite realistic model. Everything Huang does in the chapter is done in terms of this model and they all send the message that this model is the relevant one to use to understand phase transitions.

We will focus on Huang's description of one point, namely whether the formalism of statistical mechanics is compatible with phase transitions. Huang's discussion of this issue draws on a general description of the mathematical conditions for a phase transition given by Yang and Lee in 1952. In principle, Yang and Lee's very technical theory enables us to determine the nature of the phase transition of a system with a given interaction, but our insufficient mathematical powers make it impossible to do so for the model above. The theory does, however, give a criterion for showing that a system will exhibit a particular kind of phase transition, called first-order. Since there is nothing in this description of phase transitions that prevents the above model from satisfying this criterion, Huang concludes that it is possible that the above model can display the phenomenon of phase transition that is the existence of phase transitions is not in contradiction to this model. On the other hand, since the theory cannot establish that the model does in fact satisfy the criterion, he is forced to write that the uniqueness of the description cannot be proved or disproved.

The Ising model, described earlier, enters the stage in this connection, not as the basis of the new theory or description, but as an illustration. After noting the 'deficiency' of the theory of Yang and Lee that it cannot rule out other descriptions of phase transitions, at least at present, Huang argues that 'it is interesting to

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[5] Since several different potentials fulfill this requirement, this means that Huang is in fact describing a class of models, rather than a single one.

test the validity of our description in simpler models' (Huang, 1963, p. 320). The two-dimensional Ising

model can be used in this respect because it shows, he writes, that the description of phase transitions given

previously is valid for at least one problem. However, it is important to realise that Huang conveys the

impression that it is the previous model, not the Ising model, which is relevant for the understanding of phase

transitions. The Ising model is, for instance, not placed in the chapter on phase transitions, but in a special

section in the part of the book called Special Topics in Statistical Mechanics.

Huang introduces the Ising model, after a short phenomenological description of the phase transition

in magnets, with the words:

> The Ising model is a crude attempt to simulate the structure of a physical ferromagnetic substance... Its main
> virtue lies in the fact that a two-dimensional Ising model yields to an exact treatment in statistical mechanics. It
> is the only nontrivial example of a phase transition that can be worked out with mathematical rigor. (Huang,
> 1963, p. 329)

This explicitly expressed view of the Ising model as lacking physical realism permeates the book. Concerning

an equally simple model, the so-called lattice gas model, which describes gases, he writes that it 'does not

directly correspond to any real system in nature' (Huang, 1963, p. 335).[6]

The Ising model's two fundamental assumptions can be introduced in two ways: either by stressing

that the model is an approximation to another model, the well-founded Heisenberg model (which became the

typical way of putting it forward after the middle of the 1960s[7]) or in a neutral way by simply stating the

assumptions. Huang does the latter, after noting that that the model lives on an n-dimensional lattice:

> Associated with each lattice site is a spin variable s_i ($i = 1,...N$) which is a *number* that is either 1 or -1.
> There are no other variables. If $s_i = +1$, the ith site is said to have spin up, and if $s_i = -1$, it is said to have
> spin down. (Huang, 1963, p. 330)

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[6] He does open for the possibility that the model corresponds to a real gas, if the atoms interact through a zero range potential. He
doesn't asses the status of another equivalent model, the binary alloy model.
[7] To my knowledge the first textbook in English on statistical mechanics to do so was Wannier (1966).

The statement of the model's other assumption is equally neutral. The descriptions of the assumptions, combined with Huang's emphasis on the unity of physics, further underline Huang's implicit message that the model is of peripheral interest only.

Huang determines approximate expressions for the magnetization and the specific heat capacity of the Ising model, but he does not compare these results with experiments. This is in agreement with his tendency to emphasise mathematical deductions rather than physical interpretations. A further case in point occurs in the subsequent chapter where he goes through a solution of the two-dimensional variant of the Ising model. After 24 pages of complex mathematics, Huang reaches an expression for the specific heat, this time exact. He does not interpret this result except that he points out that it shows that a phase transition occurs in the model and that the approximations from the previous chapter are qualitatively incorrect.

The messages conveyed to the student in Huang's chapters on phase transitions are the following. First of all, there is an explicit message that the physicists' overall goal is to provide a unified theory of all natural phenomena on the basis of quantum mechanics. Moreover, the prominent place of the realistic model in the chapter on phase transitions sends a message that this model is relevant for the understanding of phase transitions. The treatment of the Ising model also sends messages. This model is introduced as a crude attempt of representing physical system and Huang says explicitly that the model is only interesting because of its tractability as a test of the validity of the general theory and it is incapable of providing insight into real systems. The model is not compared to experiments, so Huang implicitly tells the student that it is too far from real materials to say anything about physical systems and their behaviour. More generally, one gets the impression that only realistic models are of direct interest to the phenomenological theory of phase transitions, while caricature models are irrelevant. Even though this views is not explicitly stated, when the reader attempts to construct meaning of text, it is very likely that she or he will pick up this message based on the explicit messages sent by the text.

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Different types of models – Pathria (1972)

The chapter on phase transitions in R. K. Pathria's textbook of 1972 contains much of the same material as Huang's, but there is a great difference in perspective on models in the two. This difference is brought out in the view of caricature models (such as the Ising model) because the two books send the same messages about the realistic model used in establishing the possibility of phase transitions etc. What is of interest to us here is therefore the messages sent in the introduction and usage of caricature models.

In contrast to Huang's book, where these models hold a sideway position, the view that caricature models may provide insight into real systems permeates Pathria's chapter on phase transitions. A case in point is the fact that the treatment of the prime example of such a simplified model, the Ising model, is placed in the chapter on phase transitions and not in an independent chapter. This conveys the impression that the model has a say on real systems. The same message is sent when the stage is set for the discussion of phase transitions. Pathria notes that because of the formidable mathematical problems involved in the study of such phenomena one is forced to introduce simplified models. 'One then hopes,' he continues 'that a statistical study of the simplified models, which still involves serious difficulties of analysis, might simulate the basic features of the phenomena exhibited by actual physical systems.' (Pathria, 1972, p. 375)

Pathria's motivation for using the Ising model reflects this view. 'There is no doubt,' he writes, 'that this model considerably oversimplifies the actual physical systems it is supposed to represent; nevertheless, it does retain the essential statistical features of the problem' (Pathria, 1972, p. 392), including the occurrence of phase transitions, the most important aspect of cooperative phenomena. His view that simplified models can give insight into nature is in line with the caricature view of modelling discussed in relation to Fowler, but differs strongly from the one expressed in Huang where only realistic models are seen as physically relevant.

The description of the physical basis of the Ising model is the opposite of Huang's minimalist account, both in terms of sheer length (it fills almost three pages) and justification. It is along the lines of the above description of magnetic modelling. The Ising model is introduced by simplifying the Heisenberg model,

which is plausible as well as practical, he writes, but it does produce consequences which we cannot ignore when we interpret the physical results of the model. The second assumption of the model (that only nearest-neighbours interact), he writes, is 'in the hope that the remaining contributions would not affect the results qualitatively' (Pathria, p. 395). This thorough description of the Ising model conveys the student with the impression that the model is firmly based on quantum mechanics –it can almost be derived from this theory – while at the same time stressing the fact that it is a simplified model. His description of the lattice gas and binary alloys corresponds to his views of the magnet model: both models are simplified but are nevertheless able to shed light on real systems.

As we saw, Fowler appealed to common sense arguments rather than quantum mechanics in his discussion of the alloy model and the assumptions appear to be somewhat ad hoc. In contrast, Pathria's description of the Ising model has almost the character of a derivation from quantum mechanics and the model appears to be much more well-founded. The latter treatment gives the impression that the assumptions of the model can be critically examined by comparison with experiment as well as foundational theory.

Pathria's book does not only give the impression that the Ising model is useful; he also conveys the impression that the model is the main tool for the understanding of phase transitions. The model, which occupies 42 pages out of the 65 pages constituting the chapter, is both compared to experimental data as well as used to give theoretical understanding. The chapter's most prominent comparison of experimental and theoretical data is a table (the only one in the chapter) where he confronts experimental values of characteristic quantities called critical indices with values for two and three dimensional Ising models. For some of the comparisons, he concludes that the model is to be able to capture the essence of data, while in other he regards the model merely as a first approximation. It is obvious however that the model holds a prominent place and hence he gives the student the impression that the model is the main tool for the discussion of phase transitions.

In the cases where he notes a discrepancy between the model and experimental data, Pathria does not discuss the origin of this, in contrast to Fowler. While he thus seems content with the performance of the caricature model, Fowler calls for improvement of the alloy model and writes for example that greater agreement between this model and experimental data maybe obtained by taking the fact that the lattice depends on the order of the alloy into account. Pathria is not discussing such issues. In contrast to modern textbooks – as we shall see – he sticks to scattered comments and specific comparisons and does not create a more systematic phenomenological theory of phase transitions based on the model.

There are multiple approaches in this chapter on phase transitions, which blends realistic models and caricature models. The chapter starts in the vein of Huang and discusses realistic models. Pathria talks about understanding phase transitions as a special consequence of the interaction between particles. Even though he mentions the lattice gas model, it is too simplified to provide such an understanding. This usage of more realistic models sends a message that caricature models cannot stand alone (why use other types of models if they could?). This combined with the prominent role of caricature models means that the student receives mixed messages from the book about modelling. On the one hand, the caricature models are physically relevant; on the other hand, they can not stand alone. Moreover, the place of the Ising-model after the more realistic models and Pathria's introduction of the model as the solution of the formidable mathematical problems give the student the impression that the more realistic models are preferable.

The Modern View – Wilde and Singh (1998) and Salinas (2001)

While Pathria's book was in press, the research on phase transitions changed considerably with the advent of the so-called renormalization group technique (RG) approach to critical phenomena, which is a systematic way to remove degrees of freedom of a system. This technique was the culmination of developments in the 1960s where the following picture of the experimental situation of phase transitions emerged: The temperature dependence of several thermodynamical quantities, for example the specific heat or

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the magnetization, can be described by power laws in the vicinity of the phase transition and the value of the

power gives a characterisation of how the quantity depends on the temperature. It was found that some

physically very different systems, such as liquids and magnets, exhibit the same values for equivalent powers,

called critical exponents. The nature of phase transition of these systems is therefore in a sense the same, so

the behaviour is dubbed universal. Even more remarkable was the experimental fact that systems exhibiting

phase transitions could be grouped into a few classes according to the values of their exponents. A few

parameters, such as the dimension of the system, are enough to define the critical exponents of the system

belonging to that class. The RG became the main tool for understanding these experimental results.

The emergence of RG as well as the above picture gave the treatments of phase transitions in all

subsequent textbooks on statistical mechanics a uniform appearance. These books organise their chapter(s) on

phase transitions around the material needed to allow the student to understand the idea and method of the

RG. This means that the books contain more or less the same elements (but the order may differ): A

description of the Ising model, a number of phenomenological approaches to phase transitions that are not

derived from microscopic models, but from macroscopic assumptions,[8] the so-called scaling hypothesis, a

macroscopic hypothesis that reduces the number of parameters needed to describe experimental results is

drastically, and the RG. The Ising model shows, which had been known for a long time, that the

phenomenological approaches are fundamentally incorrect because the exact two-dimensional result reveals

that a crucial assumption of these approaches is incorrect. The scaling hypothesis is a successful way to go

beyond them, but it needs a microscopic justification, which is provided by the RG. This is the core of the

argument in all the post-RG textbooks.

These new textbooks present a particular view of the theorist's task in relation to phase transitions. Let

us take Wilde and Singh (1998) as an example, because they express this point explicitly. Firslty, they write,

should a theory of phase transitions explain the universality of the exponents, that is why these exponents

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attain the same values for systems that are physically different. Secondly, the theory should account for the relationship between the interaction of the individual constituents, i.e., the atoms or molecules, of systems exhibiting phase transitions and the values of the systems' critical exponents. Different systems have different types of interaction energies and the second job of the theorist is to characterize what general features of the interaction energies lead to which values of the critical exponents. The first problem is solved by the RG; while the solution to the other problem is obtained by considering a host of caricature models, including several variants of the Ising model.

The modern textbooks, either explicit or implicit, send the message that the theorist's task is the examination of the relation between model and the nature of the phase transition in this way. Good modelling, they say, is not a question of achieving the most precise description possible of a concrete physical phenomenon, but to elucidate universal properties. If a description can be given of how overall features of the total interaction energy of the constituents lead to exponents, i.e. the universal behaviour of the system, the textbooks say that we have understood the phenomenon.

This is a new way of organizing the phenomenological theory of phase transitions. Fowler attempts to capture the essentials of the phenomenon in question, but he treats the various phase transitions as isolated phenomena, and do not provide a unified description of them. Huang attempts to give such a description, but stresses that a theory should be an integral part of a unified theory of all of physics and to him the connection with quantum mechanics is important. According to this point of view, the new organization of the theory is too loose. Pathria uses the Ising model to capture the essential features of a system, but does not go any further except pointing out whether the model is capable of description the features. The modern textbooks give a systematic exposition of what it means to understand a phenomenon.

The Ising model plays a prominent role in the RG scheme not only because it shoots down the phenomenological approaches, but also because the model is used extensively in the RG. I will not go into the

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[8] This group includes the so-called mean-field theory of van der Waals and others and a theory of phase transitions due to Landau.

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technical aspects of how this done, but only make a few remarks. The main result of this technique, the

microscopic justification of the scaling hypothesis, is obtained by applying the RG to the Ising model.

Through mathematical manipulations on this model it is shown that this hypothesis is fulfilled for this model.

This is the most prominent example, but far from the only one, of the use of the Ising model to understand the

empirical results. These examples are not simply illustrations of a theory. On the contrary, they establish the

phenomenological theory. The books all send the message to the student that this model, and thus caricature

models in general, are of great importance. The general theory of Yang and Lee is no longer needed in this

scheme, so this theory disappears from the textbooks.[9]

The Ising model thus permeates the treatment of phase transitions in these new textbooks, but the

books justify the model and caricature models more generally in very different ways. In the following I will

use two modern textbooks to span two different ways of motivating the use of simple models.

In their previously mentioned book, Richard E. Wilde and Surjit Singh start their chapter on phase

transitions -- the first one in the part on the application of statistical mechanics -- head on with a defence of

using caricature models. After giving a recipe for statistical mechanical modelling similar to the one on page

9, they observe that physicists typically view the first two steps – the discovery of laws of motion --as the

most profound ones. This view 'seems to imply that once the fundamental laws of particle motion are

discovered, the rest is either easy or just consists of applications' (Wilde & Singh, 1998). However, they

continue, the condensed matter physicist P.W. Anderson have demolished this point of view in a 1972 paper

titled More is Different. Anderson argues that even if the laws of motion of constituent particles and the

Theory of Everything are known, there would still remain fundamental work, which concerns the basic

properties of the systems. The reason is that systems composed of many particles have properties that only

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[9] To my knowledge, the last of the widespread textbooks to discuss this theory is Toda, Kubo and Saitô (1983) and they treat the theory only rudimentary.

appear when the systems are sufficiently large. The behaviour of these systems is thus different from the

behaviour of the sum of the particles. Such systems therefore pose their own fundamental problems.

To this "more is different" point, Wilde and Singh add one by another condensed matter physicist,

Michael Fisher. He argues that our aim is *not* that our models mimic the real systems as closely as possible,

because then we would only have reproduced the system and not discovered anything new and we would

therefore have understood nothing. Rather, 'We must go beyond the calculations and look for universal

behavior. Only then shall we find that certain properties of the system are fundamental to its understanding

and certain others are just unessential details.' (Wilde & Singh, 1998, p. 84) Universality, Wilde and Singh

explain, looks for the essential features that depend only on a few parameters and discards specific traits. In

order to discover such behaviour 'one must study as many models as possible. Only from such studies can

new behavior, which is absent in few-body systems, emerge.' (Wilde & Singh, p. 84). In this endeavour,

caricature models are invaluable. Wilde and Singh does not restrict their defence of caricature models to the

field of phase transitions and critical phenomena, but see it as applicable to all many-body systems.

In his textbook, Silvio R. A. Salinas motivates the use of caricature models in another way. He also

appeals to universality, but not as an ideal for our understanding. Universality, in Salinas's account, is

something inherent in the phenomena irrespective of what we might be looking for. He starts his first chapter

out of three on phase transitions and critical phenomena with reporting the emergence of the picture of the

experimental results given in the beginning of the present section. This leads him to the following conclusion

which appears in the beginning of his treatment of phase transitions: 'Owing to the universal character of

critical phenomena, it becomes relevant to consider simplified but nontrivial statistical models, as the Ising

model' (Salinas, 2001, p. 236). Universality shows that the individual features of the systems exhibiting phase

transitions cannot be significant. This means that we should look for prototypical systems that represent the

main features of the systems. So, where Wilde and Singh employ a sort of ideology to argue that we should

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use simplified models, Salinas employs the theoretical and experimental insights of the field to say that it is

sufficient to analyse such models in order to construct a microscopic theory. Consequently there is actually a

huge difference in the messages sent by the two textbooks.

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Since both the two modern textbooks put some efforts into arguing that it is in fact a virtue of the Ising

model (Wilde and Singh) or that it does not matter (Salinas), that the model is a simplified representation of

physical systems, neither textbook have to use the heavy machinery that is its quantum-mechanical foundation

employed by Pathria to argue for the relevance of the model. And both of the modern books simply state that

the model can represent the phenomena in question -- in the words of Salinas: 'The multiplicity of

interpretations is compatible with the ability of the Ising model to represent the main features of the critical

behaviour of many different physical systems.' (Salinas, 2001, p. 258)

Comparison and implications for teaching

The above analysis of the five textbooks shows that there are considerable differences between the

metamodelling messages conveyed, explicitly or implicitly, by the books to the student about physical

modelling. In light of the significance of modelling in physics, the messages sent by the textbooks are of great

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importance. The differences between models are summarized in figure 2.

Insert table 1 about here

Firstly, they send different messages on what constitutes a good model. Huang's book is at one

extreme. His ideal of physics means that the models treated in his chapter on phase transitions are restricted to

fairly realistic ones, where the intermolecular potential is 'to a good approximation' that of ordinary matter.

The Ising model is too simplified to be of value to the theory of phase transitions except as an illustration. In

short, he sends a message that only well-grounded models are acceptable. This is in contrast to the other

textbooks: they all accept models which are very simplified, but for different reasons. For Fowler it is not an

issue whether the model is derivable from quantum mechanics; what matters is that the model seems

reasonable. The last three textbooks all accept the Ising model, but they see its physical realism differently.

Pathria's description of the model as an approximation to the well-founded Heisenberg model gives the impression that the Ising model can almost be derived from quantum mechanics. In the modern books, the attitude to the model is more neutral: the model captures the essential features, but it has some significant flaws. The modern textbooks use, at least, two strategies to justify caricature models more generally, including the Ising-model. Wilde and Singh give an ideological argument that we ought to use such models, while Salinas argue that the features of phase transitions mean that such models are sufficient.

All the textbooks use models to make a phenomenological theory of phase transitions, but it is very different theories they aim to build. Huang puts phase transitions into a unified view of theoretical physics and argues that in principle quantum mechanics should provide the theory of phase transitions. In the other textbooks, the phenomena per se are in focus. Statistical mechanical models are here used operatively to understand these phenomena. Fowler gives the impression that modelling is a question of giving a simple model of specific phenomena. A model is analysed and compared to the experimental data of the phenomenon in question. The model can be accepted easily or dropped just as easily depending on how well its agreement with experimental results. Fowler's aim is not universal in the sense of the modern textbooks that looks for the shared features of different physical systems. According to the books after Huang, the models should be placed in a larger theoretical scheme. This is not a scheme provided by quantum mechanics, but by some phenomenological laws we want to justify. Pathria's scheme is a patchwork of multiple approaches. He employs several different models (including the Ising model) that have widely different status. Some are realistic representations of the physical system, while other caricatures it. The modern textbooks, in contrast, display a fixed idea of theory organization: From a host of caricature models the relation between features of the total interaction energy and the values of the critical exponents is determined that is what type of behaviour these features lead to.

In these books there are different notions of what it means to understand a physical phenomenon. Huang conveys the message that this amounts to giving a model compatible with quantum mechanics that is able to reproduce the features of the physical phenomenon. Pathria is vaguer in this respect and gives the impression that several different types of models can provide insight. The modern textbooks are sharper: to understand a phenomenon means to be able to capture the essential features of the system. This is done by the organizing the theory as described above.

Another trend is towards universality in the sense of capturing different physical systems under the same umbrella. While the models of Fowler and Huang only represent specific systems, alloys or condensation of gas, the models in the books from Pathria and onwards, attempted to capture several systems. In the words of Pathria, the Ising model, 'turns out to be good enough to provide a unified theoretical basis for understanding a variety of phenomena' (Pathria, 1972, p. 392). The price of this property of the model to represent such diverse phenomena is a lack of detail representation, so there is also a tendency towards generic properties of the systems in question. In the words of Pathria, the Ising model, 'does retain the essential statistical features of the problem' (Pathria, 1972, p. 392). The way the Ising model and caricature models more generally achieve this is by seeing the features schematically. In the Ising model the potential is reduced to bare-bones -- only nearest neighbours interact -- in contrast to the more realistic potentials of the theory of Yang and Lee. So, there was a shift towards toward greater generality and greater scope of the treatment at the expense of detail.

A physics student who gets his or her knowledge of phase transitions mainly from textbooks would acquire different metamodelling knowledge by reading the five books analysed here. Even for a student who receives messages from other sources as well, the textbook are a significant factor in the acquisition of metamodelling knowledge and we should pay attention to what story they tell. Let us consider a hypothetical

student, for whom *all* sources (other books, lectures etc) of ideas about modelling send messages identical to the ones in each of the books.

What are the consequences for such a hypothetical reader of Fowler? It is natural to assume that such a student in a future modelling situation will make simple models based on common-sense ideas about how the phenomenon works, and have as main goal that the model is capable of explaining experiments. The student would not feel a need for giving a more unified description of a host of phenomena nor to base the models on fundamental theories.

A reader of Huang would have quite different views. In particular, she or he would probably reject caricature models of others as being too simplified. Moreover, the student will most probably not set up this kind of models herself or himself, but only consider more realistic models. How can a student who always has been taught that caricature models are of no use react otherwise? If one thinks that this kind of models have no place in physics, this is not a problem; it is, however, difficult to claim that such models do not play an important role in modern physics. If the physics teacher does see such models as relevant to physics, it is essential that she or he counters the view expressed in Huang's book, for instance by including material that conveys other messages.

If the hypothetical student works with Pathria's book rather than Huang's, she or he doesn't get the idea that caricature models are of no use. Thus it is very likely that the student will accept caricature models in future situations even though she or he will prefer more realistic models. It is natural to assume that the absence of a complete phenomenological theory may give the student a somewhat confused picture of the purpose of modelling in general: are we satisfied with understanding of isolated parts of the phenomena using simplified models or do we aim at a general phenomenological model based on more realistic models? The teacher should organise the instruction so that this confusion is eliminated. The multiple approaches in this

book give the teacher a great opportunity to discuss merits and drawbacks of the various modelling

approaches and thus clarifying the student's knowledge about modelling purpose.

The hypothetical reader of either Wilde and Singh (1998) or Salinas (2001) would also accept and use

caricature models, but the student would get a more elaborate picture of what a phenomenological theory is.

On the other hand, one could argue that not *all* phenomenological theories should be like the theory of phase

transitions and the teacher may want to broaden the view of the students to meet this objection. Moreover, it is

not always the case that it is enough that models captures the universal features; once again, the teacher

should act against such tendencies.

The textbooks rarely declare explicitly what messages they sent about the important issue of

metamodelling knowledge. The analysis above can functions as a guide to some of the crucial differences

between textbooks.

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Figure 1: Magnetic models.

Table 1: Comparison of the metamodelling messages in the five books.

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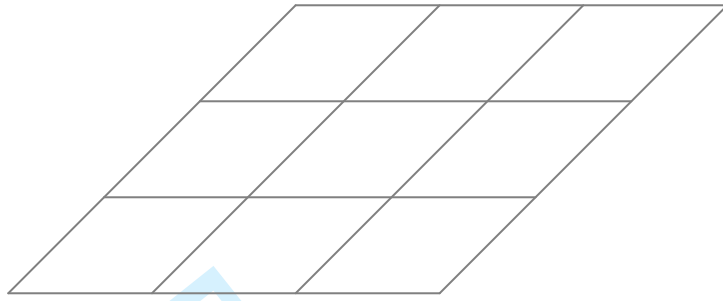27 | Page 31: [14] Deleted | maniss | 10/8/2007 3:11:00 PM |
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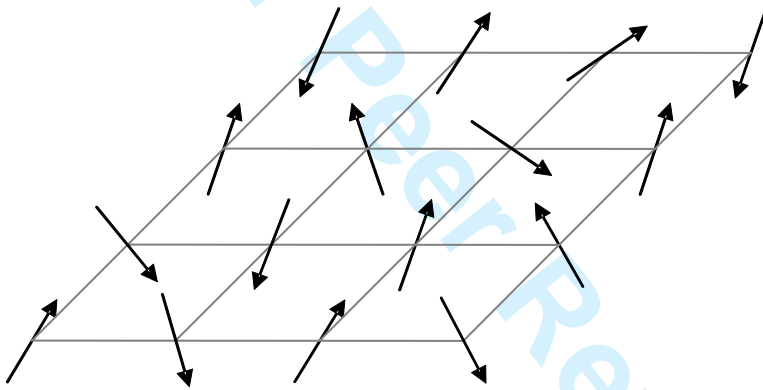32   , Berlin, New York
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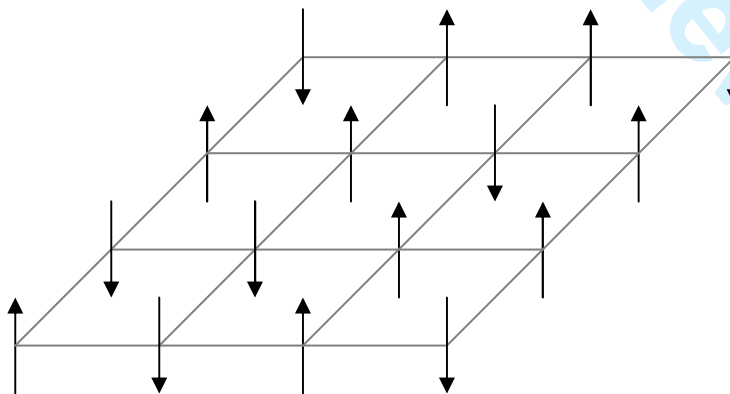41
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	What constitutes a good model?	How is the phenomenological theory organized?	What does it mean to explain a physical phenomenon?	Universality
Fowler (1936)	Caricature models are relevant if they agree with experimental data.	As a simple model of a specific phenomenon.	To have a simple model of a specific phenomenon.	Does not attempt to capture several systems under one umbrella.
Huang (1963)	Only fairly realistic models are of value for the understanding of phenomena. Caricature models are only relevant as means to illustrate theory.	As a unified account of phase transitions which is in accordance with the rest of theoretical physics.	To have a realistic model that is able to reproduce the features of the phenomenon.	Gives a framework for all phase transitions, but does not attempt to pin point the universal features of several systems.
Pathria (1972)	Both realistic models and caricature models can be used, but for different purposes.	As a patchwork of multiple approaches.	To have a range of models that can reproduce various aspects of the phenomenon.	Aims to provide a unified description of the common features of several systems.
Wilde & Singh (1998)	Caricature models are important because they are what we are looking for.	As an elaborate scheme of caricature models combined with a technique to show their universality.	To have a model that captures the essential features.	Aims to provide a unified description of the common features of several systems.
Salinas (2001)	Caricature models are important because we can argue that they capture the essentials.	As an elaborate scheme of caricature models combined with a technique to show their universality.	To have a model that captures the essential features.	Aims to provide a unified description of the common features of several systems.

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