Compendium

Introduction to University Pedagogy

Version 2

Contents

Introduction

Welcome to the course “Introduction to University Pedagogy” or IUP. We are looking forward to seeing you in the course. Page 3 offers a general overview of the course.

In preparation

Before the course, we expect you to familiarise yourself with this compendium. You do not have to read the entire compendium before the course as some of the material has been chosen as reference material to be used during and after the course.

However, in preparation for the course, please read the following texts in the compendium in the following order:

- Entwistle – 2009 – Learning and the influences on it
  12 pages: provides a short introduction to learning
- Entwistle – 2009 – How students learn and study
  15 pages: provides an overview of learning relevant to university teaching
- Christiansen & Olsen – 2006 – Analysis and design of didactic situations
  17 pages: on different phases in a lesson. The paper will give you a notion of key concepts that are used throughout the course

During the course all participants will teach the other participants for around 20 minutes (during what we call lesson exercises). You will not know ahead of time what day you have been assigned a lesson exercise. However, you need to consider the following:

- Think of a subject which is suitable for 20 minutes of teaching. Take into account the fact that the participants have different backgrounds (but most have a university degree in science). Choose something that you consider to be central to the subject, but not too difficult. Pick a subject that allows experimentation with different ways of organising a teaching/learning situation.
- Think about what the participants are expected to learn from your short lesson. How will you help the students learn this? What are the most important elements in the subject matter, and how will you know if you have reached your objectives?

Do not plan your lesson exercise in advance. There will be time during the course to discuss the lesson plan with other participants. But please remember to bring relevant teaching materials (Power Point slides, illustrations, models, videos) so you can work on preparing the lesson exercise with help from your lesson exercise group.

Course objectives

After the course participants are able to:

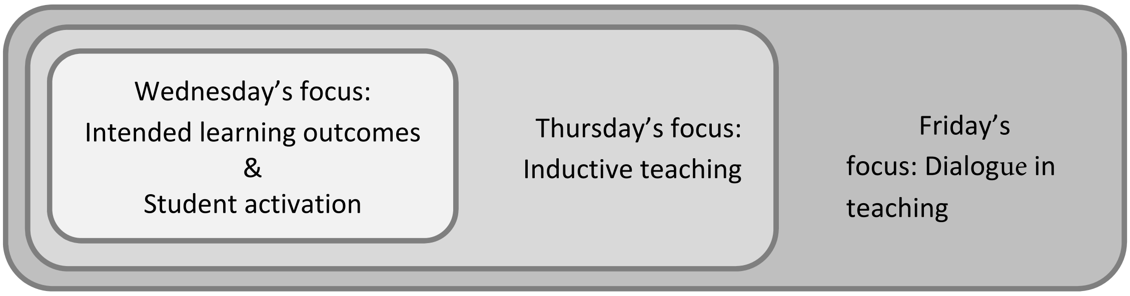
- plan, carry out and evaluate central aspects of their own teaching
- select and apply pedagogical principles to their own teaching
- evaluate other's teaching constructively
- identify and discuss key issues concerning teaching in higher education

The course concerns the basics of university pedagogy including the following topics:

- Student learning and competence
- Planning teaching
- Structuring learning situations
- Reflecting on own and others' teaching

Participants will reflect and evaluate others and their own teaching as compared to the theoretical elements of the course.

Lesson exercises takes place Wednesday, Thursday and Friday (see course overview page 4). Each set of lesson exercises focus on particular ways for teachers to engage students in learning, but each focus is integrated in consecutive lesson exercises throughout the week:



Course weight

3 ECTS (European Credit Transfer System).

77 working hours

Practical information

The course takes place at the Department of Science Education in the Observatory at Øster Voldgade 3, 1350 KBH K (it's on a small hill in the Botanical Gardens just opposite Rosenborg Castle) where we will start every day. There will be signs to guide you to where you need to be.

The course is a one-week, full-time course running Monday, Wednesday, Thursday and Friday from 9-16. There will be some required reading throughout the week and you will also be required to do some work on your own during Tuesday. Finally, depending on when your lesson exercise is scheduled, you may need to spend extra time in preparation for that. Therefore, you should expect to spend most of your week working on the course.

The course is passed on the basis of active participation in the full course and you cannot pass the course if you miss more than half a day. If, for some reason, you are unable to participate in any parts of the course, please inform the course teachers so they may take appropriate measures to adjust the programme.

It is very important that you arrive on time every day. We have a tight programme and start on time. Our activities depend on people being present.

Questions?

If you have any questions about the practical information or in case you cannot attend due to an emergency, please contact our clerical officer:

Nadja Nordmaj, nnordmaj@ind.ku.dk, +45 35320388

If you have any other questions about IUP, please contact the course responsible.

We look forward to seeing you at the course.

Sincerely,
Lene Møller Madsen, lmmadsen@ind.ku.dk Marianne Achiam, achiam@ind.ku.dk, +45 35320357 Course responsibles

Course overview

Below is an overview of the course structure. The structure varies, depending on what team you belong to. Most Danish speaking participants have been assigned to the Danish Team, while non-native speakers have been assigned to the English Team.

Instructions are lectures and exercises that take place prior to lesson exercises. They ensure that participants are prepared for and equipped to plan their lesson exercise.

Lesson exercises are when participants teach participants. Each participant will have one hour allotted – of which 20 minutes is for teaching and 40 minutes is for feedback and for discussing techniques utilized during each lesson exercise.
NOTICE the pages for planning your lesson exercise at the end of this compendium.

<table>
<tr><th colspan="6">If you are on TEAM 1 (usually the Danish language team) this applies to you</th></tr>
<tr><td></td><td>Monday</td><td>Tuesday</td><td>Wednesday</td><td>Thursday</td><td>Friday</td></tr>
<tr><td>09-12</td><td>Instruction</td><td rowspan="4">Read & Reflect*</td><td>Lesson exercises</td><td>Lesson exercises</td><td>Lesson exercises</td></tr>
<tr><td>12-13</td><td>Lunch, incl.</td><td colspan="3">Lunch – it is included!</td></tr>
<tr><td>13-15</td><td>Instruction</td><td>Instruction</td><td>Instruction</td><td>End of course discussion</td></tr>
<tr><td>15-16</td><td>Planning of lesson exercises</td><td>Planning of lesson exercises</td><td>Planning of lesson exercises</td><td>Evaluation</td></tr>
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<table>
<tr><th colspan="6">If you are on TEAM 2 (usually the English language team) this applies to you</th></tr>
<tr><td></td><td>Monday</td><td>Tuesday</td><td>Wednesday</td><td>Thursday</td><td>Friday</td></tr>
<tr><td rowspan="2">09-12</td><td rowspan="2">Instruction</td><td rowspan="5">Read & Reflect*</td><td>Instruction</td><td>Instruction</td><td rowspan="2">Lesson exercises</td></tr>
<tr><td>Planning of lesson exercises</td><td>Planning of lesson exercises</td></tr>
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<tr><td>Planning of lesson exercises</td><td>Evaluation</td></tr>
</table>

* Use Tuesday to consider what you want to teach while reading this compendium. Only prepare your lesson in detail if you are teaching Wednesday. Those who will be teaching Thursday and Friday will receive instructions later about how to prepare their lesson in detail.

From: Entwistle, N (2009): *Teaching for understanding at university*. Basingstoke: Palgrave Macmillan. 13-24

2 Learning and the Influences on It

Fundamental processes of learning

In the 1950s, psychologists were pointing out that each person was, in certain respects, like everyone else, like some other people, and like nobody else. Different theorists tended to take more account of one or other of these perspectives, with some using small-scale experiments to study memory and learning processes used by everyone, and others relying on large-scale surveys to find traits distinguishing between groups of people with similar characteristics. At that time, psychotherapists seemed to be the only theorists stressing the importance of individuality, as that was the main focus of their work with clients. In this book we shall be using all these perspectives in trying to explain the effects of teaching on learning and how students react to their educational experiences. In this chapter, we shall be looking at aspects of learning that everyone shares, before considering some well-established traits describing group differences.

Practice and feedback

In psychology, there has been a tendency to discard earlier theories as newer ideas emerge, and yet some of the previous ideas remain valid and important in education. From the early behaviourist theories, we know that skills are developed through practice and that repetition of words or phrases strengthens the memory of them. But the form of practice is even more important, doing the same action repeatedly is rarely the best approach. For example, throwing a ball through a hoop set several metres away can be repeated until it can be done successfully on most occasions. Yet the real skill involves being able to do this from different distances and directions, and that depends on having varied practice, not just repetition. And this principle is important not only in skill learning but also in establishing concepts, as we shall see.

The other crucial finding from behaviourist psychology is the effect of reward or punishment on deciding whether an action will be repeated. The essence of conditioning is strengthening the connection between stimulus and response. We tend to repeat actions or strategies we have found rewarding, either because of the pleasure they give in themselves or from the praise, or other rewards, like grades, we receive afterwards. Behaviour is also shaped by punishment or criticism, but people react differently to praise and blame; harsh criticism rarely promotes learning, whereas most people can be encouraged to learn through praise or by gently correcting and explaining mistakes. Thus helpful, understandable comments on work carried out are essential if students are to learn from their mistakes. This may seem obvious, but such feedback is not always given at university, as we shall see later. It is true that the general notion of conditioning in education has been challenged, even discredited, as it makes the role of teacher too controlling and the approach too mechanistic, but the main principles can be applied effectively in gentler and more imaginative ways.

Attention and memory

An early theory that still holds true, describes the way sensory information is recognized by the brain and is then processed for subsequent use. The description was originally based on an analogy with a library cataloguing system, but has since been supported by evidence about neurological processes. The starting point is *attention*. Unless we focus on what is most salient in the information coming to us, and are consciously aware of it, it will barely register in our memory. Early hominids survived by being able to recognize very rapidly any important, or potentially threatening, aspect of the environment and reacting to it. In everyday life, attention is still driven in similar ways, but in university education it is generally interest or the need to pass exams, which arouses and maintains attention in lectures or while studying.

Attention is directed towards incoming sensory signals, which are initially recognized and then passed to *short-term memory* (STM), where their meaning is interpreted by comparing them to previously stored information. Short-term memory has another important function, it is where we bring together material from long-term memory to work on problems, linking together ideas or relating new knowledge with old. But short-term memory, as its name implies, does not last long – about 20 seconds on average. It is also severely restricted in size, allowing us to handle only between 5 and 9 separate pieces of information at a time. We do, however, develop strategies of grouping separate bits of information together, and this technique is crucial in building up an understanding of complex ideas. Experiences lead to concepts, and sets of concepts are brought together to create higher-level concepts or theories. But to do this, we often have to put our ideas on to paper or computer so that we can think about many more elements at the same time.

In presenting ideas to students in lectures, the restricted size of STM has important implications. It makes it impossible for students to handle more than a limited set of ideas or pieces of evidence within a short time span, so the amount of material introduced within each lecture has to be carefully weighed up. Students also need a good deal of help with techniques of handling complex information in their own studying, for example, by using concept maps or other diagrams. In this book, we shall be using diagrams to bring sets of ideas together, and we shall also be introducing a new way of using concept maps to help students develop a deeper understanding.

Conceptual development

Information that comes into STM has to be passed into *long-term memory* (LTM) and linked to relevant areas of knowledge and experience. Past events or episodes are stored in *episodic* long-term memory as visual images, often with associated sounds, smells and feelings. Knowledge and ideas are stored somewhat separately, in *semantic* long-term memory. To recall information accurately, it has to have been 'filed' correctly, making sure it is related to similar prior memories, and linking it closely with associated experiences, images or patterns (diagrams) within episodic LTM. Although episodic and semantic memories are described as being distinct, they are really closely linked, with visualization or rhymes being an important way of triggering semantic memory, through mnemonics, for example. Although long-term memory has been often likened to a library with its own categorization system, or to coding material into a computer, it is also importantly different. People not only store information, they keep it continuously under review to make connections or expand their existing knowledge. And this is done at both conscious and subconscious levels.

From an early age, grouping similar events or objects together is fundamental to cognitive development; even young babies recognize similarities and differences and group them in a process that later makes use of language to form *concepts*. The earliest concepts are of those experienced in our everyday environment: food, table, chair, horse, dog, pig, and so on. Concepts are established through meeting varied examples of them in contrasting circumstances and discriminating them from similar concepts (dog from cat, for example). The defining features of such concepts are easy to discern and are widely agreed upon. But with abstract concepts, like 'justice', 'freedom', 'education', 'learning' or 'understanding', consensus is much more difficult to establish, because these depend on the particular examples each person has met. So we all have rather different *conceptions* of such concepts, in which previous experience, knowledge, values and feelings become intertwined.

Indeed, the continuing search for meaningful connections among our experiences is an important driving force in human behaviour, as Gerald Edelman has argued on the basis of neuroscience. He has drawn attention to the 'correlative urges' that suffuse our thinking and have their origins in the survival demands facing early mankind. So we bring together experiences and events in creating concepts and link together concepts in developing understanding, or in creating new ideas or techniques.

> Higher-order consciousness leads to the construction of an imaginative domain, one of feeling, emotion, thought, fantasy, self, and will. It constructs artificial objects that are mental. In culture, these acts lead to studies of stable relations among things (science), … among mental objects (mathematics) and … between sentences that are applicable to things and to mental objects (logic). … Thinking occurs in terms of *synthesized* patterns.
>
> (Edelman, 1992: 151–2)

Not only are these patterns or conceptions, to a certain extent, personal, we may also retain several alternative versions of a concept that we use for differing purposes. Even when we have met precisely defined technical concepts in, say, physics or economics, our earlier everyday conceptions often remain. We have to learn which conception is most appropriate for each task or situation we meet. Explaining an idea in a pub to our friends has to be geared to what they know and what they are interested in, and carried out in an appropriately colloquial manner. Giving that kind of explanation in a tutorial would not be sensible.

Rote and meaningful learning

Just as there are distinct forms of memory, there are equivalent differences in learning processes. If we want to remember essentially meaningless material, like a telephone number, we repeat it over and over until it is firmly transferred from working memory to LTM. This process of repetitive *overlearning* does not depend on links with previous knowledge; it is a matter of forcing the information directly into the memory, and is described as *rote learning*. Repetition plays an important part in learning a poem by heart or making sure you can give the technical name of a flower or a fossil when seeing it. Establishing concepts or understanding ideas, however, depends on making links with what we know already and that demands what has been called *meaningful learning* – the conscious attempt to make sense of topics for oneself. But some students come to treat academic work as being essentially meaningless, and so see rote learning as an appropriate approach to use in a routine way. Such an attitude all too easily becomes a habit, which seriously affects the ability to learn academic material, as we shall see in the next chapter.

Learning processes in studying

The raw material for forming concepts comes from experiences, either first-hand or provided and organized by others. Simple concepts are formed subconsciously, but the more abstract ideas introduced in higher education generally require considerable conscious effort before the underlying meaning of a concept can be grasped. Even the term 'concept' has limited applicability; in the humanities, the looser notion of an *organizing idea* is more appropriate. But we shall use 'concept' as an encompassing idea covering both terms.

Academic concepts come at different levels. Some are the basic building blocks of a discipline – like 'current' in electronics, 'price' in economics or 'photosynthesis' in biology, while others are introduced to show important interconnections between groups of basic concepts and may be expressed as theories or laws – like 'Ohm's law' in physics, 'opportunity cost' in economics or 'optimal foraging' in zoology. In 2003, Jan Meyer and Ray Land suggested that, in many subject areas, there are *threshold concepts* that play a critical role in understanding a topic area, sometimes by integrating lower-level concepts, but always by opening up a new perspective on the landscape of knowledge to the student. Grasping such integrative concepts allows students to understand the subject more deeply, but the ideas often prove challenging. Unless they are thoroughly understood, students will find it difficult to make progress in the subject. And higher-level thresholds are even more difficult to grasp, where they involve the distinctive ways of thinking within a discipline that provide the foundation of a professional approach to the subject. Students generally only come to terms with these thresholds later in their degree.

In meeting a new topic it is crucial for students to be able to distinguish what is salient from what is incidental, and this often proves difficult in the early stages of a degree course. Without this recognition, students cannot see the important landmarks they need to guide their own explorations of an academic domain. This ability to discern what is salient has become a central part of a recent pedagogical theory of learning developed by

Ference Marton. An accurate conception depends on recognizing the defining features of the target concept, and also on discriminating it from similar ones. To be able to do this, we need to have experienced the variations that make up the characteristic features of the concept. To take a simple example, the concept of 'colour' depends on experiencing the differences between red, blue, green, and so on. This variation is something we experience every day and so we are able to build up, subconsciously, an accurate conception of 'colour'. When it comes to abstract concepts, however, the variations are rarely self-evident, and if students cannot recognize the defining features for themselves, they will inevitably develop inaccurate or incomplete conceptions.

> In order to see something in a certain way, a person must discern certain features of that thing. We should also be clear about the difference between 'discerning' and 'being told'. Medical students, for instance, might be advised by their professor to try to notice the different features of their patients, such as the colour of the lips, the moisture of the skin, the ease of breathing, and so on. This is 'being told'. But in order to follow this advice the students must experience … how they can vary. … By experiencing variation, people discern certain aspects of their environment; we could perhaps say that they become 'sensitized' to those aspects. This means that they are likely to see future events in terms of those aspects; … [so learning depends] on experiencing variation.
>
> (Marton & Tsui, 2004: 10–11)

The starting point of this *variation theory* is thus *discerning* critical features, and this depends on the students' active use of prior knowledge and experience to separate out for themselves the critical features from the more incidental ones. Just being told which are the critical features will rarely suffice; they have to be experienced. The salient *dimensions of variation* within a concept or topic may be met in everyday living, or can be systematically provided by a teacher, but without the opportunity to see and reflect on the meaning of these variations, students cannot understand how they fit together. And yet a full understanding of a concept or a topic depends on being able to see the overall *pattern of variation*, the links between the various parts that create a coherent whole, so students have to keep these dimensions of variation in mind (in working memory) *simultaneously*. So understanding depends on actively exploring the interconnections that make up a concept, phenomenon or process, and comparing and ordering them until a clear overall pattern of variation is seen.

Examples of the use of variation theory in university teaching provided in Chapter 6 will help to make the idea more concrete. For now, we will use an extract from the writing of an eminent biologist, Edmund Wilson, to bring together psychological and neurological descriptions of memory and learning processes mentioned earlier.

> Mind is a stream of conscious and subconscious experience. … It is at root the coded representation of sensory impressions and the memory and imagination of sensory impressions. … Long-term memory recalls specific events. … It also re-creates not just moving images and sound but meaning in the form of linked concepts simultaneously experienced. … The conscious mind summons information from the store of long-term memory … and holds it for a brief period in short-term memory. During this time it processes the information, … while scenarios arising from the information

> compete for dominance. … As the scenarios of consciousness fly by, driven by stimuli and drawing upon memories of prior scenarios, they are weighted and modified by emotion … which animates and focuses mental activity. … What we call meaning is the linkage among neural networks created by spreading activation that enlarges imagery and engages emotion.
>
> (Edited from Wilson, 1998: 119, 121, 122, 123, 126)

This view of how a personal web of understanding is formed is consonant with Edelman's notion of 'correlative urges' and of Marton's idea of grasping critical features and their interconnections. Creating such an integrated 'whole' is crucial to an understanding that is personally satisfying, and so has an emotional tone. It is this view of *personal understanding* that is at the heart of our thinking about university teaching and we shall look at it in more detail in Chapter 4.

Influences on learning

So far we have looked at some of the processes of learning that everyone uses, but now we come to the contrasts that can be found between groups of individuals. These differences in, for example, ability, motivation and personality are no longer seen as fixed characteristics, but ones that develop through the interplay of inherited capabilities and many subsequent experiences and relationships. Their importance in thinking about university teaching lies in the effects they have on how students learn, and how they react to the teaching they experience. The concepts introduced in this chapter come from mainstream psychological research, but in the next chapter we shall meet other ideas that have been developed in trying to explain students' experiences of learning and studying.

Previous knowledge and experience

Until the 1980s, universities in Britain had a rather homogeneous intake, mainly of students coming more or less straight from school with recent experiences of studying and accredited knowledge of their chosen subject area. Now the situation is very different, with much greater diversity. The rapid expansion of higher education has provided opportunities for social groups previously unlikely to enter higher education, as well as to students coming from ethnic minorities and bringing with them different cultural beliefs and attitudes to education. There are also students at university with disabilities that might previously have excluded them. These changes have created a more varied and richer mix of experience among students, but at the same time have caused additional problems for academic staff. Syllabuses and ways of teaching that were appropriate for the top quarter of young students from homogenous backgrounds cannot offer a suitable academic diet for students who are less well prepared for university learning or have varying cultural backgrounds.

However, one of the main influences on the ease with which all students acquire new knowledge is their prior knowledge and how well it has been organized – what they already know about the subject matter and about how to handle ideas within their chosen subject area. Indeed, David Ausubel's influential book on educational psychology begins by stating:

> If I had to reduce all of educational psychology to just one principle, I would say this: The most important single factor influencing learning is what the learner knows already. Ascertain this and teach ... accordingly.
>
> (Ausubel, Novak & Hanesian, 1978: iv)

This adage, while true as a logical and theoretical principle, was difficult enough to apply in the late 1970s with a large class of students. Then, individual prior knowledge was still varied, but it was possible to have a reasonable idea of what most students would know. Now it is much more difficult to know how to 'teach accordingly', given the diversity of students and the modular system, but we still need to have a good idea of the spread of subject knowledge and other differences within a class of students to prepare for teaching.

Abilities and learning styles

There continues to be considerable disagreement about the relative importance for education of what has been called *general intelligence* or '*g*', and also about how much it is likely to change over time and circumstance. Verbal and logical forms of intelligence, which are at the heart of '*g*', have clear relationships with most areas of academic attainment, and also have proved to be remarkably stable, even between childhood and old age, except where early experience has severely inhibited normal cognitive development. Nevertheless in higher education more specific abilities are also important, not just in areas such as music and art, but also in most other academic areas.

It has been suggested through studies in cognitive archaeology that separate 'modules in the mind' evolved in early humans in response to the demands of everyday life. These experiences ranged from artifacts and tool making (the physical domain) to animals and animal behaviour (the biological domain) and to other people (the social and interpersonal domain). Howard Gardner has argued that it is possible nowadays to make even finer distinctions, to recognize *multiple intelligences*, including logical thinking, and also the specialized abilities involved in, for example, mathematics and music, as well as the interpersonal intelligence needed in human relationships and the intrapersonal ability to understand oneself. Students' academic progress is quite strongly related to general ability, and also depends on having a profile of other abilities compatible with their chosen subject area. But people also learn to use their intelligence and abilities more effectively over time, making better use of their whole profile of abilities and other qualities by using stronger elements to compensate for weaker ones.

A different line of research has drawn attention to the distinctive preferences that people have for learning in particular ways, for example, by a specific mode of sensory input (e.g. visual, auditory, kinaesthetic) or through contrasting forms of mental representation. These so-called *learning styles* are often described in terms of polar opposites, thought by some researchers to be rooted in contrasting hemispheric brain functions, with the right brain involved more in imagery and the left brain dealing with analytic processes. And distinctive learning styles have been found in how students tackle their academic work.

For example, Gordon Pask contrasted *serialists* with *holists* through the ways in which they went about studying. When starting a new piece of work, serialists prefer to go about it step-by-step, thriving on the logical development of topics, and building gradually towards an overall understanding. In contrast, holists look straightaway for the whole picture and depend on lively illustrations and anecdotes to help them fit the details and the evidence into it. Pask also identified stylistic differences in students' explanations of what they had understood, with serialists presenting more formal, well-structured scientific descriptions and holists developing a more personal narrative account. In other research, in which students were asked to mark and comment on short essays written in deliberately contrasting styles, higher marks were given to the essays in the learning style closest to their own. But a thorough academic understanding generally involves a *versatile* interplay between overview and detail, as we shall see in Chapter 4.

What implications can be drawn from this research for university teaching? Lecturers have to aware not just of the range of abilities to be found in any class, but also of the existence of distinct stylistic preferences. This means that presentations have to start at a level that all the students can understand and build gradually in complexity, and also that they should contain both the strong logical development favoured by serialists and broad overview and more personal approach preferred by holists. This idea will be revisited in Chapter 5 to suggest a more general – 'multipli-inclusive' – approach to teaching.

Personality and motivation

As we saw in the Bridge Passage, introverts are likely to be more successful at university than stable extroverts, whose need for social interaction distracts them from studying. But it was subsequently found that the more direct influences on academic success came from a combination of motivation and well-organized study methods. Although, like intelligence, the term motivation is often used to denote a single entity, it again has importantly different forms. A basic distinction can be made between *intrinsic* and *extrinsic* motivation. Intrinsic motivation comes from interest in what is being learned and the feelings of pleasure derived from it, while extrinsic motivation depends on external rewards, such as grades or praise. The early research on conditioning saw reward solely in extrinsic forms, but in higher education it is intrinsic motivation that engages learning processes leading to personal understanding.

Other important forms of motivation are vocational motivation, achievement motivation and fear of failure. Students from non-western cultures are more likely, in addition, to describe motives relating to *social responsibility* – acquiring knowledge for the benefit of other people in their country. Where students have a clear vocational goal, it forms an important driving force in studying, leading them to look for immediate relevance in their courses. If they do not find that link, however, they may rapidly become demotivated. Some courses, of course, have no obvious vocational target, and so depend on interest in the subject matter or the need to obtain a degree.

When it was introduced into the psychological literature, *achievement motivation* was described as a stable personality characteristic, fed by 'hope for success' and the rewards that came from high grades. In higher education, it was often found to fuel strong competition with other students, being found more frequently among men than women, and in applied areas such as business studies and engineering. *Fear of failure* can also drive attainment through feelings of anxiety, but it is likely to lead to the 'safer' approach of rote learning, rather than the more 'risky' attempts to reach an independent understanding. In some of the early research into student learning, the distinction between achievement motivation and fear of failure was seen as creating marked differences in how students perceived both themselves and their whole university experience.

> Some students are stable, confident and highly motivated by hope for success, while others are anxious, uncertain of themselves and haunted by fear of failure, and yet both groups are capable of high levels of academic performance. The interview data take the differences even further. Students of differing personality and motivational types not only tackle their academic work in different ways but, from their descriptions of their university experience, they evidently perceive themselves to be in differing environments.
>
> (Entwistle, Thompson & Wilson, 1974: 393)

Although, at the time of this research, motivation was seen as a relatively fixed characteristic, subsequent studies have shown that it is much more malleable, being strongly affected by experience. Intrinsic motivation and interest in the subject, in particular, are affected by the nature of the teaching experienced. Nevertheless students have a responsibility to develop their own motivation and interest, it is not a one-way process.

Thinking dispositions

So far we have concentrated on separate concepts describing aspects of learning, but recent research has been looking at groups of concepts that act together in affecting how people think. David Perkins and his colleagues at Harvard have been using the term *thinking disposition* to indicate the ways in which several relatively stable characteristics of individuals seem to work together synergistically to affect academic learning.

> The three aspects of thinking are called sensitivity, inclination, and ability. *Sensitivity* concerns whether a person notices occasions in the ongoing flow of events that might call for thinking, as in noticing a possibly hasty causal inference, a sweeping generalization, a limiting assumption to be challenged, or a provocative problem to be solved. *Inclination* concerns whether a person is inclined to invest effort in thinking the matter through, because of curiosity, personal relevance, … habits of mind, and so on. *Ability* concerns the capability to think effectively about the matter in a sustained way, for instance, to generate alternative explanations for the supposed causal relationship.
>
> (Perkins & Ritchhart, 2004: 358–9)

Perkins has subsequently argued that we should be encouraging students to go 'beyond understanding'. Academic understanding, in itself, may be of little value unless it is used actively, looking out for and recognizing opportunities to make use of it in everyday life;

in problem finding as well as problem solving, and in designing specifications as well as designing to specifications. And in education, we need to invite students to discover, not just perform, leading to a culture of opportunity, rather than a culture of compliance. In Chapter 4 we shall be extending the notion of a thinking disposition more directly into the sphere of student learning by introducing the idea of a *disposition to understand for oneself*.

An alternative research paradigm

This chapter has been mainly following the evolutionary path in educational psychology from behaviourism, through descriptions of the memory and information processing, and the identification of individual differences in ability and personality, towards the more integrative conception of dispositions. All this research is essentially positivist, seeking the *causes* of differences in learning outcomes, but educational psychology has also followed an importantly different line of development, originating in the work of Vygotsky. He saw learning in terms of the interactions between young people and adults in social contexts. Out of this seminal work, an alternative view of human learning has developed, seeing human actions as dependent on their intentions, on their interpretations of their experiences in the everyday social world and on the language through which those experiences are discussed. Bruner has argued that the most important intellectual activity is 'meaning-making', which is inevitably social, depending on culturally acquired ways of thinking and on social conventions about the aspects of phenomena or events that are seen to be salient. He argued that psychology

> must venture beyond the conventional aims of positivistic science with its ideals of *reductionism, causal explanation* and *prediction*. ... To reduce meaning or culture to a material base, to say that they 'depend', say, on the left hemisphere, is to trivialize both in the service of misplaced concreteness. ... To insist upon explanation in terms of 'causes' simply bars us from trying to understand how human beings interpret their worlds and how *we* interpret *their* acts of interpretation. ... The study of human mind is so difficult, so caught in the dilemma of being both the object and the agent of its own study, that it cannot limit its inquiries to ways of thinking that grew out of yesterday's physics.
>
> (Bruner, 1990: xii–xiii)

As we shall see in the next chapter, much of the research into student learning and university teaching has followed a research approach that is both cognitive and social, focusing on learning within specific academic contexts, as it has tried to understand the differences in how students tackle their academic work and the reasons for those differences. Seeing human action within this perspective, however, does not mean that we have to abandon the findings of positivist research. The cognitive processes and individual differences discussed earlier are still important to bear in mind, underpinning, as they do, the more directly relevant research into student learning.

In his 1990 book, Bruner stressed that meaning has to be constructed by the individual in relating new experiences both to previous knowledge and to earlier experiences within a social setting. But in academic study, students' understandings have to be sufficiently in line with the requirements of the teachers to satisfy assessment criteria. In some subject areas students will be encouraged to arrive at their own interpretations, but in all subject areas understandings have to be expressed within an accepted academic discourse, using the concepts and ways of treating evidence that are characteristic of the discipline being studied. And each discourse amounts to a contrasting culture into which students have to be gradually inducted. In the traditional university disciplines, the ways of thinking are derived, historically, from the underlying philosophy of the Western world, involving causal explanations and critical reasoning, which can be alien to students coming from very different cultural backgrounds. With the substantial influx of overseas students into universities in Europe, North America and Australia, there needs to be a greater awareness of the ways of thinking and acting that are found in other cultures, and the implications these have for university teaching.

Concluding summary

The simplest forms of learning depend on attention, practice and feedback, and these are also important in more complex forms of learning. The two main learning processes established from psychological research are rote learning and meaningful learning. Rote learning transfers information in an unchanged form into long-term memory, whereas meaningful learning creates connections with knowledge already held there, often across quite varied topics. Meaningful learning thus not only takes in information, it can integrate it into a personal understanding.

There are definite limits in how many pieces of information we can process together within the short-term working memory and these constraints also affect the number of interrelationships we can handle in thinking about concepts. Concepts have agreed defining features, and for simple concepts these are readily recognized through repeated experiences in varying contexts. But abstract and complex concepts are often understood in quite different ways – people develop individual *conceptions* that depend on their own prior knowledge and experience.

Some students have considerable difficulty in developing conceptions that match the 'target understandings' expected by university teachers. Certain abstract concepts may prove difficult for a substantial proportion of students, and yet these often have a crucial part to play in understanding the subject, acting as *threshold concepts* that open up the subject in important ways. Students can be helped with such concepts or other difficult topics by focusing on their *critical features* and how those aspects relate to each other.

There are many influences on the effectiveness of learning. Here we have surveyed some of the more basic ones – previous knowledge and experience, abilities and learning styles, personality and motivation – while the idea of thinking dispositions suggests how several of them can work together to bring about learning and understanding. The final section introduced an alternative approach to educational psychology that describes learning as being social in origin, with meaning-making being a major activity, and this underpins much of the research into student learning we shall be coming to next.

Further reading

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3 How Students Learn and Study

As we have just seen, the nature of research into student learning changed in the mid-1970s, and now we will see how the field has moved on since then. This different approach introduced a broader perspective on learning, one that saw individuals as having their own intentions and seeking to make sense of the world for themselves within a social setting. This approach relied much less on the concepts and categories developed by theorists from other disciplines and, instead, sought explanations based on the experiences of students. Marked differences were found in how students studied and in the reasons students gave for studying in those ways, which then provoked questions about how existing teaching methods affect student learning, as we shall see in Chapter 5.

Concepts describing student learning

The concepts come with different explanatory breadths, with broader constructs describing *identity*, *orientations to learning*, *conceptions of knowledge* and *conceptions of learning*, and the more narrowly defined concepts, covering *approaches to learning and studying*, which focus on the specific subject matter being learned and the study tasks that students undertake. The great advantage of these concepts is that they relate to aspects that are immediately recognizable by both staff and students, and that they are all open to change, being influenced by students' experiences at university as well as by the teaching they meet. Although inevitably oversimplifying a more complex reality, the concepts have not only proved powerful in describing and explaining salient differences in how students learn and study, they have led to a clearer understanding of how different types of teaching and assessment affect the quality of learning being achieved.

Identity and self-confidence

One of the most important influences on how students go about learning is their previous experience, not just of education, but also in the family and with their peers. Social and cultural attitudes are formed early and have a continuing influence on how students adjust to higher education. Interviews with students have shown the importance of their feelings about themselves – their self-confidence in the role of student and in social interchange – and their allegiances to their individual social and cultural backgrounds. The term 'identity' has been used widely in sociology to describe our sense of self within the varying social situations we find ourselves in and the differing roles we have to play. This sense of self develops through comparing ourselves with other people and is strongly dependent on how we are seen and described by parents, partners and friends – our *significant others*. In schooling, and higher education, teachers can also affect the development of identity quite strongly, and in particular the sense of identity as a student and feelings of self-confidence or the lack of it.

Although the term 'identity' sounds as if it were a single characteristic, we actually see ourselves in several quite distinct ways, depending on the situation we are in and the role we are expected to play. Sociological descriptions often relate identity primarily to group membership (such as social class or ethnicity) or to power relationships, and that is certainly an important aspect of the sense of self, but it is only one aspect. There is also a tendency to stress changes in identity over time, and yet people also have a strong feeling of continuity about who they are, sustained by internal or shared narratives about their life history.

Identities do not change easily or quickly, and so the adaptations students have to make as they enter higher education often prove difficult and take time. If they have come straight from school, young people are still in the process of establishing their social and sexual identities, while at the same time trying to discover how the demands of teaching and learning at university differ from those experienced at school: they may also be living away from home for the first time. Overseas students are also having to learn how to live in a different society, as well as possibly meeting very different expectations and forms of teaching than those in their own country. And mature students, whatever their origins, often have to juggle multiple demands on their time, with work and family commitments. How students settle into their new role as students, and the self-confidence or otherwise they have in that role, markedly affects their academic progress, particularly in the early stages of a degree course.

The composite narrative in Table 3.1 has been built up from interview comments by mature students to illustrate how personal circumstances may affect students' perceptions

Table 3.1 Mature students' comments about their experiences of studying at university

The whole set-up of the thing, the buildings, trying to find out who people were, where you should be, [was difficult]. I know everybody's an adult when they come to university but I just felt, 'Oh, God!'. When you walk in you haven't a clue what building or where to go for them. … I realized before I came that everything would be unfamiliar and that I would need to get used to how things worked. Coming up to the essays, I just felt that I wasted a whole lot of time, getting the wrong kinds of information, getting readings that I didn't really need. … You [have to] do a lot more yourself and there's nobody to spoon-feed you, as such. It's a bit of a shock to the system, but you just have to adapt quick! … That's the big difference; … you're expected to do it yourself, and the help you get is minimum …

It's a constant struggle between looking after the kids, work and study. I sometimes have to do my university work from eleven at night till four in the morning. Then I have a quick sleep, then breakfast, get the kids to school, and then off to work: that's what a day's like for me. … Because you don't have a lot of time, you've got to work out if it is worth going to that, or is it something I'm never going to use: you really have to be quite selective …

Dipping in confidence [early on] seems to be a very common thing, but I came back in term two with a renewed determination that ultimately this is what I want to do, and some bits you just have to work through and you might not particularly like, but you've got to achieve it and that's it. … This term I'm quite happy to join in tutorials; last term it made me nervous, but I just had a word with myself and now I feel better.

Source: Composite of selected quotes from interviews analysed by Viviene Cree, Hazel Christie, Jenny Hounsell, Velda McCune and Lyn Tett, at the University of Edinburgh.

of their university experience, as well as their attitudes and their self-confidence about themselves as learners. Although these were all mature students who have additional difficulties in adjusting, other students also struggle to make sense of their initial experiences of university, often with much less help than they feel they need in those early stages.

Personal and vocational aspirations

The sense of self in university or college becomes bound up with the reasons for continuing one's education and often with a vocational goal that can strongly affect the emerging sense of adult identity. It is hardly surprising to find that students' aspirations have a major influence on how well they do, but it is important to be clear what reasons are typically given. Liz Beaty introduced the idea of a *learning orientation* which described not just reasons students gave for attending university, but also the continuing, and changing, attitudes and feelings they expressed towards their studying. The contrasting orientations she identified represent the four main social functions of higher education – academic, vocational, personal and social. She suggested that each of these could be separated into two distinctive kinds of interest in the courses being taken – extrinsic and intrinsic.

> The idea of an orientation assumes that students have an active relationship with their studying, [with] … success and failure judged in terms of the extent to which students fulfil their own aims … [and which] may change over time. The analysis of learning orientation … sets out to … show the implications of different types of orientation for the approach a student takes to learning. … It is important to recognize that the categories and sub-categories used to describe learning orientations are simply an analytic framework and not descriptions of the types of student found in the study. In fact, any particular student's orientation [at any one time] will usually be a complex mix of two or more of these [categories].
>
> (Beaty, Gibbs & Morgan, 1997: 76–7)

The warning about not using categories to label students applies to all the qualitative research described in this chapter, as students have mixed motives, and ways of studying alter according to circumstances. The analytic framework shown in Table 3.2 can be used to make sense of the aspirations and attitudes of individual students, and also to map the general pattern shown in a particular class or intake. Beaty went on to suggest that students establish an implicit *learning contract* with themselves – what they want to achieve while at university – and this changes over time as students adjust their expectations to the level of grades they are obtaining and how interested they are in their academic work.

Conceptions of knowledge and learning

William Perry in Harvard carried out some of the earliest interview research with university students. He was interested in how they developed intellectually while at university or college, his analyses revealing an important trend in how they were thinking about the

Table 3.2 Categories describing differing learning orientations

Orientation	Interest	Aim	Concern
Vocational	Intrinsic	Training	Relevance of course to future career
	Extrinsic	Qualification	Recognition of qualification's worth
Academic	Intrinsic	Intellectual interest	Choosing stimulating lectures
	Extrinsic	Educational progression	Grades and academic progress
Personal	Intrinsic	Broadening or self-improvement	Challenging, interesting material
	Extrinsic	Compensation or proof of capability	Feedback and passing the course
Social	Intrinsic	Making a contribution to society	Courses focusing on improving social or personal conditions
	Extrinsic	Having a good time	Facilities for sport and social activities

Note: The social intrinsic category was not in the original study but was found in subsequent research.
Source: Beaty, Gibbs & Morgan, 1997: 77.

nature of knowledge – their *conception of knowledge*. Students entering university tended to see knowledge as firmly established and conveyed to them by teachers or in books. Only gradually did they begin to understand how knowledge changes over time, and so recognize its provisional nature. The starting point of Perry's developmental scheme involved seeing knowledge as either 'right' or 'wrong' (dualistic) and then moved, first, towards a recognition of how evidence is used to reach conclusions, and beyond that to an acceptance that knowledge is still developing and open to challenge, and thus ultimately uncertain and socially constructed (relativism). The initial recognition of relativism takes students

> over a watershed, a critical traverse in our Pilgrim's Progress. ... In crossing the ridge of the divide, ... [students] see before [them] a perspective in which the relation of learner to knowledge is radically transformed. In this new context, Authority, formerly a source and dispenser of all knowing, is suddenly authority, ideally a resource, a mentor, a model, and potentially a colleague in consensual estimation of interpretations of reality. ... [Students] are no longer receptacles, but the primary agents responsible for their own learning.
>
> (Perry, 1988: 156)

Subsequent research has largely supported Perry's developmental scheme, but has suggested gender differences in the extent to which the learning is seen in more personal or impersonal terms and has also led to debates about whether his scheme should be seen as applying generally, or as differing across subject areas. Nevertheless some of the learning 'blocks' that students come up against while studying are caused by their struggles in coming to terms with the nature of disciplinary knowledge. And it is only towards the end of a degree course that students begin to discern, in a conscious and reflective way, how evidence and reasoning are being used to create new knowledge. The slowness in this 'pilgrim's progress' is often not sufficiently appreciated by academics who are already comfortable with the knowledge in their specialism, but the finding reminds us how important it is not to overestimate students' grasp of the subject in the early stages of a degree.

Subsequent interviews by Roger Säljö in Gothenburg also showed important differences in how students think about the nature of learning. He asked adults to explain what they meant by 'learning' and found that these *conceptions of learning* also showed a developmental trend from simpler to more complex views. At the simplest level, learning was seen as taking in bits of knowledge that could then be given back later on, in the same form. This meant that learning was being equated with memorizing or rote learning. A slightly more advanced view recognized that learning involved acquiring knowledge for future use. This conception seemed to be carried over from experiences in school and seemed to be quite resistant to change as students entered higher education. However, a significant change came about when learning was seen to depend on understanding the material for oneself, and so coming to see aspects of the world in importantly different ways. Subsequent research suggested an even greater sense of personal involvement, with learning involving a change in oneself as a person.

In the later stages of this intellectual and ethical development an important additional change takes place, with students realizing that, for some purposes, rote learning is still necessary, even though conceptual understanding is the main goal at university. In other words, memorizing often plays a supportive role in building up initial understanding, but also later on, ensuring that understanding is firmly lodged in the memory. In general, the more sophisticated views of academic knowledge and learning tend to be broader, more inclusive and more coherent than the less sophisticated ones, and this also applies to the ways students approach their studying, and even to how academics see their role as university teachers, as we shall see in Chapter 5.

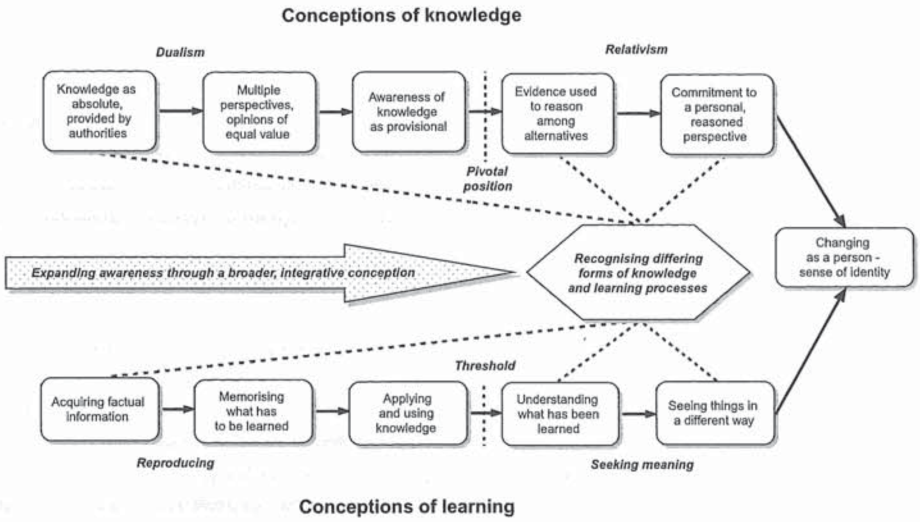

Figure 3.1 Categories of conceptions of knowledge and learning

There is a clear parallel in the developmental trend shown in the work of Perry and Säljö, and this is illustrated in Figure 3.1. Both sets of categories show an increasing sophistication in the conceptualizations of knowledge and learning and also identify critical points at which students' conceptions appear to change radically – the pivotal position of acknowledging relativism in knowledge and the threshold through which learning at university level comes to be seen as seeking meaning for oneself. The sets of categories are essentially hierarchies in which the more sophisticated conceptions incorporate aspects of the earlier conceptions, add others and also show a growing awareness of the implications of the different ways of seeing knowledge and learning. This recognition then shows itself in a greater awareness of the students' own ways of studying.

Approaches to learning

While conceptions of knowledge and learning are rather abstract notions, approaches to learning and studying relate very directly to students' experiences at university. The idea originated with Ference Marton and his research team, as we have already seen. Students had been asked to read an academic article and were then asked questions about it. First of all, they were asked to describe the author's main message, with responses varying from a complete misunderstanding of the argument to a good grasp of it, with some cogent additional comments. They were then asked how they had gone about the task, with the interview transcripts then being analysed to discover possible reasons for different levels of understanding. What emerged was the dichotomy in *approaches to learning*, distinguishing a *deep* from a *surface* approach. In the words of the researchers:

> All our readings and re-readings, our iterations and reiterations, our comparisons and groupings, finally turned into an astonishingly simple picture. We had been looking for the answer to the question of why the students had arrived at those qualitatively different ways of understanding the text as a whole. What we found was that the students who did not get 'the point', failed to do so simply because they were not looking for it. The main difference we found in the process of learning concerned whether the students *focused on the text itself or on what the text was about*: the authors intention, the main point, the conclusion to be drawn.
>
> (Marton & Säljö, 1997: 43)

The approach essentially depends on the student's intention. Students adopting a surface approach see the task as no more than second-guessing the examiner, they decide what type of questions they expect and then trawl through the article looking for likely questions. They then memorize just those pieces of information and are totally floored by any question that demands an understanding of what they have read. Students adopting a deep approach set about the task with the intention of understanding it for themselves which, of course, makes it much more likely that they will grasp the author's meaning. Other research showed that both the deep and the surface approach varied in terms of how much effort the students had put into that approach, making four categories in all (see Table 3.3).

Table 3.3 Students' descriptions of their approaches to learning

Approaches to learning adopted in reading an academic article

Surface passive – Level of understanding = mentioning
In the beginning I read very carefully, but after that I hurried through it. I lost interest (and) I didn't think about what I was reading.

Surface active – describing
In reading the article I was looking out mainly for facts and examples. … I thought the questions would be about the facts in the article (and) … this did influence the way I read: I tried to memorize names and figures quoted … I tried hard to concentrate – too hard – therefore my attention seemed to be on 'concentration' rather than on reading, thinking, interpreting and remembering.

Deep passive – relating
I read it in a casual, interested manner, not being influenced by the fact that I was to be questioned, mainly because I didn't expect (to be asked) any details of the article. Consequently, I read with impartial interest – extracting the underlying meaning, but letting facts and examples go unheeded.

Deep active – explaining
Whilst reading the article, I took great care to understand what the author was getting at, looking out for arguments, and facts which backed up the arguments. … I found myself continually relating the article to personal experience, and this (helped me to understand it). The fact of being asked questions on it afterwards made my attention more intense. (*From Entwistle, 1988: 78*)

Approaches to learning in electronic engineering

Surface approach
I suppose I'm mainly concerned about being able to remember all the important facts and theories that we've been given in the lectures. We are given an awful lot of stuff to learn, so I just plough through it as best I can. I try to take it all down in the lectures, and then go over it until I'm sure they won't catch me out in the exams. … (With the problem sheets) the first step is to decide which part of the lecture course the problem comes from. Then I look through my notes until I find an example that looks similar, and I try it out. Basically, I just apply the formula and see if it works. If it doesn't, I look for another example, and try a different formula. Usually it's fairly obvious which formula fits the problem, but sometimes it doesn't seem to work out, and then I'm really stuck.

Deep approach
It is not easy, you know. There is a great deal to cover, and I am not satisfied unless I really understand what we're given. I take quite full notes, but afterwards I go through them and check on things which I'm not clear about. I find that working through the problem sheets we're given is a good way to test whether I know how to apply the theory covered in lectures, and I do that regularly. Once you realise what lies behind the problems – that's the physics of it and what makes it a problem – then you can do them. You get a kick out of it too, when it all begins to make sense. Applying the right formula is not difficult, once you know you are on the right lines. (*Adapted from Entwistle et al., 1989*)

Seeing what students themselves actually said in interviews may help to clarify the meaning of these important categories. The first set of extracts in Table 3.3 illustrates the four categories of approach and effort shown in the original research reports, along with the levels of understanding that students showed after reading the article. The second set illustrates how deep and surface approaches are seen in everyday studying, when students are asked how they go about tackling their work – in electronic engineering in this instance.

The distinctive intentions associated with approaches stem from different motives and lead to contrasting processes of learning – essentially rote/reproductive or meaningful learning. Intrinsic motivation and interest in the subject are more likely to lead to a deep approach, particularly if these intentions are supported by a sophisticated conception of learning. With this combination, students will generally try to understand for themselves, leading them to look for relationships between ideas and also to check the logic of the argument and the evidence supporting it. But to be effective, a deep approach does depend on having adequate prior knowledge to link the new ideas to, and also the necessary reasoning ability to make sense of those links.

In contrast, seeing learning in terms of building up bits and pieces of knowledge to give back to the teacher almost inevitably leads to an intention to memorize or reproduce material. And if this develops into a habitual way of learning, without considering its consequences for understanding the subject matter, the effect on studying is damaging. A surface approach often stems from, but also creates, a lack of interest in the subject, no matter how much time and effort the students may put into studying. The effort is almost always misplaced because the requirements of the task are not fully appreciated. Moreover, a surface approach is often associated with higher levels of anxiety and fear of failure as the students begin to realize that their attempts at studying are not meeting academic requirements. There can then be a downward spiral of demoralization that leads to less effort being put into the work, as interest and self-confidence drain away.

Although the terms 'deep' and 'surface' were chosen to describe the specific instance of reading an academic article, subsequent research showed that they can be applied equally well to the way students take notes in lectures, write essays and prepare for examinations: indeed, to whatever task the students meet. But that does not mean that any individual student will use the same approach for every assignment, or in every course they take. Marton emphasized that approaches should be seen as essentially 'relational', in other words they necessarily depend on how the student interprets a particular task: does it seem interesting, important and worth doing, or not. It is thus quite wrong to characterize students as 'deep learners' or 'surface learners'; approaches certainly change as students meet different types of teaching, as we shall see later on. And yet there remains an element of consistency in the approach, which may reflect personality differences or vocational aspirations, and that leads some students to adopt surface approaches habitually, while others generally seek personal understanding. Most students, however, lie between these extremes, so that even where an approach proves to be relatively consistent, students will still show different reactions to individual teachers and to specific courses, so approaches are essentially variable.

Table 3.4 sets out the defining features of approaches to learning as they have emerged from the research, but the danger in looking through these lists of characteristics is that they may come to be seen as polar opposites. In earlier descriptions, that tendency was marked, but the current meaning introduces an important qualification.

Table 3.4 Defining features on approaches to learning

Deep Approach	*Seeking meaning*
Intention – to understand ideas for yourself	by
Relating ideas to previous knowledge and experience Looking for patterns and underlying principles	
Checking evidence and relating it to conclusions Examining logic and argument cautiously and critically Using rote learning where necessary	
	And as a result
Being aware of one's own understanding as it develops Becoming more actively interested in the course content	
Surface Approach	*Reproducing*
Intention – to cope with course requirements	by
Treating the course as unrelated bits of knowledge Routinely memorizing facts or carrying out set procedures Studying without reflecting on either purpose or strategy	
	And as a result
Finding difficulty in making sense of new ideas Seeing little value or meaning in either the courses or the tasks set Feeling undue pressure and worry about work	

Source: Adapted from Entwistle 1997, Table 1.1:19

Students with an intention to understand, and who have a sophisticated conception of learning, will realize that memorizing is an appropriate learning process for some tasks – like remembering the names of fossils or plants, or historical dates – and that this rote-learned material can then be used, in subsequent learning, to develop conceptual understanding. Some students consistently adopting a deep approach may also feel undue pressure and worry about work, as they try to understand complex abstract material for themselves.

In a forthcoming publication, Carol Bond is arguing that we should see progressions from surface to deep approach as representing not separate categories, but rather an improving awareness by students of which learning processes are most appropriate for specific purposes, with a gradual development taking place paralleling those shown in conceptions of learning (see Figure 3.1). She has identified experiences of learning that describe, initially, a preponderant use of reproductive learning, merging later with an emphasis on acquiring knowledge, before gradually incorporating the processes involved in developing, first, a passive form of understanding to satisfy a lecturer and, finally, an active form of understanding that involves transforming previous ways of seeing the world, and oneself in relation to it. We shall meet this final form again in Chapter 4 in looking at the *disposition to understand for oneself*.

The main difference between deep and surface is in the *intention* – either to reproduce the material presented or to understand it for oneself, and that is a dichotomy. It is also important to realize that the generalized description of the processes of learning involved

Table 3.5 Deep approaches shown in contrasting subject areas

Physics	I suppose I'm trying to imagine what the experiment is about, in a physical sense, sort of get the picture. ... I was looking for pattern [in the results] which I could relate to the theory. I knew what was supposed to be happening and I was looking out for it happening in the graph – fortunately it did.
Engineering	You have to go through quite a few different designs to get the right one. I'm always thinking about what I can put into the conclusion when I'm writing about a project and I'll try to show what I have understood from the project.
Psychology	I started to realize that the English I'm doing as an option is very closely connected to psychology – the novelist is just more artistic – and when I realized they were so close, then I saw how interrelated all the topics in psychology were and that putting your own pattern on an essay would probably make it better – and it did – it's just a better way of learning.
History	There are always underlying themes in any period of history, and if you can sort of pick out those themes and really understand what was going on and what it was all about, then you've got a good chance of discovering it on an equal basis to the tutor or in an exam.
English	The work demands, in a way, a completely different sort of intelligence. For us, it's more interpretation, analysis, penetration into the material – you have to see implicit meaning. ... For example, seeing whether Tennyson compromised his art to the age or whether he wrote what he really wanted to write. That's what I'm thinking about all the time as I'm reading it.

Source: From Entwistle & Ramsden, 1983: 142–5.

in a deep approach cannot apply in the same form to each subject area. The way understanding is developed in contrasting disciplines is so different that what is involved in a deep approach is bound to vary (as illustrated in Table 3.5). In thinking about how best to support a deep approach by students, it is important to clarify, for each subject area, and even for each topic, the processes of learning that are necessary to develop deep conceptual understanding. That will then be the most useful definition of a deep approach in that context.

Even though there are these major differences in the specific processes of learning involved in contrasting disciplines, the common features shown in Table 3.4 can still generally be seen in the approaches adopted by students across subject areas. Besides the contrasting intention, students adopting a deep approach will be looking for patterns and connections, and viewing the subject as a whole; they will also be alert to exceptions, looking for alternative interpretations and be aware of the types of learning the subject requires of them.

Organized effort

The terms 'deep' and 'surface' apply to learning and were observed originally within a naturalistic experimental setting, as we saw earlier. Although the task was one commonly met by students, it lacked one crucial ingredient – formal assessment. In the work done subsequently with Paul Ramsden, we asked students how they went about their everyday

Table 3.6 Items used to identify the 'organized effort' put into studying

Organized studying
- I organize my study time carefully to make the best use of it.
- I carefully prioritize my time to make sure I can fit everything in.
- I work steadily during the course, rather than just leaving things until the last minute.
- I'm quite good at preparing for classes in advance.

Effort
- I try really hard to do just as well as I possibly can.
- I generally put a lot of effort into my studying.
- I generally keep working hard even when things aren't going all that well.
- Whatever I'm working on, I generally push myself to make a good job of it.

Source: From the ETL project website – http://www.etl.tla.ed.ac.uk/publications.html.

studying, which extended the notions of deep and surface approaches to a range of other academic tasks besides reading, such as learning from lectures, writing essays and revising for examinations. And the effect of assessment then became very clear, and required an additional category to describe it – a *strategic approach to studying* that involved the intention to achieve high grades, driven by either achievement motivation or a sense of responsibility.

Recent work with Velda McCune, however, has suggested that use of the term 'approach' is not really appropriate. The questionnaires used to measure strategic behaviour defined it in terms of systematic organization of studying, time management, effort and concentration. The determination to do well is still a characteristic of organized effort, but the competitive element no longer appears to be consistently strong. Typical items used in the questionnaires to cover this aspect of studying are shown in Table 3.6 to clarify its specific meaning.

Organized effort can be applied to either a deep or a surface approach to learning. Combined with a surface approach it has often served students well prior to entering university and may well still lead to satisfactory levels of performance early in a degree course. But later on it will become increasingly ineffective, as tasks and assessment criteria change. When understanding becomes a more important criterion in assessment, only a deep approach combined with organized effort will be consistently rewarded.

Recently, there has been growing concern in British universities about an imbalance in the reasons given for student failure, with poor teaching or inadequate supervision often being seen as the culprits. Of course that may be true in some instances, and a contributory cause in others, but the legal proceedings, brought by some students against universities or colleges they accuse of being responsible for their failure, have led to attempts to redress the balance. Some universities have been considering formal contracts with students that require attendance at classes and satisfactory completion of course work. Other institutions have been introducing students to the idea of *responsible learning* right from the beginning of the course, with a moral imperative to put sufficient time and effort into their independent learning. Students are then regularly reminded why study organization, time management, effort and sustained concentration are their own responsibility. Of course, lecturers, too, have a moral and contractual responsibility for helping students to learn, but in the end it is the students who have to do the learning.

We shall come to the role of assessment in affecting approaches to learning and studying in Chapter 8, but it is important to note here just how strongly assessment works as a 'driver', affecting how much effort students put into their studying and what direction that effort takes – towards reproducing or understanding. Some forms of assessment are likely to increase a deep approach in most students, while others are more likely to evoke a surface approach, in ways we shall explore later.

Cultural differences in learning and studying

The differences described so far come from research into the relatively homogeneous student intakes found in British higher education until comparatively recently. Now, not only are there many more mature students entering higher education, but also increasing numbers of students from other countries. Such students bring with them not only experiences of a different educational system and ways of teaching, but may also have quite different cultural expectations about the nature of academic learning. It is, of course, impossible to generalize about overseas students, but it is clear that there are marked variations in previous educational experience, even within Europe. For example, students coming from the southern countries are likely to have experienced more didactic approaches to teaching than those from Northern Europe. Students from the Middle East and Far East may rely more on rote learning than in Western countries, and may also be used to an authoritarian climate in educational institutions. As a result such students are more likely to see what university teachers and academic textbooks present to them as 'the truth', which has to be learned uncritically, but they also will show more respect for their teachers and see learning as depending mainly on their own efforts.

There are cultural differences in the way that memorizing is used, with it being an integral part of the process of developing understanding within many Eastern cultures. An example comes from the extensive research on student learning carried out in Hong Kong.

> Although Hong Kong is a modern society substantially affected by Western views, it is still influenced by traditional Chinese values. There is no formal Confucian teaching in schools, and yet traditional beliefs still prevail in child-rearing practices. The Confucian heritage emphasises the virtue of effort and 'filial piety', which includes respect for teachers as purveyors of authoritative knowledge. The belief that academic success comes from effort, and that knowledge is presented for students to learn, puts a premium on memorization in learning, even when personal understanding is sought. From a very young age, students in Hong Kong are expected to adopt rote memorization as a routine way of learning. ... By the end of secondary school, memorization and understanding seem to have become part of a single process of learning; ... students tend to see memorization and understanding as often taking place at the same time; they believe that if they really understand the material, ... [that] will help them to memorize without much effort. ... This form of combined understanding and remembering has been labelled *deep memorising*.
>
> (Adapted from Au & Entwistle, 1999)

This description should not be taken to suggest that Chinese students do not develop critical thinking, but rather that their respect for teachers and academic authority means that they are more cautious in challenging interpretations until they have sufficient well-established knowledge.

Students with disabilities

Whereas, in the past, students with disabilities were effectively excluded from entering higher education, government legislation in Britain has meant that universities and colleges have had to adjust their facilities and teaching approaches to cater for at least some forms of disability. And these policies mean that university teachers have to be equally inclusive in their attitudes and methods of teaching.

In a recent study of the experiences of disabled students within the ESRC Teaching and Learning Research Programme (TLRP), staff were found to differ markedly in their readiness to make special arrangements to allow these students to learn effectively. Usually, the university has to put in place procedures to allow, for example, Braille translations of lecture notes, provision of special laptops, and allowing extra time for students with dyslexia. But these arrangements are not flexible enough to take into account differing degrees of disability, and so university teachers have to be willing to make additional adjustments to their teaching, and to discuss individual requirements where necessary. The researchers were, however, concerned that special provisions draw attention to disability, whereas flexible arrangements in teaching and learning introduced more generally would benefit all students, and so avoid singling out individuals. However, the level of flexibility necessary for this may be impossible to achieve, leaving a mixed approach as all that can be achieved. The types of adjustments made in the universities taking part in this study included:

> *Individual assimilations* ... – special arrangements made for [various categories of] disabled students to help them cope with existing learning, teaching and assessment practices, [such as] being given extra time or a separate room in exams, or being provided with a note-taker. ...
>
> *Alternative arrangements* ... are provided for particular disabled students. Examples include a virtual field course for a student with a mobility impairment, and a viva ... as an alternative [to a written] assessment.
>
> *Inclusive arrangements* ... are provided for all students. One example ... is to make alternative assessments designed to test the same learning outcomes available to all students, [and] the provision of handouts before lectures.
>
> (Healy et al., 2008)

Concluding summary

This chapter drew on research carried out in universities and colleges to present a series of concepts that describe students' experiences of learning and studying in higher education. The broadest concepts are 'identity' and 'aspiration', along with conceptions of both knowledge and learning. Students entering university have to adjust to the social situation, as well as to different ways of learning, which can affect their sense of identity and self-confidence. They also have differing reasons for studying, and varied conceptions about the nature of academic knowledge and how it should be learned. These conceptions develop along recognizable paths during the degree course, beginning with the uncritical acceptance of the new ideas and gradually coming to an appreciation that knowledge has to be judged in terms of the strength of the evidence and ultimately in relativistic terms. In the early stages of a degree course, however, students' ideas about knowledge and learning may be far removed from what university teachers would hope them to be, and limited conceptions make it difficult, if not impossible, to learn and study in effective ways.

One of the most influential concepts describing student learning distinguishes between deep and surface approaches, showing how students' intentions affect how they learn, and thus the levels of understanding they reach. Surface approaches involve an intention to reproduce the learning material, with only limited engagement, and are found in much the same form across subject areas. Deep approaches depend on the intention to understand for oneself, involving relating ideas and using evidence, but the specific learning processes needed depend on the discipline. Each of these approaches can be carried out with differing levels of self-confidence and with varying amounts of organized effort. These other aspects interact with the approach to affect what is learned.

Although some students can reasonably be called 'deep learners' or 'surface learners' because of their relatively consistent use of one approach or the other, approaches more often vary, depending on reactions to both the subject matter – whether it is perceived to be relevant and interesting – and the context – whether that is supportive or anxiety provoking. And later on we shall find that experiences of teaching and assessment have important effects on how students go about their learning.

The burgeoning numbers of overseas students in British universities has increased the importance of recognizing the effects of differing educational systems and contrasting cultural experiences on students' learning. Universities are also making it easier for disabled students to take degree courses, which depends not just on 'reasonable adjustments' to general procedures, but also on university teachers being more sensitive to any special arrangements that may be needed for individual students.

Underlying much of this chapter has been a stress on making sense for oneself of the academic content of a course, and that emphasis will continue in the next chapter. Starting with students' experiences of developing their own personal understanding, we shall go on to explore 'target understandings' – what university teachers expect students to acquire in terms of knowledge, skills and understanding.

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Analysis and design of didactic situations: a pharmaceutical example

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A 29-year-old man took his allergy medication twice daily for a year. One day, he drank two glasses of grapefruit juice before he took his medicine. He died shortly after. The autopsy showed increased levels of the drug in his body. On the basis of this case, a teaching session on recognition and conversion of pharmaceutical drugs in the human body is described. The lesson is analysed on the basis of the Theory of Didactic Situations; a theory that was originally developed within the didactics of mathematics didactics. The authors argue that this theory can be used when analysing and designing teaching situations in many subjects other than mathematics (e.g. chemistry and pharmaceutical subjects) at all educational levels.

Introduction

Characteristic of teaching at university and upper-secondary-school level is that this kind of teaching aims at students gaining specific knowledge. At upper-secondary-school level this knowledge (learning objectives and core material) is specified in the curriculum for each subject, and it is up to the individual teacher to decide how to plan his or her teaching over a longer period. Technical and natural science subjects at university level are often taught by a group of teachers, and the knowledge aimed at is typically specified in course plans prepared by the course manager(s) (and approved by the study board). Numerous 'rank-and-file' teachers in technical and natural science subjects are responsible for smaller parts of the course, however an overall specific academic agenda is set for the teaching as a whole.

We may ask "How can we plan teaching that is both challenging and motivating for the students, and at the same time ensure that they actually learn what they are supposed to learn?" Of course, there are many answers to this question, as well as several theories about learning and teaching that can shed light on this. In this article we focus on one of these theories, the theory of didactic situations (TDS). As an example, we outline a lesson about recognition and conversion of pharmaceutical drugs in the human body, and on the basis of this lesson, we describe several fundamental principles from TDS that we believe can be useful if we are to achieve the goal of offering challenging and motivating teaching when analysing and planning teaching. The theory of didactic situations was developed by Guy Brousseau, a researcher within the field of mathematics didactics

(Brousseau, 1997, also see Winsløw 2006, 2006b). Brousseau based his theory on the study of mathematics teaching (especially at primary and secondary level), however we will illustrate that his theory can also be applied in many other technical and natural science subjects (e.g. chemistry and pharmaceutical subjects), and that his theory is also useful when dealing with university teaching.

We believe that our description and analysis of a specific lesson offers a concrete example of the theory's applicability when analysing teaching situations. Brousseau's theory is not only applicable when *analysing* teaching situations (our focus here), but can also be used *to design* teaching situations. For example, the teaching material and teaching plans used today are soon to be updated, and it is in this context that TDS can be used. Thus analysis and design are usually two sides of the same coin, and we hope that readers will also see the potential of the theory when designing teaching, even though this article focuses on analysing teaching.

Description of the lesson

The following example is based on a teaching session on the *recognition and conversion of pharmaceutical substances in the liver*.

In principle, the lesson includes an introduction to the subject and the students are asked to work on an overall assignment. In the process, the students are given two shorter assignments that together deal with the central elements of the subject (criteria for recognition and conversion of pharmaceutical drugs). The teaching as described here was tested in connection with the course *Introduction to University Teaching,* carried out at the Department of Science Education and the Faculty of Pharmaceutical Sciences in November 2005. As a central part of this course, participants (typically assistant professors and PhD students) plan and teach a lesson lasting approximately 25 minutes. The course participants had very different academic backgrounds, and therefore the level was set to match the highest level for chemistry/biology at upper secondary school or the first year of university. In connection with the course *Structural Chemistry*, a fourth-year subject in the MSc programme in pharmaceutical sciences, the same subject was taught as described here and on the basis of the same principles (however at a higher academic level).

The knowledge aimed at

Upon ingestion of a pharmaceutical drug, the drug is absorbed into the body and delivered to the part of the body where it has an effect. However, it is important that the drug can be broken down in the body again, after it has done its job. This typically happens through a number of various reactions that convert the drug into substances that the body can more easily break down. Drugs can be converted via a number of enzymes that are found in the liver and other organs. In order for a substance to be converted by liver enzymes, it is crucial that first the drug is *recognised* by the liver enzymes (in the same way that a key fits a lock). However, it is not enough that the drug is recognised, the enzymes must also be able to convert the drug. An important characteristic of enzymes is that in addition to recognising a drug, they also play an important role in the conversion of the drug. This distinguishes enzymes from the other proteins in our body that merely recognise substances.

The knowledge aimed at and the objective of the lesson is for the students to understand the basic mechanisms of enzyme recognition and conversion of pharmaceutical drugs in the human body, and for them to be able to account for phenomena related to lack of conversion of a drug.

The lesson

The lesson begins with a presentation of two cases (described in text box 1). The objective of the lesson is for the students to be able to explain why a 9-year-old boy who had taken antidepressant medicine and the 29-year-old allergy patient died, on the basis of their knowledge about recognition and conversion of pharmaceutical drugs in the liver.

Text box 1A

A 29-year-old man from Australia on allergy medication drank a couple of glasses of grapefruit juice a week. He took his medication twice daily for a year. One day, he drank two glasses of grapefruit juice immediately after having taken his medication. After which he mowed the lawn. Soon after he felt poorly, collapsed and died. The autopsy showed elevated levels of the drug in the man. (Spence, 1997)

Text box 1B

A nine-year-old American boy with Tourette's syndrome (tics, etc.), DAMP and other difficulties was given antidepressant medication over a period of 10 months. During this period the boy's situation deteriorated, he suffered from epileptic fits and heart attacks, and finally he died. The autopsy showed elevated levels of the drug in the boy. (Sallee et al., 2000)

Obviously, the students cannot immediately explain why the two patients died (this is what they are to learn in the lesson), however the two cases are so spectacular that their interest is awakened. This is not least because the situations described are perceived as being realistic. Many students take medication on a regular basis themselves, or they know someone who does, so they find it easy to relate the two cases to their own world.

After presenting the two cases, the teacher begins to present a sub-assignment. It is important that the students understand the methods of representation to be used in the assignment, and the teacher describes these.

Figure 1 illustrates the basic principles for the conversion of drugs and introduces the representation method to be used in the lesson. In figure 1a, a molecule (a drug) is illustrated as a surface and a 'ball-and-stick' model (each ball and stick represents an atom and a bond between two atoms, respectively). What is important here is the *surface* of the molecule and the electrical charge in the different areas of the molecule. Therefore, in the lesson, figure 1a is simplified as seen in figure 1b. The colour scale (light-grey, black, dark-grey) represents neutral, positive and negative areas of the molecule. Figure 1d describes what happens when the drug is converted. Following conversion of the drug, there are two new charged areas to the right of the drug. Substances where larger areas are charged (more polar substances) are more easily broken down by the kidneys.

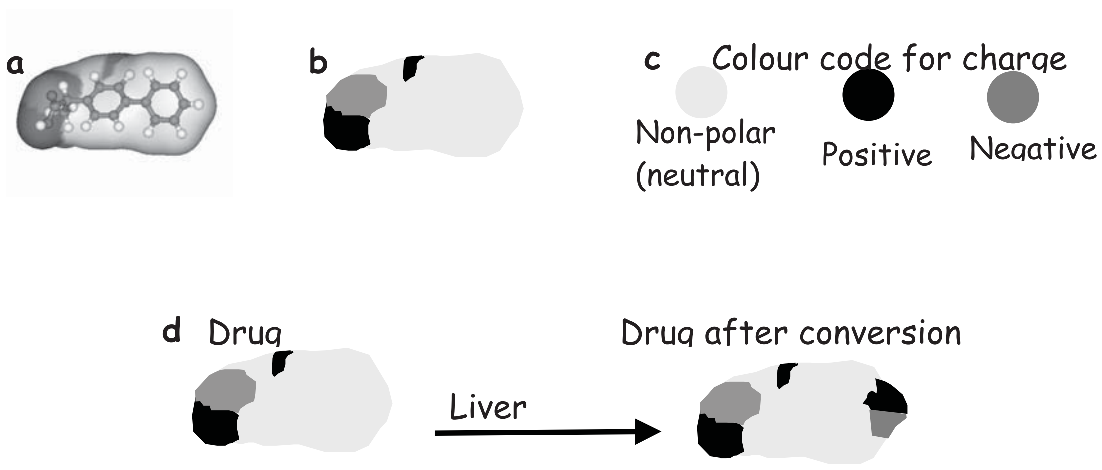

Figure 1. *Representations of the drug molecule and the principles for conversion. (a) The molecule is seen as a 'ball-and-stick' model, encapsulated by the surface of the molecule. (b) Schematic drawing of the surface of the molecule. (c) Colour code for charge of molecule surface. (d) The liver enzyme converts the drug into another substance that has increased surface charge (is more polar) and therefore is easier to break down in the body.*

The teacher explains that in order for a drug to be broken down in the liver, the drug needs to be recognised by the liver enzymes. It is crucial to the recognition process that the drug's shape fits into the enzyme and that the drug and enzyme's electrical charges match one another.

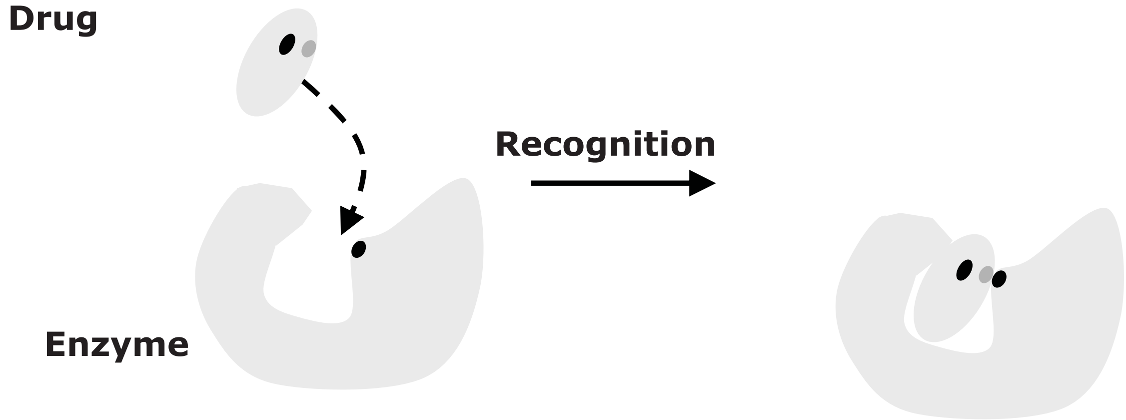

Figure 2. A liver enzyme recognises a drug on the basis of shape and charge. Here the enzyme surface is depicted in the same manner as in figure 1.

As is seen in figure 2, here the drug is almost a perfect match with the liver enzyme. There is recognition because a significant neutral area of the drug matches a corresponding neutral area in the liver enzyme, and the charged areas of the drug match areas with the opposite charge in the enzyme. After this brief introduction, the students are instructed to work on assignment 1a (described in figure 3). The students are given a piece of paper with the assignment on it as well as a pair of scissors that they can use when working on the assignment. The instructions and the 'rules' the students are to base their work on can be seen in the figure text.

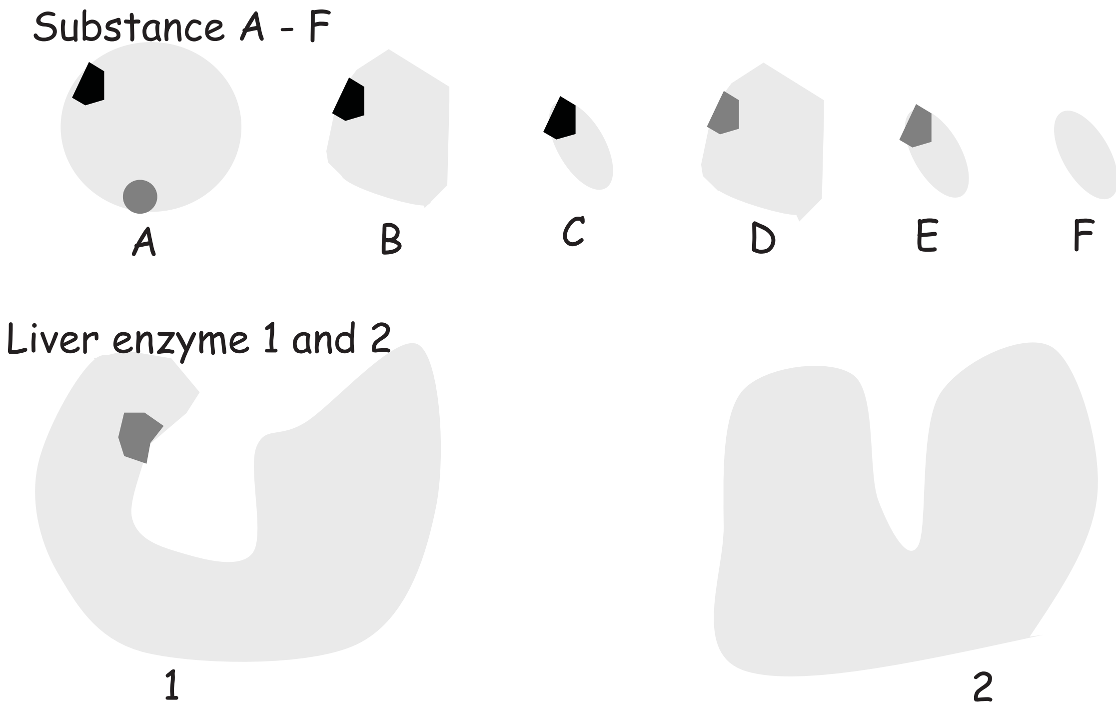

Figure 3. *Assignment 1a On the basis of the following rules, determine which of the substances (A-F) are recognised by the liver enzymes (1-2). Light-grey prefers light-grey to nothing. Dark-grey and black attract one another. Monochrome black and monochrome dark-grey repel one another. Spatial overlap between the substance and the enzyme is not allowed. Dark-grey and black are neither attracted nor repelled by light-grey.*

After working together in small buzz groups for a few minutes, the students present their results in a plenary session. This leads to the following points: First of all, some drugs have an extremely good match, both with regard to shape and 'colour' (B and C fit enzyme 1). Furthermore, some drugs fit both liver enzymes (*C, E, F*), however they prefer one liver enzyme compared to the other (*C* fits best into 1, *E* fits well into 2, *F* fits best into 2).

This covers how liver enzymes *recognise* drugs, however the enzymes must also be able to *convert* these drugs. How this is done is illustrated in figure 4. In the conversion process the enzyme negatively charges a neutral (light-grey) area of the substance. That is, there is *one more requirement* for conversion to take place after recognition.

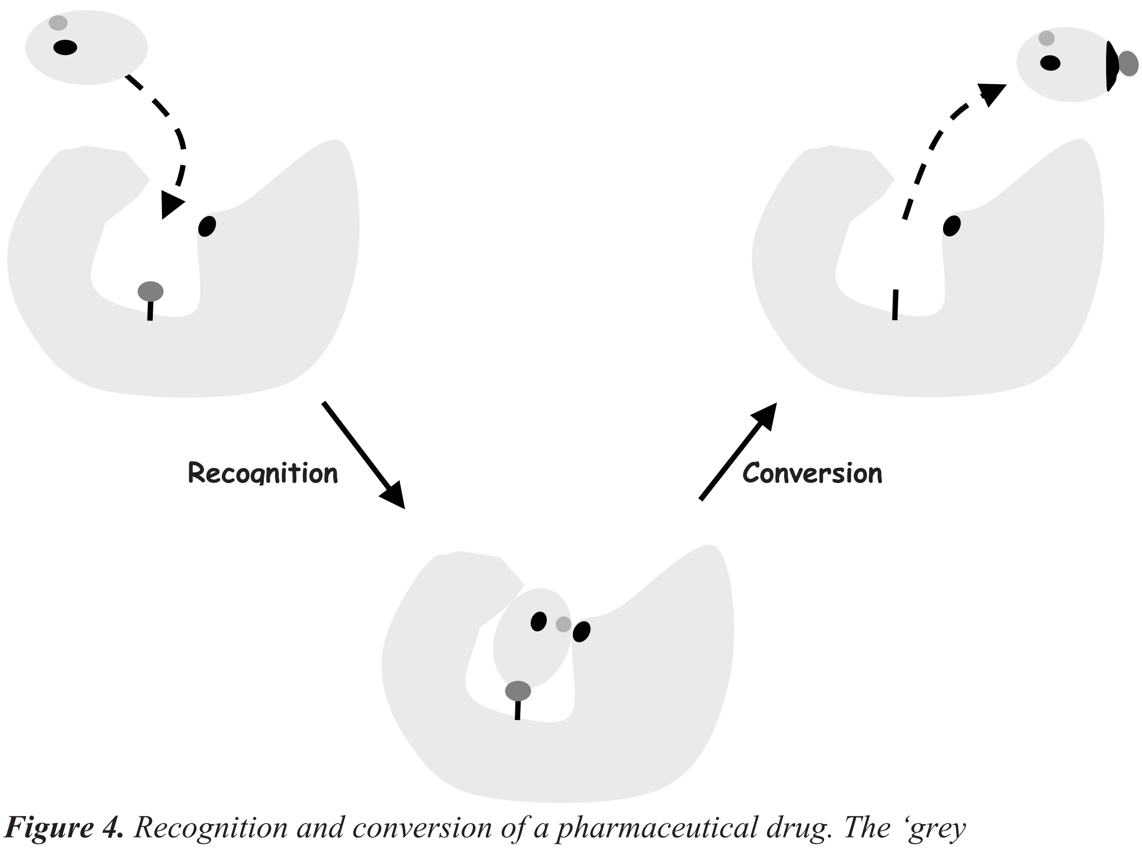

Figure 4. *Recognition and conversion of a pharmaceutical drug. The 'grey ball on the stick' that the enzyme adds to the drug is an oxygen atom.*

Because it is negatively charged, this atom contributes to increasing the drug's polarity.

After having explained this to the students, assignment 1b is presented. Here the students are to determine which of the drugs the liver enzymes will recognise and whether the enzymes can convert the drug (see figure 5).

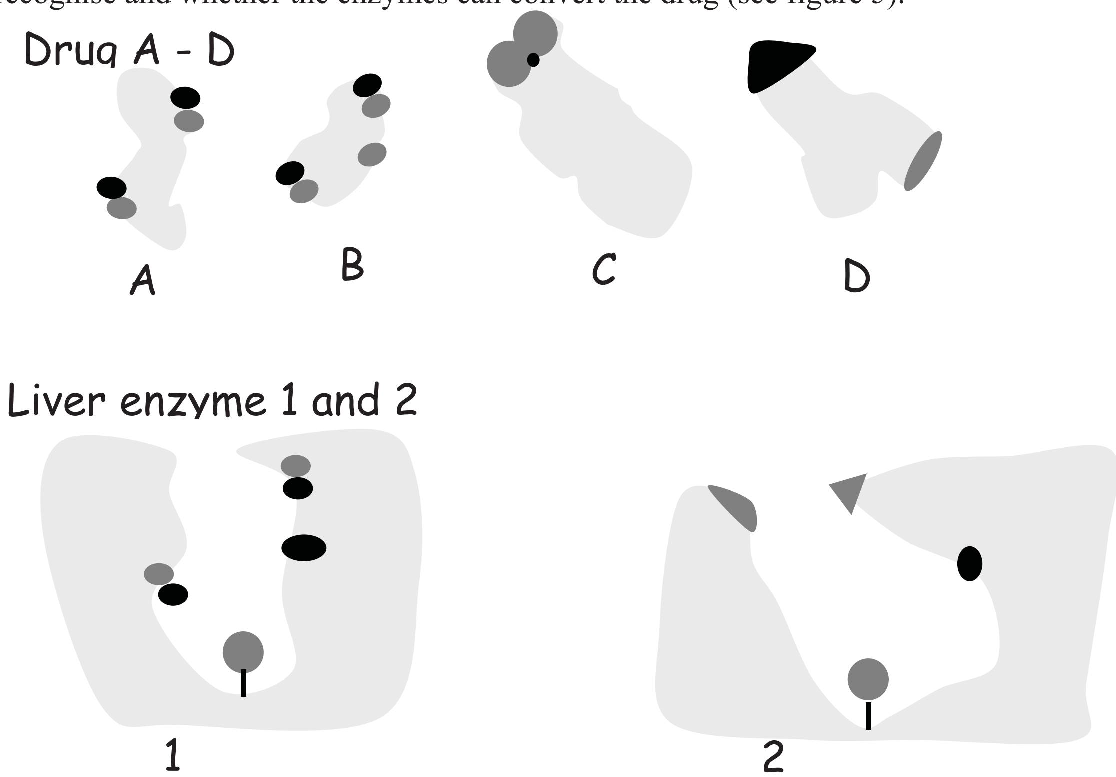

Figure 5. *Assignment 1b: Which liver enzymes recognise and convert the drugs? Rules for liver enzyme recognition and conversion of a drug: Rules of recognition from assignment 1 (see figure 3). Conversion requires that the 'grey ball on the stick' (the oxygen atom in the liver enzyme) is attached to the light-grey area of the drug.*

The students work with this assignment in the same way as with assignment 1a, and the assignment is also rounded off in a plenary session. However this time, the academic points to be noted are: Drug *A* is recognised *and* converted by 1; *B* is recognised but not converted; *C* is not recognised by 1 or 2; *D* is recognised *and* converted by 2. Here the academic insight is that while some drugs may be both recognised and converted, some drugs are recognised, but not converted.

The students have now learnt about some of the basic principles for liver enzyme recognition and conversion of drugs through their work with the assignments and the ensuing discussion of their results. Now the teacher reverts to the two cases that opened the lesson. Figure 6 shows a depiction of the substances from the cases: allergy medication, grapefruit juice and antidepressant medication. The students are now asked to think about why the 29-year-old Australian asthma patient and the 9-year-old American boy died.

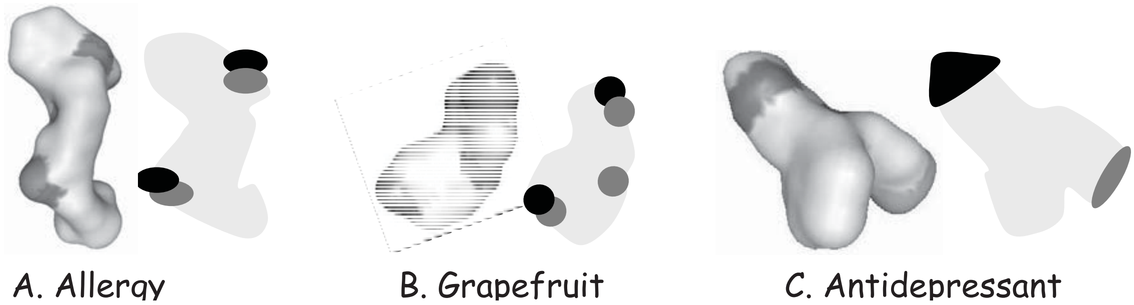

Figure 6. *Assignment 1: Why did the 29-year-old Australian man and the 9-year-old American boy die? Note the similarity between the substances used in assignment 1b (figure 5).*

One of the ingredients in the grapefruit juice blocks the liver enzyme that converts the allergy medication to another substance that is broken down more easily. This is why the allergy medication that the 29-year-old man is taking is accumulated in his body. The same inhibition of the conversion process may have been to blame for the accumulation of the antidepressant medication in the 9-year-old boy's body. However, this is not the case. The boy has a gene defect which entails that he lacks this enzyme completely and therefore there is no conversion nor breakdown of the substance (approx. 10% of all Caucasians have this gene defect). One way of avoiding these problematic situations is to design pharmaceutical drugs that are converted by more than one liver enzyme, so that another enzyme can take over the conversion process and thus ensure break down of the drug. The molecules *C*, *E,* and *F* in assignment 1a could potentially be such a substance (provided they can be broken down!).

Analysis of the lesson in the basis of TDS

In the following, we will first introduce the learning and epistemological foundation for the theory of didactic situations (TDS) and then analyse the lesson described in the above on the basis of the descriptions of the phases in the so-called 'didactic games' laid down in the TDS framework.

The epistemological hypothesis, learning as adaptation and didactic environments

The central concepts, methods and principles of a subject were developed in relation to certain types of situations and problems. The lesson described here mainly concerns the connection between recognition and conversion of pharmaceutical drugs in the human body. In many textbooks this is described in a manner that is fairly abstract, and it is a concept that students often find difficult to grasp.

The abstract approach in textbooks to the knowledge to be learned by the students is of course the result of a scientific process; originally the relevant knowledge constructed in relation to a specific situation or problem. These ‘original situations’ or problems are often not included in textbooks. The knowledge that was originally linked to a specific situation has been disjointed from the situation and generalised in order to describe not just the original situation, but a flurry of situations. We refer to “recognition and conversion of pharmaceutical drugs” as an objective knowledge area, without at the same time referring to specific situations in which the methods can be used. This generalisation process and ‘decontextualisation’ of knowledge is of course an important product of the scientific process, however it also entails a dilemma with regard to the teaching process. This is because human beings learn by relating to concrete situations. If knowledge is established historically (e.g. through the scientific process) and evolves on the basis of specific problematic situations, it seems obvious to say that all established knowledge is linked to a specific type of situation. One could also say that this knowledge can be (re)created by individuals in a similar situation and under similar circumstances. On the basis of this hypothesis, knowledge is thus the ‘answer’ to questions governed by a specific situation. This hypothesis is called “the epistemological hypothesis in science education” (Winsløw, 2006, section 1.4).

The perception of knowledge as the ‘answer to a question’ indicates a central problem in the teaching process. Of course we want to teach the students the *answers* (the knowledge aimed at), however answers rarely make sense without previous knowledge or understanding of the questions to which the answers are given. That is, it is necessary to ‘recontextualise’ the subject’s ‘decontextualised’ elements in order for them to make sense to the students. In the lesson described here, the three assignments are examples of such ‘recontextualisation’ of the general principles for enzyme recognition and conversion of substances.

Both the researcher and the student acquire knowledge by working with specific situations (typically together with others). If, through his or her learning, the student is to ‘rediscover’ the knowledge that the researcher has gained, situations where this (re)discovery can happen must be established. Obviously the history of science offers many such situations that can serve as the basis for the teacher’s planning of teaching situations (the journal *Science and Education* offers many good examples of this). However, it is just as clear that the students’ backgrounds (historical, cultural, academic, social, and possibly also cognitive) are usually rather different from that of the researcher, and therefore the history of science is seldom the best place to look for inspiration when designing a teaching situation. This points to the central issue that the ‘recontextualised’ situation must be relevant for student and his or her knowledge. If this is not the case, no learning can be expected. The importance of relevance in terms of personal experience is evident if we think of learning as ‘adapting to an environment’.

It is important that such ‘personification’ takes place and that the students can experience the teaching as both meaningful and relevant. In this lesson, the description of the two individuals who died of an overdose (assignment 1) is an important element in this personification. A connection to the student’s own life is established, spurring them to seek the solution to the assignment. Through their work with the two sub-assignments, the students find the solution to the main assignment (at least the part about the allergy patient). Pharmaceutical science has a wealth of such situations where a link can be established to the students’ own world or to their perception of what they will be dealing with professionally in the future, and this should of course be exploited in the teaching situation.

The need for relevance based on personal experience and the epistemological hypothesis reflects several standard pedagogical insights; insights that today are uncontroversial for most. More specifically, they reflect a basic inductively oriented constructivist approach to learning. Jean Piaget, who is often referred to as the father of constructivism, described learning as a personal construction process in interaction with an environment (see Winsløw, 2006, chapter 4), and Piaget’s fundamental metaphor for learning as ‘adaptation to an environment’ is also a important starting point for the theory of didactic situations (see. Winsløw, 2006b). Of course adaptation can only take place where the circumstances allow adaptation; this is why the material must be personalised. In addition to ‘recontextualisation’ of abstract knowledge, the materials used must also be ‘personalised’ by including the students’ own situation as an element in the teaching session.

This double requirement for personalisation and recontextualisation of abstract knowledge means that, as mentioned earlier, scientific situations in history on which the abstract knowledge is based seldom constitute good teaching situations. Instead, the teacher can create ‘artificial environments’ with a view to the student acquiring specific knowledge. Such ‘designed environments’, that are organised in such a way that the students acquire specific academic knowledge, are called *didactic environments* in TDS, and the interaction between the students and the didactic environment is called *the didactic game.* Let us revert to the didactic games in the lesson. Central to the design of didactic environments is that the students find the game challenging and that it motivates them to learn. Furthermore, when working with the situations, they are pointed in the direction of finding the answers to questions raised in the teaching subject. In our view, the three assignments described in the lesson constitute good examples of such didactic environments that together lead to students learning the knowledge aimed at (see Winsløw, 2006b, for a more detailed description of the concept ‘didactic environment’). The idea that didactic environments that have been specifically designed to allow the students to learn specific knowledge is a central expansion of Piaget’s description of learning in ‘natural environments’. Brousseau’s ‘environments’ (milieu) also differ from Piaget’s in other areas, e.g. Brousseau (along with others) emphasises the social relations in the environments and the importance of these relations for learning. Brousseau and Piaget agree that individual knowledge is constructed in a specific situation; on the basis of this situation; and on the basis of the knowledge the individual already possesses. The analogy of learning as ‘adaptation to an environment’ that both Brousseau and Piaget use, demonstrates their shared constructivist point of departure.

The teacher thus has an important task in designing teaching situations in which the students “can live and in which the knowledge [aimed at] appears as the optimal and discoverable solution to the given problem” (Brousseau, 1997, p. 22). In the lesson described here, designing the assignments (1, 1a, 1b) was by far the most time-consuming task. When working on the assignments, it is crucial that, within the framework of the assignments (the environment), the students are given the opportunity to express themselves and to act independently or in cooperation with others, and that the assignments actually enable them to acquire the knowledge aimed at. It is when working in the environment that the knowledge that is needed to solve the assignment is ‘personalised’ and the knowledge aimed at is (re)discovered on the basis of the student’s own construction:

> The modern view of teaching [...] requires that the teacher can provoke the expected adaptation in his or her students by presenting them with a carefully selected series of ‘problems’. These problems must be selected in such a manner that the students can accept them and they are motivated to act, think and evolve. [...] The students know very well that the problem they are presented with was selected with a view to helping them acquire new knowledge. However the students also know that this knowledge is completely based in the inner logic of the situation, and that they can construct it without calling on didactic reasoning. Not only *can* they do this, they *must*, as it is not until the students have fully acquired this knowledge that they are able to use it in situations outside of the learning context and where there is no guidance. This called an *adidactic situation*. Any specific ‘piece of knowledge’ can be characterised by one or more adidactic situations that secure the meaning of this knowledge. (Brousseau, 1997, p.30, the authors’ own translation)

Phases of the didactic game

An important element of the theory of didactic situations is the description of the various phases of the didactic game. The didactic game refers to the interaction between the student and the didactic environment. Even though the phases that the concepts describe seem almost self evident, or maybe precisely because of this, the concepts are surprisingly useful in both the analysis and design process of teaching situations. This is not least because the conceptual framework is independent of the specific teaching methods used. Overall, the phases refer to the relationship between the agents and the knowledge aimed at, and the situations that this knowledge is an 'answer' to. Therefore the conceptual framework is very broad and can be used as a 'first iteration' when planning teaching or, as here, when analysing existing teaching. The five phases in the didactic game are shown below, table 1 describes the flow of the lesson in question on the basis of these five phases.

- **Devolution:** The teacher passes a 'didactic environment' to the students
- **Action:** The students work in the environment
- **Formulation:** The students express themselves and create hypotheses about the solution to the assignment, either independently or in groups.
- **Validation:** The students test their hypotheses together or with the teacher.
- **Institutionalisation:** The teacher relates the work being carried out in the environment to the general themes of the subject, typically through a dialogue with the students.

The list of bullets is not to be understood as that the phases must follow one another in this precise order. However the phases are related to one another in specific ways, and this is what makes the concepts so useful. The devolution phase leads up to the action and formulation phases, the validation phases combine and 'set a value' on the formulations and actions. The institutionalisation phases express the results of the students' efforts in the environment in a 'formal' academic manner that can be linked to 'shared', (and therefore useful) knowledge to be used in other situations as well as in the teaching situation in question.

Table 1. *Outline of lesson focusing on the teaching phases.*

General introduction	**Specialised sub-session**	**Situation**
Devolution: Assignment 1		Didactic
	Devolution of assignment 1a: Rules of recognition	Didactic
	Action/formulation/validation	Adidactic
	Joint validation assignment 1a	?
	Institutionalisation assignment 1a:	Didactic

	Devolution of assignment 1b: Rules for recognition and conversion	Didactic
	Action/formulation/validation	Adidactic
	Joint validation of assignment 1b	?
	Institutionalisation of assignment 1b	Didactic
	Devolution: assignment 1	Didactic
	Formulation/validation assignment 1	Adidactic
Joint validation of assignment 1		?
Institutionalisation		Didactic

Table 1 describes the lesson consisting of a general introduction to the overall assignment (the two patients who died of an overdose), and an embedded sequence based on the two sub-assignments (recognition and conversion of pharmaceutical drugs). It is stated for each phase whether the situation is didactic or adidactic.

On the basis of the outlined lesson, we will analyse the various phases of the teaching process and identify overall aspects of interest.

Devolution:

Devolution is the teacher's surrender of a 'didactic environment' to the students. There are three devolutions in the lesson: The overall introduction to the lesson including description of the two patients who died of an overdose. Next, the introduction to assignment 1a that is about how liver enzymes recognise drugs, and finally an introduction to assignment 1b that is about the conversion of drugs. Devolution is typically a teacher-controlled activity in which the students are given instructions. It is important that in the course of the devolution phase, students understand the task to be undertaken correctly, and they must be given the opportunity to ask clarifying questions. Most often what is going to happen in the course of the lesson is clarified (more or less explicitly) in the devolution phase, and it is also here that the teacher's and students' roles are defined. In the lesson described here this is especially true of the preliminary devolution in which the overall course of the lesson is outlined: Here's a mysterious phenomenon! When you have dealt with two short assignments, you will be able to explain this.

It is also worth noting the relationship between the two shorter assignments (1a and 1b) and the final solution to the overall assignment. The didactic environments that the students work in are not independent of one another. More specifically, the formulation of assignment 1 is included in the environment for assignment 1a along with 'puzzle pieces', scissors and the rules for recognition of drugs. Together these elements make up the (objective) didactic environment. When working on assignment 1b, conclusions from the previous assignment (1a) are included as part of the environment, e.g. the same rules apply to recognition of substances in assignment 1b as in 1a. Furthermore the students have now seen that they can solve these 'puzzles' on the basis of the given rules. In this way the lesson can gradually increase in complexity as the students acquire more relevant knowledge.

Action, formulation and (adidactic) validation

In the lesson described here, as is often the case, the action and formulation phases are closely interconnected, not least in assignments 1a and 1b. The students work together in small groups; first they cut out the puzzle pieces, then they match them with the liver enzymes and discuss each piece on the basis of the overall rules that are specified in the assignment. While the students are trying out the pieces and independently expressing themselves on the subject, it is important that the teacher remains in the background. This can be very difficult for a teacher who most often wants to be involved in the discussion (and should be too), however the teacher should also clearly signal that he or she expects the students to work independently of the teacher. The teacher should only intervene in situations where the students cannot seem to get started on the assignment.

As the students progress with their work, they construct hypotheses about which pieces match which liver enzymes, which substances are recognised, which substances are converted, etc. These findings are discussed in the individual groups and the arguments for the hypotheses put forward are also discussed here, i.e. why the substances are recognised and converted. This is a validation situation, albeit a validation made by the students, without any interference from the teacher, a so-called adidactic validation. Often these adidactic validation situations give rise to new actions and formulations: "No, that one doesn't fit in here because then you would have two positive charges opposite one another. But what if we rotated it like this...?" It is not difficult as such to distinguish between the action, formulation and validation phases, however the shift between the phases is often very fast. The adidactic validations are, in our opinion, very important because the students are given the opportunity to substantiate their (own) hypotheses, and this process is central to their learning. As validation takes place on the basis of actions and formulations in the environment, it is important to allot sufficient time to the assignment to ensure that the students reach beyond the action and formulation phases.

Validation and institutionalisation

After the students have worked on the assignments in groups and reached a conclusion, their findings are presented in a plenary session. This is also a validation situation, however in contrast to the validation that took place in the groups, here the teacher plays a significant role. The teacher has the 'correct' answers and can therefore 'set a value on' and add to the students' arguments in a way that the students normally cannot. However, the thoughts have been thought by the students themselves, and most often the teacher's role in this situation is to coordinate and steer the discussion so that the groups that may not have reached the correct solution also learn from the other students' solutions. In the process, the students may comment on one another's answers, or the students may have found a particular part of the assignment challenging that was not anticipated in advance. Even though this validation is 'teacher controlled', it clearly reflects the students' own thoughts in the environment, and it can sometimes be difficult to say beforehand exactly how the rounding-off process will proceed (this explains the question marks in table 1). However, if the assignment is well-designed, it will often be possible for the teacher to reach exactly those points that the assignment aims at.

Whereas the design of the assignments and the students' approach to them aimed at 'recontextualisation' and 'personification' of the knowledge aimed at, the objective of validation is for 'collectivisation' of the knowledge the students gain through their work in the environment. However, this knowledge is still linked to the specific assignment the students have been working on. Therefore institutionalisation is needed, where, on the basis of the validation, the teacher describes how the specific situation related to the subject in general as well as the knowledge aimed at:

> the teacher's work is to some degree the opposite of the researcher's work; the teacher must *recontextualise* and *repersonalise* the knowledge [aimed at]. It must become the student's knowledge; i.e. a reasonably natural response to relatively specific conditions; conditions that determine whether the knowledge aimed at makes sense to the student. Any acquisition of knowledge is based on adaptation to a specific situation. [...] However the teacher must also create room for discovery of the culturally embedded and communicable knowledge that she wants to teach the students within the story that the students recreate. Subsequently, the students must *re-decontextualise* and *re-depersonalise* their knowledge in such a way that they can determine which parts of what they have learnt lie within the normal scope of the scientific and cultural community. (Brousseau, 1997, p.23, the authors' own translation)

In the final institutionalisation of the lesson described here, the teacher discusses with the students what the typical causes are for lack of conversion of a drug (that the relevant liver enzymes are 'taken' by other substances, as in the first example, or due to a gene defect, as seen in the second example). She also discusses with the students the research being carried out in developing pharmaceutical drugs that can be converted by several liver enzymes, and finally gives an example of how, what is represented here by a very simple puzzle, can be transferred to a 'real' enzyme that is significantly more complex to grasp. In this way emphasis is on the general mechanisms for recognition and conversion in play in the situations, and to a lesser degree on the specific representations (that the students probably will never encounter again).

In connection with assignment 1, it is worth noting that the students actually cannot explain why the boy with the gene defect died *solely* through their work in the environment. This indicates that there may be a difference in the way in which the theory of didactic situations is used in mathematics compared to the natural sciences. In mathematics there are no such 'exceptions' to the rules that apply in the didactic game. In the natural sciences there are very often exceptions to the rules that are used. In the lesson the students are led to the assumption that the liver enzyme is 'taken' by another substance. This is also the case in a typical situation, however it is not the case here. At this stage the students know the principle rules of recognition and conversion and understand the explanation immediately. The assignment could easily have been expanded to include another smaller assignment in which the students were asked to explain which of the rules applied in assignment 1 is problematic, considering that they now know that another substance has not 'taken the place'. If we did this, we would undoubtedly see that the students could explain why the boy died themselves.

Use of TDS

The theory of didactic situations was, as mentioned, developed within the field of the didactics of mathematics and it has found widespread use in this field. Brousseau and his colleagues demonstrated great creativity in their development and examination of a vast range of didactic situations in mathematics teaching at (especially) primary and secondary level. Obviously these situations are closely linked to mathematics. In that sense there is no doubt that the theory of didactic situations is almost exclusively a didactic theory for mathematics.

However, the theory uses a conceptual framework that can be used in a more general sense, including an understanding of learning and a basic description of teaching situations that not only bear relevance to the didactics of mathematics, but that are also relevant in the didactics of other subjects, at least the didactics of the natural sciences and technical subjects. By this we especially mean the epistemological hypothesis, the two concepts didactic environment and didactic game, as well as the phases of the didactic game. These concepts are extremely useful in the analysis of teaching situations, as we have illustrated with the lesson on recognition and conversion of pharmaceutical drugs in the liver, and the conceptual framework is also useful when designing teaching.

It should be added that other central concepts from TDS that we have not included here due to lack of space, can also be used in other technical and natural science subjects, e.g. the concepts ‘didactic contract’ and ‘epistemological and didactic obstacles’. TDS has been used in other subjects than mathematics, e.g. physics (Thibergien, 2000) and physical education (Armade-Escot, 2005), however in our opinion it has greater potential than has been demonstrated in these few and far between studies. Finally, we would like to emphasise that the theory is not limited to design of teaching at primary and secondary level, but can be used with great success when dealing with teaching and learning at university level.

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Monday

Intended learning outcomes

Lectures

After the lectures the participants are able to:

- reflect upon their own learning and assess the importance of such reflections for the planning of good teaching.
- use this assessment when planning their own teaching.
- use relevant aspects of the Theory of Didactical Situations (TDS) to analyse a lesson, and - as part of this - use the concepts that describe the phases of a lesson: Instruction, Action, Formulation, Validation and Institutionalization.

Planning of the lesson

After planning the first lesson, the participants are able to:

- prepare a set of Intended Learning Outcomes for a lesson and estimate how difficult it will be for participants to achieve these learning outcomes.
- operationalize their descriptions of these intended learning outcomes in planning a lesson that includes student activity.
- give and receive feedback constructively to/from members in the group who work together in a satisfying way, when planning the lesson.

Preparation for Wednesday

Read the papers in the compendium.

For those of you giving your lesson exercise on Wednesday, you must plan your lesson with specific focus on:

- Learning objectives
- Student activation

In your planning group discuss how to accomplish the following in your lesson:

- Formulate one or more specific learning objectives, which can form the basis for your lesson exercises.
- The objectives must be formulated so precisely, that it is clear what you expect the students to be able do after your lesson.
- Consider which student activities can be included in the lesson in order to help your students reach the objectives

From: Biggs, J. and Tang, C. (2007): *Teaching for quality learning at university.* Maidenhead: Open University Press.

Kinds of knowledge and levels of understanding

Kinds of knowledge

Knowledge, as the object of understanding at whatever level, comes in two main kinds. *Declarative*, or propositional, knowledge refers to *knowing about* things, or 'knowing-what': knowing what Freud said, knowing what the terms of an equation refer to, knowing what kinds of cloud formation can be distinguished, knowing what were the important events in Shakespeare's life. Such content knowledge accrues from research, not from personal experience. It is public knowledge, subject to rules of evidence that make it verifiable, replicable and logically consistent. It is what is in libraries and textbooks and is what teachers 'declare' in lectures. Students' understanding of it can be tested by getting them to declare it back, in their own words and using their own examples. Such knowledge is basic to applications and creations, but is separate from them.

Functioning knowledge is based on the idea of performances of various kinds underpinned by understanding. This knowledge is within the experience of the learner, who can now put declarative knowledge to work by solving problems, designing buildings, planning teaching or performing surgery. Functioning knowledge requires a solid foundation of declarative knowledge.

These distinctions tell us what our curricula might address. Curricula in many universities are overwhelmingly declarative with teaching methods correspondingly expository. One study from the University of Texas found that university teachers spent 88% of their teaching time in lecturing students (cited by Bok 2006), yet students are supposed to be educated so that they can interact thoughtfully with professional problems; to use functioning knowledge, in other words. Unfortunately, often it is only the foundation declarative knowledge that is taught, leaving it to the students when they graduate to put it to work.

The traditional way of teaching psychology to education students illustrates this problem. The reason for teaching psychology is that teachers should know something about such topics as human learning and motivation, child development, the nature of intelligence, and so on and on, not for the good of their souls, but so they may *teach better.* However, until recently, these topics were taught and the students assessed on how well they had learned them – on their declarative knowledge of the topics – not on how well they applied their topic knowledge to their teaching. With the exception of courses using problem-based learning, the *application* of the theoretical content to teaching or to any other professional practice was left up to the student, when 'out there, in the real world'. When this happens, the most important intended outcome of the course and of the whole programme – that students would teach more effectively by virtue of having learned all that theory – has been ignored in both the teaching and the assessment of the theory courses. It was this realization that prompted the use of portfolio assessment as reported in the last chapter (Box 4.1, p. 51).

This is a problem not only of teacher education. The theory component in professional programmes in general is often treated as an end in itself, not as a means to performing in a more informed and effective way. While some courses in a degree programme, and some topics in probably all courses, need to be taught and assessed in their own right, the higher levels of 'understanding', involving reflection and application, need to be assessed in terms of how students' learning is manifested in better professional practice as their functioning knowledge.

Leinhardt et al. (1995) make a similar distinction between 'professional' knowledge and 'university' knowledge:

- *Professional knowledge* is functioning, specific and pragmatic. It deals with executing, applying and making priorities.
- *University knowledge* is declarative, abstract, and conceptual. It deals with labelling, differentiating, elaborating and justifying.

In other words, would-be professionals are trained in universities to label, differentiate, elaborate and justify, when what they need out in the field is to execute, apply and prioritize!

Entwistle and Entwistle (1997) found that the forms of understanding encouraged by university accreditation and assessment procedures are not those that are professionally relevant (see later). The rhetoric is right, but, in practice, universities tend to focus on declarative knowledge, which students often see as irrelevant and hence worthy of only a surface approach.

The problem is lack of alignment between intended learning outcomes and the means of teaching and assessing them. Graduates need to face new problems and to interact with them, reflectively and thoughtfully. Predicting, diagnosing, explaining, and solving non-textbook problems are what professionals have to do, so this is what university teachers should aim to get their students to do, particularly in senior years. Building such performances of understanding into the course ILOs, aligning teaching to them and designing assessment tasks that confirm that students can or cannot carry out those performances, is a good way to start.

But first, the question of understanding 'understanding'.

Performances of understanding

Ask any teacher what they want of their students and they will say they don't want their students just to memorize, they want them to *understand.* Consequently, that verb is the first they think of when designing the intended learning outcome statements. The trouble is that 'understand' can mean very different things, from the trivial to the complex.

Does the previously mentioned teaching objective, 'The student will understand expectancy-value theory', mean that the student is able to:

1 write a textbook definition of expectancy-value theory
2 explain how it works in the student's own words
3 watch a video of a teacher–student interaction and be able to predict what is likely to happen to the student's motivation afterwards
4 reflect on the student's own teaching to illustrate that a problem that had occurred could be accounted for and rectified in terms of expectancy-value theory?

All these are examples of 'understanding' at some level or other. Clearly, we need to pin down the level of understanding we want when stating the ILO. The ILO needs to make a statement as to that standard, which is done by selecting a suitable verb.

Entwistle and Entwistle (1997) conducted a series of studies on what students meant by 'understanding' and then asked them how they attempt to understand when preparing for examinations. The students described the experience of understanding as *satisfying*; it was good to have the feeling that you understood at last. It also felt *complete*, a whole, as previously unrelated things were suddenly integrated. The experience was irreversible; what is now understood cannot be 'de-understood'. Students thought a good practical test of understanding was being able to explain to someone else or to be able to adapt and to use what had been understood. These are pretty good definitions of sound understandings that probably fit most teachers' requirements: you want students to interrelate topics, to adapt and use the knowledge so understood, to explain it to others and to feel satisfied and good about it.

Unfortunately, when it came to the examinations, these indicators of understanding evaporated. Students attempted instead to understand in ways that they thought would meet assessment requirements. Understanding then took on much less desirable forms. The Entwistles distinguished five:

1 Reproduces content from lecture notes without any clear structure.
2 Reproduces the content within the structure used by the lecturer.
3 Develops own structure, but only to generate answers to anticipated examination questions.
4 Adjusts structures from strategic reading of different sources to represent personal understanding, but also to control examination requirements.

5 Develops an individual conception of the discipline from wide reading and reflection.

Only the last form of understanding, described by a small minority of students, is anything like the students' own definitions. All other forms focused on meeting examination requirements. The examinations actually prevented students from achieving their own personal understandings of the content, which the Entwistles understandably found 'worrying'. Many of these students were in their final year, just prior to professional practice, yet the assessment system pre-empted the very level of understanding that would be professionally relevant. Worrying indeed.

To use our learning in order to negotiate with the world and to see it differently involves understanding of a high order. It is the kind of understanding that is referred to in the rhetoric of university teaching, yet seems hard to impart. If students 'really' understood a concept they would *act differently* in contexts involving that concept and would use the concept in unfamiliar or novel contexts: these are called *performances of understanding* (Gardner 1993; Wiske 1998).

The challenge is to conceive our intended learning outcomes in terms of these performances of understanding, rather than in verbal declarations of understanding. The difference between meeting the requirements of institutional learning and 'real' understanding is illustrated in Gunstone and White's (1981) demonstrations with Physics I students. In one demonstration, two balls, one heavy and one light, were held in the air in front of the students. They were asked to predict, if the balls were released simultaneously, which one would hit the ground first and why. Many predicted that the heavy one would 'because heavy things have a bigger force' or 'gravity is stronger nearer the earth' (both are true but irrelevant). These students had 'understood' gravity well enough to pass HSC (A Level) physics, but few understood well enough to answer a simple real-life question about gravity. They could correctly solve problems using the formula for g – which does not contain a term for the mass of the object falling – while still reacting in the belief that heavy objects fall faster. They didn't *really* understand gravity in the performative sense – and why should they if their teaching and assessment didn't require them to? These physics students hadn't changed their commonsense conceptions of gravity, but had placed alongside them a set of statements and formulae about physical phenomena that would see them through the exams. To really understand physics or mathematics, history or accountancy is to *think like* a physicist, a mathematician, a historian or an accountant; and that shows in how you behave. Once you really understand a sector of knowledge, it changes that part of the world; you don't behave towards that domain in the same way again.

Gunstone and White's physics students were good at verbally declaring their knowledge, for example, explaining what gravity, or the three laws of motion, are about. But is this why we are teaching these topics? Is it for acquaintance, so that students know something about the topic and can answer the sorts of stock questions that typify examination papers? In that case, declarative understanding will suffice. Or is it to change the way (sooner or later) students can understand and control reality? If that is the case, then a performative level of understanding is implicated.

Levels of understanding

So far we have been talking about the end point, 'real' understanding. However, understanding develops gradually, becoming more structured and articulated as it develops. Undergraduates will not attain the level of precision and complexity of the subject expert, but we want none to retain the plausible misunderstandings that marked Gunstone and White's physics students' understanding of gravity.

We thus need to define understanding in ways that do justice to the topics and content we teach, as appropriate to the year level taught. The task is to define what is acceptable for each stage of the degree programme, given a student's specialization and degree pattern. That is a highly specific matter that only the teacher and subject expert can decide, but a general framework for structuring levels of understanding helps teachers to make those decisions and it also provides a basis for discussing levels across different years and subject areas. Once a sound understanding of the basic structural framework is achieved, adapting it to particular course ILOs is straightforward.

how do we know this?

The SOLO taxonomy is based on the study of outcomes in a variety of academic content areas (Biggs and Collis 1982). As students learn, the outcomes of their learning display similar stages of increasing structural complexity. There are two main changes: *quantitative*, as the amount of detail in the student's response increases; and *qualitative*, as that detail becomes integrated into a structural pattern. The quantitative stages of learning occur first, then learning changes qualitatively.

SOLO, which stands for **s**tructure of the **o**bserved **l**earning **o**utcome, provides a systematic way of describing how a learner's performance grows in complexity when mastering many academic tasks. It can be used to define course ILOs, which describe where students *should* be operating and for evaluating learning outcomes so that we can know at what level individual students actually *are* operating.

To illustrate, let us take some content with which you are all now familiar and see where you stand on your level of understanding of it.

What are approaches to learning? How can knowledge of approaches to learning enhance university teaching?

In a few sentences, outline your answer to these questions. **Stop reading any further until you have completed the task.** Then turn to Task 5.1 and try to evaluate your own response and against the model responses.

Task 5.1 SOLO levels in approaches to learning question and why

The following levels of response could be observed (but, it is to be hoped, the first three responses were not):

1 *Prestructural*

'Teaching is a matter of getting students to approach their learning.'

This response could have been written by somebody with understanding at the individual word level, but little understanding of what was discussed in the previous chapter. Prestructural responses simply miss the point or, like this one, use tautology to cover lack of understanding. These responses can be quite sophisticated, such as the kind of elaborate tautology that politicians use to avoid answering questions, but, academically, they show little evidence of relevant learning.

2 *Unistructural*

'Approaches to learning are of two kinds: surface, which is inappropriate for the task at hand, and deep, which is appropriate. Teachers need to take this into account.'

This is unistructural because it meets only one part of the task, defining what approaches to learning are in terms of just one aspect, appropriateness. It misses other important attributes, for example that they are ways of describing students' learning activities and what might influence them, while the reference to teaching adds nothing. Unistructural responses deal with terminology, getting on track but little more.

3 *Multistructural*

'Approaches to learning are of two kinds: surface, which is inappropriate for the task at hand, and deep, which is appropriate. Students using a surface approach try to fool us into believing that they understand by rote learning and quoting back to us, sometimes in great detail. Students using a deep approach try to get at the underlying meaning of their learning tasks. Teaching is about getting students to learn appropriately, not getting by with shortcuts. We should therefore teach for meaning and understanding, which means encouraging them to adopt a deep approach.'

We couldn't agree more. The first part is quite detailed (but could be more so); the second part is also what good teaching is about. So what is the problem with this answer? The problem is that this response does not address the key issue: *how* can knowledge of approaches enhance teaching? not *that* they can enhance teaching. This is what Bereiter and Scardamalia (1987) call 'knowledge-telling': snowing the reader with a bunch of facts, but not structuring them as required – and don't be misled by the odd connective like 'therefore'. Here, the students see the trees but not the wood. Seeing trees is a necessary preliminary to adequate understanding, but it should not be interpreted as comprehending the wood.

4 *Relational*

'Approaches to learning are of two kinds: . . . (etc.) The approaches come about partly because of student characteristics, but also because students react differently to their teaching environment in ways that lead them into surface or deep learning. The teaching environment is a system, a resolution of all the factors present, such as curriculum, assessment, teaching methods and students' own characteristics. If there is imbalance in the environment, for example a test that allows students to respond in a way that does not do justice to the curriculum, or a classroom climate that scares the hell out of them, the resolution is in favour of a surface approach. What this means is that we should be consistent.'

And so on. Here we have an explanation. Both concepts, approaches and teaching, have been integrated by the concept of a system; examples have been given, and the structure could easily be used to generate practical steps. The trees have become the wood, a qualitative change in learning and understanding has occurred. It is no longer a matter of listing facts and details, they address a point, making sense in light of their contribution to the topic as a whole. This is the first level at which 'understanding' in an academically relevant sense may appropriately be used.

5 *Extended abstract*

We won't give a lengthy example here. The essence of the extended abstract response is that it goes beyond what has been given, whereas the relational response stays with it. The coherent whole is conceptualized at a higher level of abstraction and is applied to new and broader domains. An extended abstract response on approaches to learning would be a 'breakthrough' response, giving a perspective that changes what we think about them and their relationship to teaching. The trouble is that today's extended abstract is tomorrow's relational. Marton and Säljö's original study was such a breakthrough; linking approaches to learning to systems theory was another, but now both are conventional wisdom.

The examples illustrate the five levels of the taxonomy. Uni- and multistructural levels see understanding as a quantitative increase in what is grasped. These responses were deliberately constructed to show that the higher level contains the lower level, plus a bit more. The 'bit more' in the case of multistructural incorporates the unistructural, then more of much the same – a purely quantitative increase. The 'bit more' in the case of relational over multistructural involves a qualitative change, a conceptual restructuring of the components, the recognition of the systems property as integrating the components, while the next shift to extended abstract takes the argument into a new dimension. SOLO describes a hierarchy, where each partial construction becomes the foundation on which further learning is built.

This distinction between knowing more and restructuring parallels two major curriculum aims: to *increase knowledge* (quantitative: unistructural becoming increasingly multistructural); and to *deepen understanding* (qualitative: relational, then extended abstract). Teaching and assessment that focus only on the quantitative aspects of learning will miss the more important higher level aspects. Quantitative, Level 1, theories of teaching and learning address the first aim only, so that the deepening of understanding is left to Susan's predilections for spontaneous deep learning activities. The challenge for us is to highlight the qualitative aim in the ILOs and support it by both teaching and assessment methods. Then Robert's understanding is likely to be deepened too.

Using SOLO to design particular intended learning outcome statements is helped considerably by using verbs that parallel the SOLO taxonomy. A visual representation is given in Figure 5.2, with some verbs typical of each level.

The verbs in the staircase are general, indicating what the students need to be able to do to indicate achievement at the level in question. Table 5.1 provides many more verbs from SOLO.

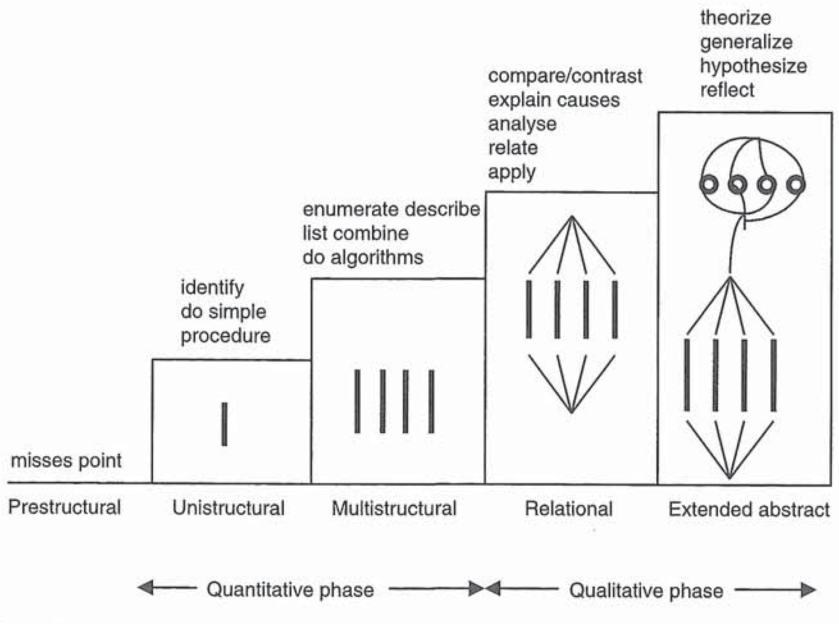

Figure 5.2 A hierarchy of verbs that may be used to form intended learning outcomes

Table 5.1 Some verbs for ILOs from the SOLO taxonomy

Unistructural	Memorize, identify, recognize, count, define, draw, find, label, match, name, quote, recall, recite, order, tell, write, imitate
Multistructural	Classify, describe, list, report, discuss, illustrate, select, narrate, compute, sequence, outline, separate
Relational	Apply, integrate, analyse, explain, predict, conclude, summarize (précis), review, argue, transfer, make a plan, characterize, compare, contrast, differentiate, organize, debate, make a case, construct, review and rewrite, examine, translate, paraphrase, solve a problem
Extended abstract	Theorize, hypothesize, generalize, reflect, generate, create, compose, invent, originate, prove from first principles, make an original case, solve from first principles

This gives us a wide range of levels that can be adapted to the levels appropriate to particular courses, from first to senior years. Particular content areas and topics would have their own specific verbs as well, which you would need to specify to suit your own course. Some verbs could be either extended abstract or relational, depending on, for example, the degree of originality or the context in which the verb was deployed: 'solve a problem', for example. And whether 'paraphrase' is relational or multistructural depends on how the student goes about paraphrasing: replacing with like-meaning phrases or rethinking the meaning of the whole text and rewriting it. Writing ILOs is one thing but when it comes to assessing them it needs to be done in a context so that these ambiguous verbs can be pinned down: to 'show your working', as maths teachers are wont to say.

For another set of verbs, based on Bloom's revised taxonomy (Anderson and Krathwohl 2001), see Table 5.2.

The original Bloom taxonomy was not based on research on student learning itself, as is SOLO, but on the judgments of educational administrators, neither is it hierarchical, as is SOLO. Anderson and Krathwohl's revision is an improvement, but even then under 'understanding' you can find 'identify', 'discuss' and 'explain', which represent three different SOLO levels. This is exactly why 'understand' and 'comprehend' are not helpful terms to use in writing ILOs. However, the Bloom taxonomy is a useful adjunct for suggesting a wider list of verbs, especially for a range of learning activities.

Table 5.2 Some more ILO verbs from Bloom's revised taxonomy

Remembering	Define, describe, draw, find, identify, label, list, match, name, quote, recall, recite, tell, write
Understanding	Classify, compare, exemplify, conclude, demonstrate, discuss, explain, identify, illustrate, interpret, paraphrase, predict, report
Applying	Apply, change, choose, compute, dramatize, implement, interview, prepare, produce, role play, select, show, transfer, use
Analysing	Analyse, characterize, classify, compare, contrast, debate, deconstruct, deduce, differentiate, discriminate, distinguish, examine, organize, outline, relate, research, separate, structure
Evaluating	Appraise, argue, assess, choose, conclude, critique, decide, evaluate, judge, justify, predict, prioritize, prove, rank, rate, select, monitor
Creating	Construct, design, develop, generate, hypothesise, invent, plan, produce, compose, create, make, perform, plan, produce

Source: Anderson and Krathwohl (2001)

Does Active Learning Work? A Review of the Research

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ABSTRACT

This study examines the evidence for the effectiveness of active learning. It defines the common forms of active learning most relevant for engineering faculty and critically examines the core element of each method. It is found that there is broad but uneven support for the core elements of active, collaborative, cooperative and problem-based learning.

Keywords: active, collaborative, cooperative, problem-based learning

I. INTRODUCTION

Active learning has received considerable attention over the past several years. Often presented or perceived as a radical change from traditional instruction, the topic frequently polarizes faculty. Active learning has attracted strong advocates among faculty looking for alternatives to traditional teaching methods, while skeptical faculty regard active learning as another in a long line of educational fads.

For many faculty there remain questions about what active learning is and how it differs from traditional engineering education, since this is already "active" through homework assignments and laboratories. Adding to the confusion, engineering faculty do not always understand how the common forms of active learning differ from each other and most engineering faculty are not inclined to comb the educational literature for answers.

This study addresses each of these issues. First, it defines active learning and distinguishes the different types of active learning most frequently discussed in the engineering literature. A core element is identified for each of these separate methods in order to differentiate between them, as well as to aid in the subsequent analysis of their effectiveness. Second, the study provides an overview of relevant cautions for the reader trying to draw quick conclusions on the effectiveness of active learning from the educational literature. Finally, it assists engineering faculty by summarizing some of the most relevant literature in the field of active learning.

II. DEFINITIONS

It is not possible to provide universally accepted definitions for all of the vocabulary of active learning since different authors in the field have interpreted some terms differently. However, it is possible to provide some generally accepted definitions and to highlight distinctions in how common terms are used.

Active learning is generally defined as any instructional method that engages students in the learning process. In short, active learning requires students to do meaningful learning activities and think about what they are doing [1]. While this definition could include traditional activities such as homework, in practice active learning refers to activities that are introduced into the classroom. The core elements of active learning are student activity and engagement in the learning process. Active learning is often contrasted to the traditional lecture where students passively receive information from the instructor.

Collaborative learning can refer to any instructional method in which students work together in small groups toward a common goal [2]. As such, collaborative learning can be viewed as encompassing all group-based instructional methods, including cooperative learning [3–7]. In contrast, some authors distinguish between collaborative and cooperative learning as having distinct historical developments and different philosophical roots [8–10]. In either interpretation, the core element of collaborative learning is the emphasis on student interactions rather than on learning as a solitary activity.

Cooperative learning can be defined as a structured form of group work where students pursue common goals while being assessed individually [3, 11]. The most common model of cooperative learning found in the engineering literature is that of Johnson, Johnson and Smith [12, 13]. This model incorporates five specific tenets, which are individual accountability, mutual interdependence, face-to-face promotive interaction, appropriate practice of interpersonal skills, and regular self-assessment of team functioning. While different cooperative learning models exist [14, 15], the core element held in common is a focus on cooperative incentives rather than competition to promote learning.

Problem-based learning (PBL) is an instructional method where relevant problems are introduced at the beginning of the instruction cycle and used to provide the context and motivation for the learning that follows. It is always active and usually (but not necessarily) collaborative or cooperative using the above definitions. PBL typically involves significant amounts of self-directed learning on the part of the students.

III. COMMON PROBLEMS INTERPRETING THE LITERATURE ON ACTIVE LEARNING

Before examining the literature to analyze the effectiveness of each approach, it is worth highlighting common problems that engineering faculty should appreciate before attempting to draw conclusions from the literature.

A. Problems Defining What Is Being Studied

Confusion can result from reading the literature on the effectiveness of any instructional method unless the reader and author take care to specify *precisely* what is being examined. For example, there are many different approaches that go under the name of problem-based learning [16]. These distinct approaches to PBL can have as many differences as they have elements in common, making interpretation of the literature difficult. In PBL, for example, students typically work in small teams to solve problems in a self-directed fashion. Looking at a number of meta-analyses [17], Norman and Schmidt [18] point out that having students work in small teams has a positive effect on academic achievement while self-directed learning has a slight negative effect on academic achievement. If PBL includes both of these elements and one asks if PBL works for promoting academic achievement, the answer seems to be that parts of it do and parts of it do not. Since different applications of PBL will emphasize different components, the literature results on the overall effectiveness of PBL are bound to be confusing unless one takes care to specify what is being examined. This is even truer of the more broadly defined approaches of active or collaborative learning, which encompass very distinct practices.

Note that this point sheds a different light on some of the available meta-analyses that are naturally attractive to a reader hoping for a quick overview of the field. In looking for a general sense of whether an approach like problem-based learning works, nothing seems as attractive as a meta-analysis that brings together the results of several studies and quantitatively examines the impact of the approach. While this has value, there are pitfalls. Aggregating the results of several studies on the effectiveness of PBL can be misleading if the forms of PBL vary significantly in each of the individual studies included in the meta-analysis.

To minimize this problem, the analysis presented in Section IV of this paper focuses on the specific core elements of a given instructional method. For example, as discussed in Section II, the core element of collaborative learning is working in groups rather than working individually. Similarly, the core element of cooperative learning is cooperation rather than competition. These distinctions can be examined without ambiguity. Furthermore, focusing on the core element of active learning methods allows a broad field to be treated concisely.

B. Problems Measuring "What Works"

Just as every instructional method consists of more than one element, it also affects more than one learning outcome [18]. When asking whether active learning "works," the broad range of outcomes should be considered such as measures of factual knowledge, relevant skills and student attitudes, and pragmatic items as student retention in academic programs. However, solid data on how an instructional method impacts all of these learning outcomes is often not available, making comprehensive assessment difficult. In addition, where data on multiple learning outcomes exists it can include mixed results. For example, some studies on problem-based learning with medical students [19, 20] suggest that clinical performance is slightly enhanced while performance on standardized exams declines slightly. In cases like this, whether an approach works is a matter of interpretation and both proponents and detractors can comfortably hold different views.

Another significant problem with assessment is that many relevant learning outcomes are simply difficult to measure. This is particularly true for some of the higher level learning outcomes that are targeted by active learning methods. For example, PBL might naturally attract instructors interested in developing their students' ability to solve open-ended problems or engage in life-long learning, since PBL typically provides practice in both skills. However, problem solving and life-long learning are difficult to measure. As a result, data are less frequently available for these outcomes than for standard measures of academic achievement such as test scores. This makes it difficult to know whether the potential of PBL to promote these outcomes is achieved in practice.

Even when data on higher-level outcomes are available, it is easy to misinterpret reported results. Consider a study by Qin et al. [21] that reports that cooperation promotes higher quality individual problem solving than does competition. The result stems from the finding that individuals in cooperative groups produced better solutions to problems than individuals working in competitive environments. While the finding might provide strong support for cooperative learning, it is important to understand what the study does *not* specifically demonstrate. It does not necessarily follow from these results that students in cooperative environments developed stronger, more permanent and more transferable problem solving skills. Faculty citing the reference to prove that cooperative learning results in individuals becoming generically better problem solvers would be over-interpreting the results.

A separate problem determining what works is deciding when an improvement is significant. Proponents of active learning sometimes cite improvements without mentioning that the magnitude of the improvement is small [22]. This is particularly misleading when extra effort or resources are required to produce an improvement. Quantifying the impact of an intervention is often done using effect sizes, which are defined to be the difference in the means of a subject and control population divided by the pooled standard deviation of the populations. An improvement with an effect size of 1.0 would mean that the test population outperformed the control group by one standard deviation. Albanese [23] cites the benefits of using effect sizes and points out that Cohen [24] arbitrarily labeled effect sizes of 0.2, 0.5 and 0.8 as small, medium and large, respectively. Colliver [22] used this fact and other arguments to suggest that effect sizes should be at least 0.8 before they be considered significant. However, this suggestion would discount almost every available finding since effect sizes of 0.8 are rare for any intervention and require truly impressive gains [23]. The effect sizes of 0.5 or higher reported in Section IV of this paper are higher than those found for most instructional interventions. Indeed, several decades of research indicated that standard measures of academic achievement were not particularly sensitive to any change in instructional approach [25]. Therefore, reported improvements in academic achievement should not be dismissed lightly.

Note that while effect sizes are a common measure of the magnitude of an improvement, absolute rather than relative values are sometimes more telling. There can be an important difference between results that are statistically significant and those that are significant in absolute terms. For this reason, it is often best to find both statistical and absolute measures of the magnitude of a reported improvement before deciding whether it is significant.

As a final cautionary note for interpreting reported results, some readers dismiss reported improvements from nontraditional instructional methods because they attribute them to the Hawthorne effect whereby the subjects knowingly react positively to any novel intervention regardless of its merit. The Hawthorne effect is generally discredited, although it retains a strong hold on the popular imagination [26].

C. Summary

There are pitfalls for engineering faculty hoping to pick up an article or two to see if active learning works. In particular, readers must clarify what is being studied and how the authors measure and interpret what "works." The former is complicated by the wide range of methods that fall under the name of active learning, but can be simplified by focusing on core elements of common active learning methods. Assessing "what works" requires looking at a broad range of learning outcomes, interpreting data carefully, quantifying the magnitude of any reported improvement and having some idea of what constitutes a "significant" improvement. This last will always be a matter of interpretation, although it is helpful to look at both statistical measures such as effect sizes and absolute values for reported learning gains.

No matter how data is presented, faculty adopting instructional practices with the expectation of seeing results similar to those reported in the literature should be aware of the practical limitations of educational studies. Educational studies tell us what worked, on average, for the populations examined and learning theories suggest why this might be so. However, claiming that faculty who adopt a specific method will see similar results in their own classrooms is simply not possible. Even if faculty master the new instructional method, they can not control all other variables that affect learning. The value of the results presented in Section IV of the paper is that they provide information to help teachers "go with the odds." The more extensive the data supporting an intervention, the more a teacher's students resemble the test population and the bigger the reported gains, the better the odds are that the method will work for a given instructor.

Notwithstanding all of these problems, engineering faculty should be strongly encouraged to look at the literature on active learning. Some of the evidence for active learning is compelling and should stimulate faculty to think about teaching and learning in nontraditional ways.

IV. The Evidence for Active Learning

Bonwell and Eison [1] summarize the literature on active learning and conclude that it leads to better student attitudes and improvements in students' thinking and writing. They also cite evidence from McKeachie that discussion, one form of active learning, surpasses traditional lectures for retention of material, motivating students for further study and developing thinking skills. Felder et al. [27] include active learning on their recommendations for teaching methods that work, noting among other things that active learning is one of Chickering and Gamson's "Seven Principles for Good Practice" [28].

However, not all of this support for active learning is compelling. McKeachie himself admits that the measured improvements of discussion over lecture are small [29]. In addition, Chickering and Gamson do not provide hard evidence to support active learning as one of their principles. Even studies addressing the research base for Chickering and Gamson's principles come across as thin with respect to empirical support for active learning. For example, Scorcelli [30], in a study aimed at presenting the research base for Chickering and Gamson's seven principles, states that, "We simply do not have much data confirming beneficial effects of other (not cooperative or social) kinds of active learning."

Despite this, the empirical support for active learning is extensive. However, the variety of instructional methods labeled as active learning muddles the issue. Given differences in the approaches labeled as active learning, it is not always clear what is being promoted by broad claims supporting the adoption of active learning. Perhaps it is best, as some proponents claim, to think of active learning as an approach rather than a method [31] and to recognize that different methods are best assessed separately.

This assessment is done in the following sections, which look at the empirical support for active, collaborative, cooperative and problem-based learning. As previously discussed, the critical elements of each approach are singled out rather than examining the effectiveness of every possible implementation scheme for each of these distinct methods. The benefits of this general approach are twofold. First, it allows the reader to examine questions that are both fundamental and pragmatic, such as whether introducing activity into the lecture or putting students into groups, is effective. Second, focusing on the core element eliminates the need to examine the effectiveness of every instructional technique that falls under a given broad category, which would be impractical within the scope of a single paper. Readers looking for literature on a number of specific active learning methods are referred to additional references [1, 6, 32].

A. Active Learning

We have defined the core elements of active learning to be introducing activities into the traditional lecture and promoting student engagement. Both elements are examined below, with an emphasis on empirical support for their effectiveness.

1) Introducing student activity into the traditional lecture: On the simplest level, active learning is introducing student activity into the traditional lecture. One example of this is for the lecturer to pause periodically and have students clarify their notes with a partner. This can be done two or three times during an hour-long class. Because this pause procedure is so simple, it provides a baseline to study whether short, informal student activities can improve the effectiveness of lectures.

Ruhl et al. [33] show some significant results of adopting this pause procedure. In a study involving 72 students over two courses in each of two semesters, the researchers examined the effect of interrupting a 45-minute lecture three times with two-minute breaks during which students worked in pairs to clarify their notes. In parallel with this approach, they taught a separate group using a straight lecture and then tested short and long-term retention of lecture material. Short-term retention was assessed by a free-recall exercise where students wrote down everything they could remember in three minutes after each lecture and results were scored by the number of correct facts recorded. Short-term recall with the pause procedure averaged 108 correct facts compared to 80 correct facts recalled in classes with straight lecture. Long-term retention was assessed with a 65 question multiple-choice exam given one and a half weeks after the last of five lectures used in the study. Test scores were 89.4 with the pause procedure compared to 80.9 without pause for one class, and 80.4 with the pause procedure compared to 72.6 with no pause in the other class. Further support for the effectiveness of pauses during the lecture is provided by Di Vesta [34].

Many proponents of active learning suggest that the effectiveness of this approach has to do with student attention span during lecture. Wankat [35] cites numerous studies that suggest that student

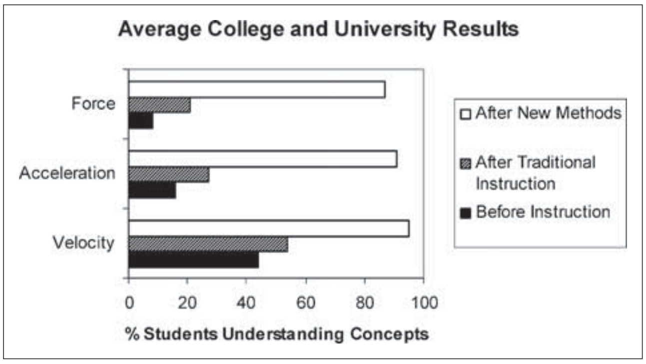

Figure 1. Active-engagement vs. traditional instruction for improving students' conceptual understanding of basic physics concepts (taken from Laws et al., 1999)

attention span during lecture is roughly fifteen minutes. After that, Hartley and Davies [36] found that the number of students paying attention begins to drop dramatically with a resulting loss in retention of lecture material. The same authors found that immediately after the lecture students remembered 70 percent of information presented in first ten minutes of the lecture and 20 percent of information presented in last ten minutes. Breaking up the lecture might work because students' minds start to wander and activities provide the opportunity to start fresh again, keeping students engaged.

2) Promoting Student Engagement: Simply introducing activity into the classroom fails to capture an important component of active learning. The type of activity, for example, influences how much classroom material is retained [34]. In "Understanding by Design" [37], the authors emphasize that good activities develop deep understanding of the important ideas to be learned. To do this, the activities must be designed around important learning outcomes and promote thoughtful engagement on the part of the student. The activity used by Ruhl, for example, encourages students to think about what they are learning. Adopting instructional practices that engage students in the learning process is the defining feature of active learning.

The importance of student engagement is widely accepted and there is considerable evidence to support the effectiveness of student engagement on a broad range of learning outcomes. Astin [38] reports that student involvement is one of the most important predictors of success in college. Hake [39] examined pre- and post-test data for over 6,000 students in introductory physics courses and found significantly improved performance for students in classes with substantial use of interactive-engagement methods. Test scores measuring conceptual understanding were roughly twice as high in classes promoting engagement than in traditional courses. Statistically, this was an improvement of two standard deviations above that of traditional courses. Other results supporting the effectiveness of active-engagement methods are reported by Redish et al. [40] and Laws et al. [41]. Redish et al. show that the improved learning gains are due to the nature of active engagement and not to extra time spent on a given topic. Figure 1, taken from Laws et al., shows that active engagement methods surpass traditional instruction for improving conceptual understanding of basic physics concepts. The differences are quite significant. Taken together, the studies of Hake et al., Redish et al. and Laws et al. provide considerable support for active engagement methods, particularly for addressing students' fundamental misconceptions. The importance of addressing student misconceptions has recently been recognized as an essential element of effective teaching [42].

In summary, considerable support exists for the core elements of active learning. Introducing activity into lectures can significantly improve recall of information while extensive evidence supports the benefits of student engagement.

B. Collaborative Learning

The central element of collaborative learning is collaborative vs. individual work and the analysis therefore focuses on how collaboration influences learning outcomes. The results of existing meta-studies on this question are consistent. In a review of 90 years of research, Johnson, Johnson and Smith found that cooperation improved learning outcomes relative to individual work across the board [12]. Similar results were found in an updated study by the same authors [13] that looked at 168 studies between 1924 and 1997. Springer et al. [43] found similar results looking at 37 studies of students in science, mathematics, engineering and technology. Reported results for each of these studies are shown in Table 1, using effect sizes to show the impact of collaboration on a range of learning outcomes.

What do these results mean in real terms instead of effect sizes, which are sometimes difficult to interpret? With respect to academic achievement, the lowest of the three studies cited would move a

Reference	Learning Outcome	Effect Size
Johnson, Johnson and Smith [12]	Improved academic achievement	0.64
	Improved quality of interpersonal interactions	0.60
	Improved self-esteem	0.44
	Improved perceptions of greater social support	0.70
Johnson, Johnson and Smith [13]	Improved academic achievement	0.53
	Improved liking among students	0.55
	Improved self-esteem	0.29
	Improved perceptions of greater social support	0.51
Springer et al. [43]	Improved academic achievement	0.51
	Improved student attitudes	0.55
	Improved retention in academic programs	0.46

Table 1. Collaborative vs. individualistic learning: Reported effect size of the improvement in different learning outcomes.

Reference	Learning Outcome	Effect Size
Johnson, Johnson and Smith [12]	Improved academic achievement	0.67
	Improved interpersonal relationships	0.82
	Improved perceptions of greater social support	0.83
	Improved self-esteem	0.67
Johnson, Johnson and Smith [13]	Improved academic achievement	0.49
	Improved liking among students	0.68
	Improved perceptions of greater social support	0.60
	Improved self-esteem	0.47

Table 2. Collaborative vs. competitive learning: Reported effect size of the improvement in different learning outcomes.

student from the 50^{th} to the 70^{th} percentile on an exam. In absolute terms, this change is consistent with raising a student's grade from 75 to 81, given classical assumptions about grade distributions.* With respect to retention, the results suggest that collaboration reduces attrition in technical programs by 22 percent, a significant finding when technical programs are struggling to attract and retain students. Furthermore, some evidence suggests that collaboration is particularly effective for improving retention of traditionally underrepresented groups [44, 45].

A related question of practical interest is whether the benefits of group work improve with frequency. Springer et al. looked specifically at the effect of incorporating small, medium and large amounts of group work on achievement and found the positive effect sizes associated with low, medium and high amount of time in groups to be 0.52, 0.73 and 0.53, respectively. That is, the highest benefit was found for medium time in groups. In contrast, more time spent in groups did produce the highest effect on promoting positive student attitudes, with low, medium and high amount of time in groups having effect sizes of 0.37, 0.26, and 0.77, respectively. Springer et al. note that the attitudinal results were based on a relatively small number of studies.

In summary, a number of meta-analyses support the premise that collaboration "works" for promoting a broad range of student learning outcomes. In particular, collaboration enhances academic achievement, student attitudes, and student retention. The magnitude, consistency and relevance of these results strongly suggest that engineering faculty promote student collaboration in their courses.

C. Cooperative Learning

At its core, cooperative learning is based on the premise that cooperation is more effective than competition among students for producing positive learning outcomes. This is examined in Table 2.

The reported results are consistently positive. Indeed, looking at high quality studies with good internal validity, the already large effect size of 0.67 shown in Table 2 for academic achievement increases to 0.88. In real terms, this would increase a student's exam score from 75 to 85 in the "classic" example cited previously, though of course this specific result is dependent on the assumed grade distribution. As seen in Table 2, cooperation also promotes interpersonal relationships, improves social support and fosters self-esteem.

Another issue of interest to engineering faculty is that cooperative learning provides a natural environment in which to promote effective teamwork and interpersonal skills. For engineering faculty, the need to develop these skills in their students is reflected by the ABET engineering criteria. Employers frequently identify team skills as a critical gap in the preparation of engineering students. Since practice is a precondition of learning any skill, it is difficult to argue that individual work in traditional classes does anything to develop team skills.

Whether cooperative learning effectively develops interpersonal skills is another question. Part of the difficulty in answering that question stems from how one defines and measures team skills. Still, there is reason to think that cooperative learning is effective in this area. Johnson et al. [12, 13] recommend explicitly training students in the skills needed to be effective team members when using cooperative learning groups. It is reasonable to assume that the opportunity to practice interpersonal skills coupled with explicit instructions in these skills is more effective than traditional instruction that emphasizes individual learning and generally has no explicit instruction in teamwork. There is also empirical evidence to support this conclusion. Johnson and Johnson report that social skills tend to increase more within cooperative rather than competitive or individual situations [46]. Terenzini et al. [47] show that students report increased team skills as a result of cooperative learning. In addition, Panitz [48] cites a number of benefits of cooperative learning for developing the interpersonal skills required for effective teamwork.

In summary, there is broad empirical support for the central premise of cooperative learning, that cooperation is more effective than competition for promoting a range of positive learning outcomes. These results include enhanced academic achievement and a number of attitudinal outcomes. In addition, cooperative learning provides a natural environment in which to enhance interpersonal skills and there are rational arguments and evidence to show the effectiveness of cooperation in this regard.

D. Problem-Based Learning

As mentioned in Section II of this paper, the first step of determining whether an educational approach works is clarifying exactly what the approach is. Unfortunately, while there is agreement on the general definition of PBL, implementation varies widely. Woods et al. [16], for example, discuss several variations of PBL.

> "Once a problem has been posed, different instructional methods may be used to facilitate the subsequent learning process: lecturing, instructor-facilitated discussion, guided decision making, or cooperative learning. As part of the problem-solving process, student groups can be assigned to

*Calculated using an effect size of 0.5, a mean of 75 and a normalized grade distribution where the top 10 percent of students receive a 90 or higher (an A) and the bottom 10 percent receive a 60 or lower (an F).

complete any of the learning tasks listed above, either in or out of class. In the latter case, three approaches may be adopted to help the groups stay on track and to monitor their progress: (1) give the groups written feedback after each task; (2) assign a tutor or teaching assistant to each group, or (3) create fully autonomous, self-assessed "tutorless" groups."

The large variation in PBL practices makes the analysis of its effectiveness more complex. Many studies comparing PBL to traditional programs are simply not talking about the same thing. For meta-studies of PBL to show any significant effect compared to traditional programs, the signal from the common elements of PBL would have to be greater than the noise produced by differences in the implementation of both PBL and the traditional curricula. Given the huge variation in PBL practices, not to mention differences in traditional programs, readers should not be surprised if no consistent results emerge from meta-studies that group together different PBL methods.

Despite this, there is at least one generally accepted finding that emerges from the literature, which is that PBL produces positive student attitudes. Vernon and Blake [19] looking at 35 studies from 1970 to 1992 for medical programs found that PBL produced a significant effective size (0.55) for improved student attitudes and opinions about their programs. Albanese and Mitchell [20] similarly found that students and faculty generally prefer the PBL approach. Norman and Schmidt [18] argue "PBL does provide a more challenging, motivating and enjoyable approach to education. That may be a sufficient raison d'etre, providing the cost of the implementation is not too great." Note that these and most of the results reported in this section come from studies of medical students, for whom PBL has been widely used. While PBL has been used in undergraduate engineering programs [49, 50] there is very little data available for its effectiveness with this population of students.

Beyond producing positive student attitudes, the effects of PBL are less generally accepted, though other supporting data do exist. Vernon and Blake [19], for example, present evidence that there is a statistically significant improvement of PBL on students' clinical performance with an effect size of 0.28. However, Colliver [22] points out that this is influenced strongly by one outlying study with a positive effect size of 2.11, which skews the data. There is also evidence that PBL improves the long-term retention of knowledge compared to traditional instruction [51–53]. Evidence also suggests that PBL promotes better study habits among students. As one might expect from an approach that requires more independence from students, PBL has frequently been shown to increase library use, textbook reading, class attendance and studying for meaning rather than simple recall [19, 20, 53, 54].

We have already discussed the problems with meta-studies that compare non-uniform and inconsistently defined educational interventions. Such studies are easily prone to factors that obscure results. The approach for handling this difficulty with active, collaborative and cooperative learning was to identify the central element of the approach and to focus on this rather than on implementation methods. That is more difficult to do with PBL since it is not clear that one or two core elements exist. PBL is active, engages students and is generally collaborative, all of which are supported by our previous analysis. It is also inductive, generally self-directed, and often includes explicit training in necessary skills. Can one or two elements be identified as common or decisive?

Norman and Schmidt [18] provide one way around the difficulty by identifying several components of PBL in order to show how they impact learning outcomes. Their results are shown in Table 3, taken directly from Norman and Schmidt using the summary of meta-studies provided by Lipsey and Wilson [17]. The measured learning outcome for all educational studies cited by Lipsey and Wilson was academic achievement.

Norman and Schmidt present this table to illustrate how different elements of PBL have different effects on learning outcomes. However, the substantive findings of Table 3 are also worth highlighting for faculty interested in adopting PBL because there seems to be considerable agreement on what works and does not work in PBL.

Looking first at the negative effects, there is a significant negative effect size using PBL with non-expert tutors. This finding is consistent with some of the literature on helping students make the transition from novice to expert problem solvers. Research comparing experts to novices in a given field has demonstrated that becoming an expert is not just a matter of "good thinking" [42]. Instead, research has demonstrated the necessity for experts to have both a deep and broad foundation of factual knowledge in their fields. The same appears to be true for tutors in PBL.

There is also a small negative effect associated with both self-paced and self-directed learning. This result is consistent with the findings of Albanese and Mitchell [20] on the effect of PBL on test results. In seven out of ten cases they found that students in PBL programs scored lower than students in traditional programs on tests of basic science. However, in three out of ten cases, PBL students actually scored higher. Albanese and Mitchell note that these three PBL programs were more "directive" than others,

Characteristic	Effect Size
(a) Individualized	0.23
(b) Cooperative	0.54
(c) Small group	0.31
(d) With non-expert tutors	-0.74
(e) Self-paced	-0.07
(f) Self-directed	-0.05
(g) Using problems	0.20
(h) Inquiry based	0.16
(i) Instruction in problem solving	0.54
(j) Inductive	0.06

Table 3. Effect sizes for academic achievement associated with various aspects of problem-based learning.

indicating that this element might be responsible for the superior exam performance for students in those programs. Therefore, faculty might be advised to be cautious about the amount of self-direction required by students in PBL, at least with regard to promoting academic achievement as measured by traditional exams.

Looking at what seems to work, there are significant positive effect sizes associated with placing students in small groups and using cooperative learning structures. This is consistent with much of the literature cited previously in support of cooperative learning. While PBL and cooperative learning are distinct approaches, there is a natural synergy that instructors should consider exploiting. That is, real problems of the sort used in PBL require teams to solve effectively. At the same time, the challenge provided by realistic problems can provide some of the mutual interdependence that is one of the five tenets of cooperative learning.

Table 3 also shows that positive results come from instruction in problem solving. This is consistent with much of the advice given by proponents of problem-based learning [55]. While practice is crucial for mastering skills such as problem solving, greater gains are realized through explicit instruction of problem solving skills. However, traditional engineering courses do not generally teach problem solving skills explicitly. Table 3 suggests that faculty using PBL consider doing just that.

In conclusion, PBL is difficult to analyze because there is not one or two core elements that can be clearly identified with student learning outcomes. Perhaps the closest candidates for core elements would be inductive or discovery learning. These have been shown by meta-studies to have only weakly positive effects on student academic achievement [56, 57] as measured by exams. This might explain why PBL similarly shows no improvement on student test scores, the most common measure of academic achievement.

However, while no evidence proves that PBL enhances academic achievement as measured by exams, there is evidence to suggest that PBL "works" for achieving other important learning outcomes. Studies suggest that PBL develops more positive student attitudes, fosters a deeper approach to learning and helps students retain knowledge longer than traditional instruction. Further, just as cooperative learning provides a natural environment to promote interpersonal skills, PBL provides a natural environment for developing problem-solving and life-long learning skills. Indeed, some evidence shows that PBL develops enhanced problem-solving skills in medical students and that these skills can be improved further by coupling PBL with explicit instruction in problem solving. Similarly, supporting arguments can be made about PBL and the important ABET engineering outcome of life-long learning. Since self-directed learning and meta-cognition are common to both PBL and life-long learning, a logical connection exists between these desired learning outcomes and PBL instruction, something often not true when trying to promote life-long learning through traditional teaching methods.

IV. Conclusions

Although the results vary in strength, this study has found support for all forms of active learning examined. Some of the findings, such as the benefits of student engagement, are unlikely to be controversial although the magnitude of improvements resulting from active-engagement methods may come as a surprise. Other findings challenge traditional assumptions about engineering education and these are most worth highlighting.

For example, students will remember more content if brief activities are introduced to the lecture. Contrast this to the prevalent content tyranny that encourages faculty to push through as much material as possible in a given session. Similarly, the support for collaborative and cooperative learning calls into question the traditional assumptions that individual work and competition best promote achievement. The best available evidence suggests that faculty should structure their courses to promote collaborative and cooperative environments. The entire course need not be team-based, as seen by the evidence in Springer et al. [43], nor must individual responsibility be absent, as seen by the emphasis on individual accountability in cooperative learning. Nevertheless, extensive and credible evidence suggests that faculty consider a nontraditional model for promoting academic achievement and positive student attitudes.

Problem-based learning presents the most difficult method to analyze because it includes a variety of practices and lacks a dominant core element to facilitate analysis. Rather, different implementations of PBL emphasize different elements, some more effective for promoting academic achievement than others. Based on the literature, faculty adopting PBL are unlikely to see improvements in student test scores, but are likely to positively influence student attitudes and study habits. Studies also suggest that students will retain information longer and perhaps develop enhanced critical thinking and problem-solving skills, especially if PBL is coupled with explicit instruction in these skills.

Teaching cannot be reduced to formulaic methods and active learning is not the cure for all educational problems. However, there is broad support for the elements of active learning most commonly discussed in the educational literature and analyzed here. Some of the findings are surprising and deserve special attention. Engineering faculty should be aware of these different instructional methods and make an effort to have their teaching informed by the literature on "what works."

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Wednesday

Intended Learning Outcomes

Lesson exercises

After the lesson exercises, the participants are able to:

- carry out a lesson exercise by making use of Intended Learning Outcomes and Student Activity as didactic tools.
- contribute constructively to the planning of this lesson and afterwards, in the planning group, contribute to a short evaluation of how the lesson was executed.
- constructively receive feedback on their own teaching.
- engage in a constructive dialogue about others' teaching, for example by evaluating the teaching by making use of the TDS-phases (devolution, action, formulation, validation and institutionalization).
- evaluate how student involvement contribute to achieving the Intended Learning Outcomes.
- relate evaluation of one teaching situation to other teaching situations and teaching contexts.

Planning the lesson exercises

After planning the lesson exercises, the participants are able to:

- plan a lesson that has an inductive approach.
- give and receive constructive feedback to/from group members while planning the lessons.

Preparation for Thursday

For those of you giving your lesson exercise on Thursday, you must plan your lesson with specific focus on (in addition to the previous days' focus):

- Problem-orientation

In your planning group discuss how to accomplish the following in your lesson:

- Think of a problem that can engage the students and motivate them to achieve your learning objectives.
- Use the problem to organise the lesson considering things like:
  - How should the problem be introduced?
  - Should there be group work?
  - What input do the students need in the form of presentation, written material and so on?
  - How much time should be spent on solving the problem?

Inductive Teaching and Learning Methods: Definitions, Comparisons, and Research Bases

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To state a theorem and then to show examples of it is literally to teach backwards.

(E. Kim Nebeuts)

ABSTRACT

Traditional engineering instruction is deductive, beginning with theories and progressing to the applications of those theories. Alternative teaching approaches are more inductive. Topics are introduced by presenting specific observations, case studies or problems, and theories are taught or the students are helped to discover them only after the need to know them has been established. This study reviews several of the most commonly used inductive teaching methods, including inquiry learning, problem-based learning, project-based learning, case-based teaching, discovery learning, and just-in-time teaching. The paper defines each method, highlights commonalities and specific differences, and reviews research on the effectiveness of the methods. While the strength of the evidence varies from one method to another, inductive methods are consistently found to be at least equal to, and in general more effective than, traditional deductive methods for achieving a broad range of learning outcomes.

Keywords: inductive, teaching, learning

I. INTRODUCTION

A. Two Approaches to Education

Engineering and science are traditionally taught deductively. The instructor introduces a topic by lecturing on general principles, then uses the principles to derive mathematical models, shows illustrative applications of the models, gives students practice in similar derivations and applications in homework, and finally tests their ability to do the same sorts of things on exams. Little or no attention is initially paid to the question of *why* any of that is being done. What real-world phenomena can the models explain? What practical problems can they be used to solve, and why should the students care about any of it? The only motivation that students get—if any—is that the material will be important later in the curriculum or in their careers.

A well-established precept of educational psychology is that people are most strongly motivated to learn things they clearly perceive a need to know [1]. Simply telling students that they will need certain knowledge and skills some day is not a particularly effective motivator. A preferable alternative is *inductive teaching and learning*. Instead of beginning with general principles and eventually getting to applications, the instruction begins with specifics—a set of observations or experimental data to interpret, a case study to analyze, or a complex real-world problem to solve. As the students attempt to analyze the data or scenario and solve the problem, they generate a need for facts, rules, procedures, and guiding principles, at which point they are either presented with the needed information or helped to discover it for themselves.

Inductive teaching and learning is an umbrella term that encompasses a range of instructional methods, including inquiry learning, problem-based learning, project-based learning, case-based teaching, discovery learning, and just-in-time teaching. These methods have many features in common, besides the fact that they all qualify as inductive. They are all *learner-centered* (also known as *student-centered*), meaning that they impose more responsibility on students for their own learning than the traditional lecture-based deductive approach. They are all supported by research findings that students learn by fitting new information into existing cognitive structures and are unlikely to learn if the information has few apparent connections to what they already know and believe. They can all be characterized as *constructivist* methods, building on the widely accepted principle that students construct their own versions of reality rather than simply absorbing versions presented by their teachers. The methods almost always involve students discussing questions and solving problems in class (*active learning*), with much of the work in and out of class being done by students working in groups (*collaborative* or *cooperative learning*). The defining characteristics of the methods and features that most of them share are summarized in Table 1.

There are also differences among the different inductive methods. The end product of a project-based assignment is typically a formal written and/or oral report, while the end product of a guided inquiry may simply be the answer to an interesting question, such as why an egg takes longer to boil at a ski resort than at the beach and how frost can form on a night when the temperature does not drop below freezing. Case-based instruction and problem-based learning involve extensive analyses of real or hypothetical scenarios while just-in-time teaching may simply call on students to answer questions about readings prior to hearing

Feature ↓ Method →	Guided Inquiry	Problem-based	Project-based	Case-based	Discovery	Just-in-Time
Questions or problems provide context for learning	**1**	2	2	2	2	2
Complex, ill-structured, open-ended real-world problems provide context for learning	4	**1**	3	2	4	4
Major projects provide context for learning	4	4	**1**	3	4	4
Case studies provide context for learning	4	4	4	**1**	4	4
Students discover course content for themselves	2	2	2	3	**1**	2
Students complete and submit conceptual exercises electronically; instructor adjusts lessons according to their responses	4	4	4	4	4	**1**
Primarily self-directed learning	4	3	3	3	2	4
Active learning	2	2	2	2	2	2
Collaborative/cooperative (team-based) learning	4	3	3	4	4	4

Note: 1–by definition, 2–always, 3–usually, 4–possibly

Table 1. Features of common inductive instructional methods.

about the content of the readings in lectures. However, the similarities trump the differences, and when variations in the implementation of the methods are taken into account, many of the differences disappear altogether.

Although we just claimed that inductive methods are essentially variations on a theme, they do not appear that way in the literature. Each method has its own history, research base, guidebooks, proponents, and detractors, and a great deal of confusion exists regarding what the methods are and how they are interrelated. Our objective in this paper is to summarize the definitions, foundations, similarities, and differences among inductive learning methods and to review the existing research evidence regarding their effectiveness.

Before we begin our review, we will attempt to clarify two points of confusion that commonly arise in discussions of inductive methods.

Is inductive learning really inductive? In practice, neither teaching nor learning is ever purely inductive or deductive. Like the scientific method, learning invariably involves movement in both directions, with the student using new observations to infer rules and theories (induction) and then testing the theories by using them to deduce consequences and applications that can be verified experimentally (deduction). Good teaching helps students learn to do both. When we speak of inductive methods, we therefore do not mean total avoidance of lecturing and complete reliance on self-discovery, but simply teaching in which induction precedes deduction. Except in the most extreme forms of discovery learning (which we do not advocate for undergraduate instruction), the instructor still has important roles to play in facilitating learning—guiding, encouraging, clarifying, mediating, and sometimes even lecturing. We agree with Bransford: "There are times, usually after people have first grappled with issues on their own, that 'teaching by telling' can work extremely well" [2, p. 11].

Are we talking about inductive learning or inductive teaching? Is there a difference? A common point of semantic confusion associated with inductive methods has to do with the distinction between teaching and learning. Thus, for example, one hears about problem-based learning but just-in-time teaching, and both inquiry learning and inquiry-based teaching are commonly encountered in the literature. There is, of course, a difference between learning (what students do) and teaching (what teachers do), but in this paper we will never examine one without explicitly or implicitly considering the other. The reader should therefore understand that when we refer to "inductive learning" or to an inductive instructional method with either teaching or learning in its name, we are talking about both strategies that an instructor might use (teaching) and experiences the students might subsequently undergo (learning).

II. Foundations of Inductive Teaching and Learning

A. Constructivism

According to the model that has dominated higher education for centuries (*positivism*), absolute knowledge ("objective reality") exists independently of human perception. The teacher's job is to transmit this knowledge to the students—lecturing being the natural method for doing so—and the students' job is to absorb it. An alternative model, *constructivism*, holds that whether or not there is an objective reality (different constructivist theories take opposing views on that issue), individuals actively construct and reconstruct their own reality in an effort to make sense of their experience. New information is filtered through mental structures (*schemata*) that incorporate the student's prior knowledge, beliefs, preconceptions and misconceptions, prejudices, and fears. If the new information is consistent with those structures it may be integrated into them, but if it is contradictory, it may be memorized for the exam but is unlikely to be truly incorporated into the individual's belief system—which is to say, it will not be learned.

Constructivism has its roots in the eighteenth-century philosophies of Immanuel Kant and Giambattista Vico, although some have traced it as far back as the fourth to sixth centuries B.C. in the works of Lao Tzu, Buddha, and Heraclitus. The constructivist view of learning is reflected in the developmental theories of Piaget [3], Dewey [4], Bruner [5], and Vygotsky [6], among others. In *cognitive constructivism*, which originated primarily in the work of Piaget, an individual's reactions to experiences lead to (or fail to lead to) learning. In *social constructivism*, whose principal proponent is Vygotsky, language and interactions with others—family, peers, teachers—play a primary role in the construction of meaning from experience. Meaning is not simply constructed, it is co-constructed.

Proponents of constructivism (e.g., Biggs [7]) offer variations of the following principles for effective instruction:

- Instruction should begin with content and experiences likely to be familiar to the students, so they can make connections to their existing knowledge structures. New material should be presented in the context of its intended real-world applications and its relationship to other areas of knowledge, rather than being taught abstractly and out of context.
- Material should not be presented in a manner that requires students to alter their cognitive models abruptly and drastically. In Vygotsky's terminology, the students should not be forced outside their "zone of proximal development," the region between what they are capable of doing independently and what they have the potential to do under adult guidance or in collaboration with more capable peers [6]. They should also be directed to continually revisit critical concepts, improving their cognitive models with each visit. As Bruner [5] puts it, instruction should be "spirally organized."
- Instruction should require students to fill in gaps and extrapolate material presented by the instructor. The goal should be to wean the students away from dependence on instructors as primary sources of required information, helping them to become self-learners.
- Instruction should involve students working together in small groups. This attribute—which is considered desirable in all forms of constructivism and essential in social constructivism—supports the use of collaborative and cooperative learning.

The traditional lecture-based teaching approach is incompatible with all of these principles. If the constructivist model of learning is accepted—and compelling research evidence supports it—then to be effective instruction must set up experiences that induce students to construct knowledge for themselves, when necessary adjusting or rejecting their prior beliefs and misconceptions in light of the evidence provided by the experiences. This description might serve as a definition of inductive learning.

B. Cognition Research

Bransford et al. [2] offer a comprehensive survey of neurological and psychological research that provides strong support for constructivism and inductive methods. Here are some of their findings:

- "*All new learning involves transfer of information based on previous learning*" [2, p. 53].

Traditional instruction in engineering and science frequently treats new courses and new topics within courses as self-contained bodies of knowledge, presenting theories and formulas with minimal grounding in students' prior knowledge and little or no grounding in their experience. Inductive instruction, on the other hand, presents new information in the context of situations, issues, and problems to which students can relate, so there is a much greater chance that the information can be linked to their existing cognitive structures.

Since learning is strongly influenced by prior knowledge, if new information is fully consistent with prior knowledge it may be learned with relative ease, but if it involves a contradiction several things may happen. If the contradiction is perceived and understood, it may initially cause confusion but the resolution of the contradiction can lead to elimination of misconceptions and greater understanding. However, if learners fail to understand the contradiction or if they can construct coherent (to them) representations of the new material based on existing misconceptions, deeper misunderstanding may follow [2, p. 70]. Traditional teaching generally does little to force students to identify and challenge their misconceptions, leading to the latter situation. The most effective implementations of inductive learning involve *diagnostic teaching*, with lessons being designed to "discover what students think in relation to the problems on hand, discussing their misconceptions sensitively, and giving them situations to go on thinking about which will enable them to readjust their ideas" [2, p. 134]. The proper choice of focus questions and problems in inquiry-based, problem-based, and discovery learning methods can serve this function.

- *Motivation to learn affects the amount of time students are willing to devote to learning. Learners are more motivated when they can see the usefulness of what they are learning and when they can use it to do something that has an impact on others* [2, p. 61].

This finding supports techniques that use authentic (real-world, professionally relevant) situations and problems to provide contexts for learning the content and skills a course is intended to teach. Inductive methods such as problem-based learning and case-based teaching do this.

- *The likelihood that knowledge and skills acquired in one course will transfer to real work settings is a function of the similarity of the two environments* [2, p. 73].

School often emphasizes abstract reasoning while work focuses almost exclusively on contextualized reasoning. Organizing learning around authentic problems, projects, and cases helps to overcome these disparities and improves the likelihood of subsequent transfer, in addition to increasing motivation to learn as noted in the previous item. Moreover, traditional schools differ from most work environments in that school heavily emphasizes individual work while most work involves extensive collaboration. Assigning teams to perform most required tasks (as most inductive methods do) thus further promotes transfer, provided that the students are helped to develop teamwork skills and the work is organized in a way that assures individual accountability for all of the learning that takes place [8–12].

- *Helping students develop metacognition—knowledge of how they learn—improves the likelihood of their transferring information learned in one context to another one* [2, p. 67].

Methods that train students in systematic problem-solving methods (generating and evaluating alternative solutions, periodically assessing progress toward the solution, extracting general principles from specific solutions, etc.) and call on them to make sense of new information, to raise questions when they cannot, and to regularly assess their own knowledge and skill levels promote the development of metacognitive skills. Most variants of problem-based learning include such steps.

C. Intellectual Development and Approaches to Learning

Most college students undergo a developmental progression from a belief in the certainty of knowledge and the omniscience of authorities to an acknowledgment of the uncertainty and contextual nature of knowledge, acceptance of personal responsibility for determining truth, inclination and ability to gather supporting evidence for judgments, and openness to change if new evidence is forthcoming [13, 14]. At the highest developmental level normally seen in college students (termed "contextual relativism" by Perry [13]), individuals display thinking patterns resembling those of expert scientists and engineers. A goal of science and engineering instruction should be to advance students to that level by the time they graduate.

In their courses, students may be inclined to approach learning in one of three ways [15]. Some take a *surface approach*, relying on rote memorization and mechanical formula substitution, making little or no effort to understand the material being taught. Others may adopt a *deep approach*, probing and questioning and exploring the limits of applicability of new material. Still others use a *strategic approach*, doing whatever is necessary to get the highest grade they can, taking a surface approach if that suffices and a deep approach when necessary. Another goal of instruction should be to induce students to adopt a deep approach to subjects that are important for their professional or personal development.

Felder and Brent [16] observe that the characteristics of high levels of intellectual development and of a deep approach to learning are essentially the same. Both contextual relativism and a deep approach involve taking responsibility for one's own learning, questioning authorities rather than accepting their statements at face value, and attempting to understand new knowledge in the context of prior knowledge and experience. It is reasonable to assume that instructional conditions that induce students to adopt a deep approach should also promote intellectual growth.

Several conditions of instruction have been shown to promote a deep approach, including interest and background knowledge of the subject, use of teaching methods that foster active and long-term engagement with learning tasks, and assessment that emphasizes conceptual understanding as opposed to recall or the application of routine procedural knowledge [17]. Well implemented inductive teaching methods serve all of these functions. Authentic problems and case studies can motivate students by helping to make the subject matter relevant, and they also tend to keep the students interested and actively engaged in their learning tasks. Having to analyze complex situations also promotes the students' adoption of a deep approach to learning, as rote memorization and simple algorithmic substitution are clearly inadequate strategies for dealing with such situations. Moreover, open-ended problems that do not have unique well-defined solutions pose serious challenges to students' low-level beliefs in the certainty of knowledge and the role of instructors as providers of knowledge. Such challenges serve as precursors to intellectual growth [14].

D. Learning Cycle-Based Instruction

Several well-known instructional models involve *learning cycles*, wherein students work through sequences of activities that involve complementary thinking and problem-solving approaches. In most of these cycles, the different activities are designed to appeal to different learning style preferences (concrete and abstract, active and reflective, etc.) [18]. When instructors *teach around the cycle* in this manner, all students are taught partly in a manner they prefer, which leads to an increased comfort level and willingness to learn, and partly in a less preferred manner, which provides practice and feedback in ways of thinking they might be inclined to avoid but which they will have to use to be fully effective professionals. Teaching around the best known of such cycles—that associated with Kolb's experiential learning model [19]—involves: (1) introducing a problem and providing motivation for solving it by relating it to students' interests and experience (the focal question is *why?*); (2) presenting pertinent facts, experimental observations, principles and theories, problem-solving methods, etc., and opportunities for the students to reflect on them (*what?*); (3) providing guided hands-on practice in the methods and types of thinking the lessons are intended to teach (*how?*); and (4) allowing and encouraging exploration of consequences and applications of the newly learned material (*what if?*).

A learning cycle developed at the Vanderbilt University Learning Technology Center is the *STAR Legacy module* (Software Technology for Action and Reflection) [20], which consists of the following steps:

1. Students are presented with a *challenge* (problem, scenario, case, news event, or common misconception presenting the targeted content in a realistic context) that establishes a need to know the content and master the skills included in the learning objectives for the module.
2. The students then formulate their *initial thoughts*, reflecting on what they already know and think about the context of the challenge and generating ideas about how they might address the challenge.
3. *Perspectives and resources* are provided next. Perspectives are statements by experts that offer insights into various dimensions of the challenge without providing a direct solution to it, and resources may include lectures, reading materials, videos, simulations, homework problems, links to websites, and other materials relevant to the challenge.
4. *Assessment* activities are then carried out in which the students apply what they know, and identify what they still need to learn to address the challenge. The activities may include engaging in self-assessments and discussions, completing homework assignments, writing essays or reports, and taking on-line quizzes or exams. Multiple iterations between Steps 3 and 4 would normally be required to fully meet the challenge.
5. In the final *wrap-up*, an expert may present a model solution to the challenge, or the students may present a report and/or complete an examination showing that they have met the challenge and demonstrated their mastery of the knowledge and skills specified in the learning objectives.

The Star Legacy module is a clear exemplar of an inductive approach to teaching and learning. Depending on the nature and scope of the challenge, instruction based on such a module would qualify as inquiry learning, project-based learning, or problem-based learning. Similarly, learning cycles based on learning styles that begin with the presentation of a realistic problem or a challenge of some sort are inductive. Instruction based on learning cycles is consistent with accepted principles of cognitive science [2] and its effectiveness has been repeatedly demonstrated empirically [21].

In summary, inductive approaches to teaching and learning have much in their favor. They are supported by the best research on learning currently available, compatible with the currently most widely accepted theories of learning, and promote problem-solving skills and attitudes to learning that most instructors would say they desire for their students. Following a brief section on assessment, we will examine the individual inductive methods—what they are, what they have in common and how they differ, and what is known about how well they succeed in achieving desired educational outcomes.

III. Assessment and Evaluation of Inductive Methods

Rigorous comparisons of inductive methods with traditional expository methods are not easy to design for several reasons [22].

- There are many varieties of inductive approaches, each of which can be implemented in many ways—with greater or lesser instructor involvement, with or without formal facilitation of teamwork, with most of the work being done in or out of class, and so on. Two articles may claim to be studies of, say, problem-based learning, but they could involve dramatically different forms of instruction and may well produce different learning outcomes.
- Instructors may have varying degrees of experience and skill with whichever method they adopt. Two different instructors using the same method in the same class could get different results.
- Student populations also vary considerably in distributions of gender and ethnicity, age, experience, motivation to learn, learning styles, and levels of intellectual development (among others) [21]. The same instructor could use the same method in two different classes and get different outcomes.
- The conclusions drawn from a study may depend strongly on the learning outcome investigated—acquisition of factual knowledge, development of a problem-solving or interpersonal skill, retention in a curriculum, self-confidence level, attitude, or any combination of these. An inductive method may be superior with respect to one outcome and inferior with respect to another. (We will shortly see an example of this phenomenon in the case of problem-based learning, which has frequently been found to lead to superior high-level skills and attitudes but inferior short-term acquisition of factual knowledge.) Moreover, reliable and valid assessments of high-level skills such as critical or creative thinking or attributes such as lifelong learning skills are difficult to obtain, and two studies that use different assessment methods could arrive at different conclusions.
- Finally, as Prince [22] points out, implementations of inductive approaches such as problem-based learning normally involve active and collaborative learning methods, both of which are known to have positive effects on many learning outcomes. If an inductive method is found to have a positive effect, sorting out how much of it can be attributed to the method itself and how much to other methods imbedded in it can be a formidable challenge.

Considering these difficulties, it is not surprising that published studies report both positive and negative outcomes for inductive learning relative to conventional instruction. Given the difficulty (if not impossibility) of carrying out a clean and conclusive comparative study, the best we can do is to look at results from a number of studies with different instructors, implementations, learning outcomes, and student populations, to see if any robust generalizations can be inferred. The sections that follow summarize results of such meta-analyses.

IV. Inquiry Learning

A. Definition and Applications

Inquiry learning begins when students are presented with questions to be answered, problems to be solved, or a set of observations to be explained [23]. If the method is implemented effectively, the students should learn to "formulate good questions, identify and collect appropriate evidence, present results systematically, analyze and interpret results, formulate conclusions, and evaluate the worth and importance of those conclusions [24]." The same statements could also be made about problem-based learning, project-based learning, discovery learning, certain forms of case-based instruction, and student research, so that inquiry learning may be considered an umbrella category that encompasses several other inductive teaching methods. Lee makes this point, observing that inquiry is also consistent with interactive lecture, discussion, simulation, service learning, and independent study, and in fact "probably the only strategy that is not consistent with inquiry-guided learning is the exclusive use of traditional lecturing" [24, p. 10]. In this paper we will use the term *inquiry learning* to refer to instruction that uses questions and problems to provide contexts for learning and does not fall into another more restrictive inductive learning category.

Besides overlapping with other inductive methods, inquiry learning encompasses a variety of techniques that differ from one another in significant ways. Staver and Bay [25] differentiate between *structured inquiry* (students are given a problem and an outline for how to solve it), *guided inquiry* (students must also figure out the solution method) and *open inquiry* (students must formulate the problem for themselves). Smith [26] makes a similar distinction between *teacher inquiry*, in which the teacher poses questions, and *learner inquiry*, in which questions are posed by the students. In *process-oriented-guided-inquiry-learning* (POGIL), students work in small groups in a class or laboratory on instructional modules that present them with information or data, followed by leading questions designed to guide them toward formulation of their own conclusions. The instructor serves as facilitator, working with student groups if they need help and addressing class-wide problems when necessary. Some proponents of inquiry suggest using a relatively structured form of inquiry in the first year, gradually shifting toward more self-directed learning (including problem formulation) as the curriculum progresses, while others advocate moving immediately to self-direction [24].

Inquiry-based methods have been used extensively in the sciences [27–32] and to a lesser extent in engineering [33, 34]. Guided inquiry has been particularly widely used in chemistry curricula. The POGIL Web site contains reports of implementations on several campuses, instructional materials for different branches of chemistry, and a video showing an implementation of the method in an introductory chemistry class.[1]

Lee et al.[24] report on a series of inquiry-based courses in different disciplines at North Carolina State University that had four desired student outcomes in common: (a) improved critical thinking skills, (b) greater capacity for independent inquiry, (c) taking more responsibility for one's own learning, (d) intellectual growth (e.g., on the Perry scale of intellectual development). Following are several examples.

- Introductory chemistry and physics courses are conducted in a hands-on inquiry-based environment called SCALE-UP (Student-Centered Activities for Large Enrollment University Programs) [35]. Students read and take quizzes about assigned material before coming to class (a characteristic of *Just-in-Time Teaching*, another inductive technique to be discussed), and work in teams on activities designed to help them discover or investigate concepts for themselves.
- In an introductory first-year microbiology course, the students read articles, generate questions stimulated by the readings, identify underlying hypotheses and assumptions in the articles, discuss their findings in small groups, and submit both their individual work and group assignments. In honors sections of several third-year microbiology courses, the students do extensive analysis and interpretation of experimental data and case studies, with emphasis being placed on collecting and interpreting scientific data and testing hypotheses [36].
- In a first-year paper science and engineering course, the students complete an open-ended design project, and in another first-year course they spend most of their time working in teams on advanced problems at a level previously reserved for seniors, learning on their own a great deal of the material that would traditionally have been delivered in lectures [37].
- In an experimental College of Engineering program, instructors are given grants to develop innovative classroom applications of laptop computers with wireless Internet access, which are made available to all students in their courses. Courses in this program that made inquiry a significant component of their instruction included the second and third semesters of calculus, in which students used MAPLE® to explore solutions to real-world problems, and a course on JAVA programming, in which students worked in pairs at the computer during class to develop and implement programs and to clarify their conceptual understanding of programming principles [38].

B. Evaluation

Several published meta-analyses conclude that inquiry-based instruction is generally more effective than traditional instruction for achieving a variety of learning outcomes [26, 39]. Shymansky et al. [40] analyzed results from 81 experimental studies involving thousands of students and found that inquiry learning produced significant positive gains for academic achievement, student perceptions, process skills and analytic abilities. In a meta-analysis of 79 individual studies between 1965 and 1995 involving students from seventh grade through college, Smith [26] found that inquiry learning improved academic achievement (effect size = 0.33), critical thinking skills (effect size = 0.77) and laboratory skills (effect size = 0.14). There was also a slight improvement in process skills (effect size = 0.05), which was not statistically significant. In a meta-study of laboratory instruction conducted over roughly the same time period, Rubin [41] found that inquiry-based instruction was superior to traditional instruction for cognitive learning outcomes, which included conceptual and subject learning, reasoning ability, and creativity (effect size = 0.18), as well as for non-cognitive outcomes, including manipulative skills and attitudes (effect size = 0.39).

Colburn's review of the literature [42] concludes that inquiry-based methods are likely to be more effective than deductive methods in helping students gain understanding of concrete observable phenomena, and less so in helping them understand how scientists explain or model phenomena (e.g., via kinetic and molecular theories in chemistry and physics). He recommends focusing activities around questions that students can answer directly via investigation, which helps assure that the activities are oriented toward concrete concepts. He also advises emphasizing activities that use materials and situations familiar to students for which they have the necessary prerequisite skills and knowledge to succeed, but pose a sufficient level of challenge to help them develop better thinking skills.

V. Problem-Based Learning

A. Definition and Applications

Problem-based learning (PBL) begins when students are confronted with an open-ended, ill-structured, authentic (real-world) problem and work in teams to identify learning needs and develop a viable solution, with instructors acting as facilitators rather than primary sources of information [43–50]. Class time may be devoted to: (a) groups reporting out their progress on previous learning issues and listing their current learning issues and plans of work, (b) mini-lectures giving information on issues being dealt with by all groups, clarifying common difficulties, and suggesting additional learning issues, and (c) whole class discussion [50]. A well-designed problem guides students to use course content and methods, illustrates fundamental principles, concepts, and procedures, and perhaps induces the students to infer those things for themselves instead of getting them directly from the instructor; and engages the students in the types of reflection and activities that lead to higher-order learning. Problems may vary significantly in scope, from single-topic single-discipline problems that can be solved in a matter of days to multidisciplinary problems that may take an entire semester to solve. The formulation of problems is discussed by Weiss [47], Tan [48, Ch. 6], and several authors in the edited volume of Duch et al. [49].

PBL may be implemented in a variety of ways [50]. In the *medical school model*, students work in groups of 7–10 under the supervision of a faculty member or another designated tutor (e.g. a graduate student or advanced undergraduate). There is very little formal class time, if any. In the *floating facilitator model*, students work on problems in groups of three to five during class. The instructor moves from group to group during class, asking questions

[1]Web site: www.pogil.org; Video: www.pogil.org/resources/GI_video.php.

and probing for understanding. Different levels of external guidance may be provided by a faculty member or a designated tutor, or responsibility for the work may be taken by the groups themselves in what Woods [51] calls *self-directed*, *interdependent*, *small group problem-based learning.* Acar and Newman [52] describe a module in which students in their final year of a systems engineering program served as tutors to first and second year students doing PBL-based project work. The experience was instructive for both the tutors and the tutees, with the former noting its helpfulness in interviews and as preparation for the workplace.

Modern problem-based learning originated in medical schools, principally those at Case Western Reserve University in the 1950s and McMaster University in the 1960s. It is now extensively practiced in medical education and other health-related disciplines including veterinary medicine and nursing [53], and in other fields including architecture, psychology, business and management, and engineering [48, 54]. It has been used in a number of curricula at the University of Delaware and Samford University in the United States, McMaster University in Canada, the University of Maastricht in the Netherlands, Linköping University in Sweden, and the University of Newcastle in Australia; in chemical engineering at McMaster [51, 55], Bucknell University [56, 57] and the Universitat Rovira I Virgili in Spain [58] and civil engineering at Monash University in Australia [59–61]; and in an integrated physics, mathematics, and computer science course at the Instituto Tecnológico y de Estudios Superiores de Monterrey, Mexico [62]. PBL problems in chemistry and physics (and many other fields) and guidance on how to use them are given in Duch et al. [49] and on Web sites maintained at the University of Delaware[2] and Samford University[3], both of which provide links to many other resources. A 2003 issue of the *International Journal of Engineering Education* (Vol. 19, No. 5) is devoted entirely to PBL implementations at universities around the world.

Nelson [63] discusses using design projects as a basis for problem-based learning, observing that the stages of design—*naming* (identifying main issues in the problem), *framing* (establishing the limits of the problem), *moving* (taking an experimental action), and *reflecting* (evaluating and criticizing the move and the frame) provides an ideal framework for the PBL process. He cites examples in which he used PBL successfully to teach graduate courses in instructional design, software development, and project management. The previously described Star Legacy module developed at Vanderbilt University [20] provides another excellent framework for PBL.

B. Evaluation

Dochy et al. [64] published a meta-analysis of the effectiveness of problem-based learning. The authors identified 43 empirical studies of the effects of PBL on knowledge acquisition and development of problem-solving skills in college students. Only studies that utilized natural classroom instruction (as opposed to controlled laboratory studies) were included in the data base. The average effect size was calculated both in an unweighted form and with each effect size weighted by the inverse of the variance (which being proportional to N gives greater weight to larger samples).

Seven of the studies analyzed found a positive effect of PBL on knowledge acquisition and 15 found a negative effect, with a weighted average effect size and 95 percent confidence interval of -0.223 (± 0.058). When only true randomized tests are included; however, the negative effect of PBL on knowledge acquisition almost disappears, and when the assessment of knowledge is carried out some time after the instruction was given, the effect of PBL is positive. The implication is that students may acquire more knowledge in the short term when instruction is conventional but students taught with PBL retain the knowledge they acquire for a longer period of time. For skill development, the results are unequivocal: 14 studies found a positive effect and none found a negative effect, and the weighted average effect size was 0.460 (± 0.058). The positive effect of PBL on skill development holds regardless of whether the assessment is concurrent with the instruction or delayed.

Prince [22] examined several meta-analyses of problem-based learning, separately considering the effects of its constituent approaches: active learning (actively engaging students in the learning process in class, as opposed to merely presenting them with information), collaborative learning (students work on problems and projects collaboratively rather than doing everything individually), and cooperative learning (team-based learning in which certain criteria must be met, most notably, individual accountability for all of the learning that is supposed to take place). He concluded that the strongest positive effects of PBL related to the student and faculty responses to the method and to a small but robust improvement in students' skill development. While a statistically significant effect was not found for improvement of academic achievement as measured by exams, there was evidence that PBL enhanced students' retention and ability to apply material.

Individual studies have found a robust positive effect of PBL on skill development [1, 65, 66], understanding the interconnections among concepts [65], deep conceptual understanding [67], ability to apply appropriate metacognitive and reasoning strategies [68], teamwork skills [69], and even class attendance [70], but have not reached any firm conclusion about the effect on content knowledge. A longitudinal study of the effectiveness of the McMaster PBL program in chemical engineering demonstrated its superiority to traditional education in the development of key process skills [55]. PBL has also been shown to promote self-directed learning [71] and the adoption of a deep (meaning-oriented) approach to learning, as opposed to a superficial (memorization-based) approach [21, 46, 72].

Several papers discuss the possible tradeoff between knowledge acquisition and skill development, or alternatively, between breadth and depth of content coverage when PBL is used. de Graaf and Kolmos [73] observe that students may be expected to reach a level of analytical comprehension through problem-based work that cannot be attained in conventionally-taught classes, but they might experience subject area gaps in doing so and so should be equipped to fill in such gaps when a need arises. Perrenet et al. [74] make a similar point specifically related to engineering education. They observe that if PBL is implemented in a way that permits considerable self direction by the students, the learning that takes place may not necessarily attack and correct the misconceptions that hinder understanding of critical engineering concepts, which could in turn interfere with the students' ability to

[2]www.udel.edu/pbl
[3]www.samford.edu/pbl

apply their learning to novel problems in a professional setting. They also note that unlike medicine, which has an encyclopedic structure, the knowledge structures of engineering and the sciences tend to be hierarchical. Engineering students engaged in self-guided PBL might easily overlook or bypass critical topics, which could interfere with future learning of important content, especially if the implementation of PBL is curriculum-wide rather than being limited to a few specific courses. Instructors should be aware of these potential pitfalls and design courses and problem sets so that all essential concepts are addressed.

Problem-based learning is not an easy instructional method to implement. It requires considerable subject expertise and flexibility on the part of instructors, who may be forced out of their areas of expertise when student teams set off in unpredictable and unfamiliar directions. PBL also makes students assume unaccustomed levels of responsibility for their own learning, and all of the project management problems and interpersonal conflicts that commonly occur when students are required to work in teams crop up in PBL. Many students are consequently hostile to PBL when they first encounter it, which can be intimidating to instructors who are unprepared for this reaction. Instructors—particularly relatively new ones—are therefore not advised to jump into full-scale problem-based learning until they familiarize themselves with proven facilitation techniques, and they are also advised to use *scaffolding*, providing a fairly high level of guidance to students who are new to PBL and gradually withdrawing it as the students gain more experience with the approach [75]. Tan [48, Ch. 4] provides an excellent guide to instructors on preparing students for PBL and helping them adjust to this instructional method, and good guidance is also provided by Duch et al. [49] and Woods [51].

The possibility of student resistance should not deter knowledgeable instructors from adopting the method. A number of studies offer evidence that most students who experience PBL eventually come to favor it over traditional methods [66, 67, 70, 76, 77].

VI. Project-Based Learning and Hybrid (Problem/Project-Based) Approaches

A. Definition and Applications

Project-based learning begins with an assignment to carry out one or more tasks that lead to the production of a final product—a design, a model, a device or a computer simulation. The culmination of the project is normally a written and/or oral report summarizing the procedure used to produce the product and presenting the outcome. (Note: The acronym PBL is frequently used to denote project-based learning as well as problem-based learning. We will not do so in this paper to avoid adding to the confusion this labeling may cause.)

A trade-off exists between instructors being fairly directive in choosing projects, which helps maintain a focus on course and curriculum objectives, and allowing students the autonomy to choose their own project formulations and strategies, which increases their motivation. de Graaf and Kolmos [73] define three types of projects that differ in the degree of student autonomy:

- *Task project:* Student teams work on projects that have been defined by the instructor, using largely instructor-prescribed methods. This type of project provides minimal student motivation and skill development, and is part of traditional instruction in most engineering curricula.
- *Discipline project:* The instructor defines the subject area of the projects and specifies in general terms the approaches to be used (which normally involve methods common in the discipline of the subject area), but the students identify the specific project and design the particular approach they will take to complete it.
- *Problem project:* The students have nearly complete autonomy to choose their project and their approach to it.

de Graaf and Kolmos [73] note that a common difficulty faced by students in a project-based environment is transferring methods and skills acquired in one project to another project in a different subject or discipline. Instructors should include such transference in their course objectives and should guide students to see connections between their current project and what they have learned previously, gradually withdrawing this support as the students become more adept at seeing the connections themselves. The instructors should also prepare students to fill in gaps in content knowledge when a need arises, taking into account the fact that such gaps may be more likely to arise in project-based learning than in conventional lecture-based instruction.

Project-based learning at the individual course level is familiar in engineering education, having been used almost universally in capstone design and laboratory courses and with growing frequency in first-year engineering courses and courses that engage students in consulting projects [78–80]. A few schools have made project-based learning the focus of many or most of their engineering courses, including the Universities of Aalborg and Roskilde in Denmark; Bremen, TU Berlin, Dortmund, and Oldenburg in Germany, Delft and Wageningen in the Netherlands [81], Monash University and Central Queensland University in Australia [82], and Olin College in the United States [83].

Project-based learning is similar to problem-based learning in several respects. Both normally involve teams of students in open-ended assignments that resemble challenges the students are likely to encounter as professionals, and both call for the students to formulate solution strategies and to continually re-evaluate their approach in response to outcomes of their efforts. However, there are differences in the two approaches as they have traditionally been implemented. A project typically has a broader scope and may encompass several problems. Also, in project-based learning, the end product is the central focus of the assignment and the completion of the project primarily requires application of previously acquired knowledge, while solving a problem requires the acquisition of new knowledge and the solution may be less important than the knowledge gained in obtaining it. In other words, the emphasis in project-based learning is on applying or integrating knowledge while that in problem-based learning is on acquiring it.

In practice, however, the distinction between the two methods is not necessarily that clean, and programs have recently adopted approaches that include features of both of them. The University of Aalborg has the oldest and best known project-based engineering curriculum in the world, which began with the formation of the university in 1974. Project work accounts for roughly 50 percent of the curriculum, with task and problem projects dominating the first year of instruction, task and discipline projects dominating the second and third years, and problem projects dominating the fourth and fifth years [73]. The current approach at Aalborg is a hybrid of problem-based and project-based learning, with the projects being more about acquiring knowledge than applying it [84]. The main goal in the first year is to give students a general competence in project work and an awareness of general problem solving methods, while in the rest of the curriculum the focus shifts to more specific technical and scientific learning objectives, with the project work being mainly a mechanism for achieving those goals.

Aalborg has recently adapted its project-based approach to distance education offerings, with virtual groups meeting once or twice a week using Internet chat facilities [85]. Many of the positive features of project work have been observed in this format as well, although the authors note that the experience seems to accentuate the differences between strong and weak students, with the latter being more likely to become less motivated and to make less progress in the distance environment than they do in a conventional classroom environment.

Another institutional implementation of problem/project-based learning was initiated in 2000 by the engineering school of the University of Louvain in Belgium, with both week-long problems and semester-long projects being routinely assigned to student teams in the first two years of the engineering curriculum [86]. The evaluation of this program summarized in the next section provides some of the best available evidence for the effectiveness of the hybrid approach.

B. Evaluation

Thomas [87] carried out an extensive review of research on project-based learning done primarily at the pre-college level, considering only projects that (a) were central to the course, (b) focused on central concepts and principles of the discipline, (c) required acquisition of some new knowledge rather than being straightforward applications of existing knowledge, (d) were student-driven to some degree (as opposed to being "cookbook" exercises), and (e) were authentic, containing as many elements as possible of the type of environment the students are likely to encounter as professionals. The findings resemble those found for problem-based learning: comparable or somewhat better performance in project-based environments on tests of content knowledge, and significantly better performance on assessments of conceptual understanding and ability to solve problems that require it, metacognitive skills, and attitudes to learning. Thomas also cites studies suggesting that project-based learning may effectively reach students whose learning styles are poorly suited to a traditional lecture-based classroom environment.

More recently, Mills and Treagust [82] reviewed published evaluations of project-based learning programs in engineering and concluded that the findings are similar to those for problem-based learning in medicine. Relative to traditionally-taught students, students who participate in project-based learning are more motivated, demonstrate better communication and teamwork skills, and have a better understanding of issues of professional practice and how to apply their learning to realistic problems; however, they may have a less complete mastery of engineering fundamentals, and some of them may be unhappy over the time and effort required by projects and the interpersonal conflicts they experience in team work, particularly with teammates who fail to pull their weight. In addition, if the project work is done entirely in groups, the students may be less well equipped to work independently.

The hybrid (problem/project-based) curriculum at the University of Louvain was assessed by a multidisciplinary team of engineers and educators, who compared three cohorts of students who passed through the new curriculum with two cohorts from the final years of the old (traditional) curriculum [86]. The assessment measures included pretests and posttests of students' basic knowledge, understanding of concepts, and ability to apply them; students' self-efficacy, intrinsic vs. extrinsic goal orientation, satisfaction with the curriculum, learning and self-regulating strategies, and attitudes toward group work; and instructors' teaching practices, satisfaction with teaching, and perceptions of the impact of the PBL curriculum on the instructional environment. The student tests and questionnaire responses were blind-rated after the fourth year of the study, so that the raters did not know whether the subjects had gone through the old or the new curriculum.

The results of the Louvain study are dramatic. Of 79 between-group comparisons of knowledge, conceptual understanding, and application, 23 favored the new curriculum, one favored the old one, and the remainder showed no significant differences. Students in the new curriculum felt that they received more support from their instructors, saw more connections between theory and practice, were more inclined to use autonomous learning strategies (search for information, seek help when needed, verify completed work), and were less reliant on rote memorization relative to students in the old curriculum. The superior outcomes for the PBL-taught students could be attributed in part to their perception of greater support from their instructors, a factor known to have a positive impact on both performance and attitudes. They also felt that they had to work more and harder than students taught traditionally, and they had problems with being tested individually after doing most of their work in groups (a common complaint of students working in a heavily collaborative learning environment). Teachers in the study saw a positive impact of the PBL curriculum on student competencies in teamwork, modeling, transfer of knowledge, and analysis; the quality of student-teacher interactions and teacher-teacher interactions; their satisfaction with and pleasure in teaching; and their engagement in teaching and willingness to change their teaching practices. The last two outcomes were particularly strong among teachers who perceived their administration to be supportive of teaching (encouraging discussion of teaching, valuing teaching improvement, and offering training and collegial support). This result has important implications for the critical role of administrators in attempts to reform education.

VII. Case-Based Teaching

A. Definition and Applications

In case-based teaching, students analyze case studies of historical or hypothetical situations that involve solving problems and/or making decisions. Kardos and Smith [88] defined a case in the context of engineering education as "an account of an engineering activity, event or problem containing some of the background and complexities actually encountered by an engineer." The same definition (with the appropriate substitution being made for "engineering") applies to law, medicine, management, teacher education, or any of the other fields that have made extensive use of cases for professional training.

Cases in all fields typically involve one or more challenges of various types, such as diagnosing technical problems and formulating solution strategies, making business management decisions taking into account technical, economic, and possibly social and psychological considerations, and confronting ethical dilemmas. The cases should be authentic—representative of situations likely to be encountered in professional practice—and may be drawn from stories in newspapers or magazines or built from interviews with individuals involved in the situations in question. A case might include descriptions of what happened and what led up to it, the problems and challenges, the resources and constraints under which solutions could be sought, the decisions that were made, the actions that were taken, and the outcomes. The idea is that in analyzing complex authentic cases, the students become aware of the kinds of situations and dilemmas they might have to face as professionals, gain both theoretical and practical understanding of their subjects, develop critical reasoning skills, explore their existing preconceptions, beliefs, and patterns of thinking, and make necessary modifications in those preconceptions, beliefs, and patterns to accommodate the realities of the cases [89]. These attributes of case-based teaching—particularly those related to making students aware of their preconceptions and beliefs—clearly fit comfortably in the framework of constructivism.

Whether or not case-based instruction qualifies as inductive (and, one might suspect, whether and how well it succeeds) depends on how it is implemented. In one variant (which Lynn [90] terms a "research case"), the case is a complete narrative of a problematic situation, how people dealt with it, and what the outcomes were. Students may be called on to study the case ahead of time and be prepared to discuss it in class, but the same may be said of any traditional lecture-based approach that incorporates Socratic questioning. Lynn observes that research cases can be useful for illustrating appropriate, typical, or exemplary decision making but not for teaching critical thinking and decision-making skills, since in those cases the thinking has already been done, the decisions made, and the outcomes determined and given to the students. Instruction based on the use of such cases cannot be considered inductive.

Forms of case-based instruction that *are* inductive use what Lynn calls "teaching cases," in which the circumstances of the case are described but the decisions made by the protagonists are withheld so that the students can do their own analysis and decision-making. Analyses of teaching cases involve several steps [91]: (1) review of the case content, (2) statement of the problem, (3) collection of relevant information, (4) development of alternatives, (5) evaluation of alternatives, (6) selection of a course of action, and (7) evaluation of solutions, and possibly review of actual case outcomes. The similarities of this method to problem-based learning are evident; however, unlike the problems generally used in PBL, cases tend to be relatively well-structured, rich contextual details are provided, and students are called on to apply material that is already somewhat familiar, whereas PBL tends to use poorly structured problems to drive the acquisition of new content knowledge [92].

The use of cases for teaching probably goes back to about 1870 at the Harvard Law School. The method was subsequently adopted by the Harvard Business School after World War I, and is now used routinely in schools of law, medicine, public administration and business management [90]. Cases are also used with increasing frequency in science education [93] and engineering education [94, 95]. Libraries of cases in science and engineering and resources for teachers wishing to use them have been compiled by the National Center for Case Study Teaching in Science,[4] the Penn State Center for Teaching and Learning with Technology,[5] and the Center for Case Studies in Engineering.[6] Most of the cases in the latter database are decades old and might therefore involve obsolete technology, but they should still be useful vehicles for promoting the types of critical thinking and problem-solving skills that are as vital today as they were when the cases were developed. Engineering case studies are also regularly published in the *Journal of STEM Education (Science, Technology, Engineering and Math).*[7]

B. Evaluation

Case-based teaching has strong proponents among practitioners; however, there is relatively little solid empirical support for it, a fact noted by several authors [89, 96, 97]. Lundeberg et al. [89] report that the use of case studies enhanced students' ability to recognize multiple perspectives (a finding that is further supported by Adams [98]), and they also note that the use of cases developed students' ability to identify relevant issues. Levin [99] found that cases improved students' reasoning and problem-solving skills, and Gabel [100] claims that they increased the use of higher-order thinking on Bloom's taxonomy. Fasko [97] found that most studies he examined showed little or no difference in knowledge acquisition between case studies, discussion, and lecture-based methods, but both cases and discussions were better than lectures for retention and application of material as well as problem-solving skills. Katsikitis et al. [101] compared case studies to PBL and found no significant difference between the two methods related to performance or knowledge acquisition.

VIII. Discovery Learning

A. Definition

Discovery learning is an inquiry-based approach in which students are given a question to answer, a problem to solve, or a set of observations to explain, and then work in a largely self-directed manner to complete their assigned tasks and draw appropriate inferences from the outcomes, "discovering" the desired factual and conceptual knowledge in the process [5]. In the purest form of this method, teachers set the problems and provide feedback on the students' efforts but do not direct or guide those efforts. There are many reasons why this method is rarely used in higher education, among those being because instructors who hear about it fear—probably with good cause—that they would only be able to cover a small fraction of their prescribed content if students were required to discover everything for themselves. The only way to counter this fear would be to present solid evidence that discovery learning produces improved learning outcomes without requiring a major sacrifice of content, and as we will see in the next section,

[4]/ublib.buffalo.edu/libraries/projects/cases/ubcase.htm
[5]tlt.its.psu.edu/suggestions/cases
[6]www.civeng.carleton.ca/ECL
[7]www.jstem.org

such evidence does not exist. What instructors are more likely to do is apply a variant of discovery learning (sometimes called "guided discovery") that involves the instructor providing some guidance throughout the learning process [102]. Once this is done, the distinctions between discovery and guided inquiry or problem-based learning tend to disappear.

B. Evaluation

Leonard [103] studied the use of guided inquiry and discovery learning in science laboratory courses and found no statistically significant differences in student scores on tests and lab reports. Some studies suggest that discovery learning can enhance students' retention of material and others reach the opposite conclusion [104–108]. The studies that show a positive effect also suggest that retention is improved only when the learning task is based on previously understood principles. Singer and Pease [109] compared the effectiveness of guided inquiry and discovery learning on the acquisition, transfer and retention of motor skills. They concluded that for learning new tasks, guided inquiry was more efficient, and for transferring learned skills to tasks of similar or greater difficulty there was no difference.

IX. Just-in-Time Teaching

A. Definition and Applications

Just-in-Time Teaching (JiTT) combines Web-based technology with active learning methods in the classroom [110–113]. Students individually complete Web-based assignments a few hours before class in which they answer questions, and the instructor reads through their answers before class and adjusts the lessons accordingly ("just in time"). This process is repeated several times a week. The use of questions to drive learning makes the method inductive. The technique was developed jointly by physics faculty at IUPUI (Indiana University-Purdue University Indianapolis), the U.S. Air Force Academy, and Davidson College. It can be combined with almost any in-class active learning approach.

The preliminary Web-based exercises (termed "Warmups" at IUPUI and Davidson and "Preflights" at the Air Force Academy) normally require the student to preview the textbook material. The exercises are conceptual in nature and are designed to help students confront misconceptions they may have about the course material. They serve the functions of encouraging students to prepare for class regularly, helping teachers to identify students' difficulties in time to adjust their lesson plans, and setting the stage for active engagement in the classroom. They are individualized to minimize plagiarism and graded using an automated on-line system, although the authors stress the importance of instructors reading a representative selection of responses to monitor the students' qualitative understanding of the material. The students may submit solutions any number of times with no penalty until they get them correct.

JiTT resources also include enrichment materials of several types [110]:

- course-related news stories that demonstrate the real-world relevance of the course material, historical anecdotes, and descriptions of familiar phenomena or devices that illustrate course concepts;
- on-line homework, extra-credit assignments that often deal with the enrichment materials, and "puzzles," additional conceptual questions that force the students to think about the material at a deeper level than the straightforward preparatory assignments;
- various computer-based mechanisms for communication between students and the instructor and among students, including an electronic suggestion box that instructors monitor regularly, a course bulletin board that students may use to communicate among themselves (e.g. to set up study sessions or team meetings, or to raise and answer questions), archives of previous materials, and a "credit check" in which they can monitor their assignment grades and see how they are doing with respect to the class as a whole.

Novak et al. [112], the physicists who developed JiTT, cast many of their Web-based materials in the form of Java applets that they call *physlets*. The students are presented with a problem that presents a set of observations or experimental data in a visual manner, and they have to analyze it qualitatively before they are allowed to do any mathematical analysis, figuring out what they know and what they need to find out and then planning a solution strategy. The connection to inquiry learning and problem-based learning is clear.

JITT classes are a combination of *interactive lectures*, in which the instructor does a fair amount of mini-lecturing between activities; *collaborative recitations*, which are not necessarily preceded by preparatory Web-based exercises, and laboratories. In the lectures, the instructor might begin by summarizing student responses to the preparatory exercises and then discussing common errors. The end of the lecture might involve a similar discussion of a puzzle. The collaborative recitations are likely to begin with a review of the homework, and then teams of students work on new problems. Faculty members circulate, help teams that need help, and if a common problem emerges, provide some instruction on how to address it. Lectures and recitations may be held separately or they may be integrated with each other and with laboratories. Paper homework is assigned in addition to the preparatory web-based exercises.

B. Evaluation

Novak et al. [112] assess JiTT for its impact on cognitive outcomes, student attrition and student attitudes in physics. Student learning was assessed using the Force Concept Inventory, which showed normalized student gains between 35 percent and 40 percent. This gain is similar to that found for other interactive-engagement teaching methods [114] and is significantly better than the average normalized gains found in traditionally-taught physics courses. The authors also report that JiTT reduced student attrition by 40 percent compared to previous offerings taught traditionally and that student responses to JiTT have been overwhelmingly positive.

X. Getting Started With Inductive Teaching and Learning

Once instructors are persuaded that inductive teaching methods are worth attempting, they face the question of which method to use. The answer, like the answer to all real questions, begins with "it depends"; specifically, it depends on the instructor's learning objectives, the instructor's and the students' prior experience with learner-centered teaching methods, the instructor's confidence in his or her content knowledge and teaching skill, and the availability of local expertise and support for each of the various methods.

Before teaching a topic or series of lessons using any inductive method, the instructor should write *learning objectives* that define what the student should be able to do (explain, calculate, derive, design, model, critique,…) when the instruction has been concluded. The objectives should guide the choice of focus problems, learning activities, and assessment methods. Mager [115] and Gronlund [116] provide guidance on how to write effective learning objectives, and Felder and Brent [117] discuss writing objectives to address Outcomes 3a–3k of the ABET Engineering Criteria.

Once learning objectives have been defined, a suitable inductive instructional method may be identified. We propose the following guidelines for making the choice:

- *Inquiry learning*. Inquiry is the simplest of the inductive approaches and might be the best one for inexperienced or previously traditional instructors to begin with. It requires designing instruction so that as much learning as possible takes place in the context of answering questions and solving problems. As the students gain more experience with this approach, the instructor may increase the scope and difficulty of the focus questions, use more open-ended and ill-structured problems and simultaneously decrease the amount of explicit guidance provided.
- *Problem-based learning*. Problem-based learning is the most complex and difficult to implement of the methods reviewed in this paper. It calls for a complex, open-ended, authentic problem whose solution requires knowledge and skills specified in the learning objectives. Such problems take time to create. PBL also requires considerable teaching skill for instructors to deal with unfamiliar technical questions and problems, student resistance and possibe hostility toward PBL, and the array of interpersonal problems that frequently arise when students work in teams. Full-fledged PBL is therefore best undertaken by experienced instructors with solid expertise in the subject matter of the course and two or more semesters of experience with cooperative learning in a more conventional instructional environment. Smith et al. [118] offer suggestions for implementing cooperative learning, and Felder and Brent [8, 119] and Oakley et al. [10] suggest strategies for overcoming student resistance to learner-centered instructional methods and helping student groups become effective teams. Despite the challenges, PBL is a natural environment in which to develop students' professional skills such as problem-solving, team work and self-directed or lifelong learning, and it provides an excellent format to integrate material from across the curriculum. Instructors wishing to focus specifically on these learning outcomes should consider adopting PBL.
- *Project-based learning and hybrid problem/project-based approaches.* Project-based learning is well suited to the capstone design course in engineering and to laboratory courses that are more than collections of cookbook experiments, and it may also be used in other courses that deal with process or product design and development. Like the focus problems in problem-based learning, projects should be authentic and should address the instructor's learning objectives; moreover, if students work in teams, the instructor should observe the principles of cooperative learning including holding all team members individually accountable for the entire project content and facilitating their acquisition of teamwork skills [8, 10, 118, 119]. As instructors and students gain experience with project-based learning, the projects may be made more open-ended with less guidance being provided on how to complete them. In other words, they may be increasingly structured as problem-based learning exercises.
- *Case-based teaching.* Cases are effectively used when learning objectives include decision-making in complex authentic situations. With appropriate selection, case-based teaching can also provide an excellent environment in which to address specific ABET mandated outcomes such as acquiring an understanding of professional and ethical responsibility, knowledge of contemporary issues, or the ability to understand engineering solutions in a global and societal context. Scenarios suitable for cases might involve diagnosing technical problems and formulating solution strategies, making business management decisions taking into account technical, economic, and possibly social and psychological considerations, and confronting ethical dilemmas. Formulating good cases can be a difficult and time-consuming task; before trying to do it, instructors should first check the libraries of cases in science and engineering cited in Section VII to see if an existing case addresses their learning objectives.
- *Just-in-time teaching.* JiTT is a natural method to use when (1) it is important to the instructor that the students keep up with readings and assignments on a day-by-day basis, and (2) course management software is available and convenient to use for administering on-line assignments and assessing the students' responses. Instructors who plan to use the method should have solid expertise in the course content and the flexibility needed to modify their lectures on short notice after examining students' responses to the preliminary exercises. Also, a significant expenditure of time and effort is sure to be required if the preliminary Web-based exercises and Java applets must all be developed from scratch. Before undertaking this task, instructors should see if materials can be obtained from colleagues at their institution or elsewhere who have used JiTT for the same course.

We do not recommend using the pure form of discovery learning—in which students work with little or no guidance from instructors—in undergraduate engineering curricula.

Once the decision regarding adoption of a method is made, the instructor should refer to texts, articles, and Web-based resources on the chosen method and take full advantage of experienced colleagues and teaching center consultants who can offer tips on implementing it and dealing with problems that arise with its use.

XI. Summary

The traditional approach to teaching science and engineering is deductive, beginning with the presentation of basic principles in lectures and proceeding to the repetition and application of the lecture content by the students. The teaching methods discussed in this paper—inquiry learning, problem-based learning, project-based learning, case-based teaching, discovery learning, and just-in-time teaching—instead proceed inductively, beginning with observations to be interpreted, questions to be answered, problems to be solved, or case studies to be analyzed. The content knowledge, methods, and skills that the course is designed to teach are acquired by the students, with varying degrees of instructor guidance, in the context of those exercises. If and when instructors present information, they do so only once the need for that information to complete the exercises has been established.

While the quality of research data supporting the different inductive methods is variable, the collective evidence favoring the inductive approach over traditional deductive pedagogy is conclusive. Induction is supported by widely accepted educational theories such as cognitive and social constructivism, by brain research, and by empirical studies of teaching and learning. Inductive methods promote students' adoption of a deep (meaning-oriented) approach to learning, as opposed to a surface (memorization-intensive) approach. It also promotes intellectual development, challenging the dualistic type of thinking that characterizes many entering college students (which holds that all knowledge is certain, professors have it, and the task of students is to absorb and repeat it) and helping the students acquire the critical thinking and self-directed learning skills that characterize expert scientists and engineers.

This is not to say, however, that simply adopting an inductive method will automatically lead to better learning and more satisfied students. As with any form of instruction, inductive teaching can be done well or poorly, and the outcomes that result from it are only as good as the skill and care with which it is implemented. Many students are resistant to any type of instruction that makes them more responsible for their own learning, and if the appropriate amount of guidance and support is not provided when inductive methods are used, the resistance can escalate to hostility, inferior learning outcomes, poor evaluations, and a resolution by the instructor never to try anything like that again.

Instructors who set out to implement an inductive method should therefore first familiarize themselves with best practices such as providing adequate *scaffolding*—extensive support and guidance when students are first introduced to the method, followed by gradual withdrawal of the support as the students gain more experience and confidence in its use. Instructors should also anticipate some student resistance to inductive learning and should be aware of effective strategies for defusing it, many of which are outlined by Felder and Brent [8, 16, 119]. If these precautions are taken, both the students and the instructor should soon start seeing the positive outcomes promised by the research.

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Thursday

Learning objectives

Lesson Exercises

After the lesson exercises, the participants are able to:

- carry out a lesson that is problem-oriented by formulating a set of Intended Learning Outcomes and including an appropriate level of student activity as didactic tools.
- contribute constructively to the planning of this lesson and afterwards, in the planning group, contribute to a brief evaluation of how the lesson was executed.
- constructively receive feedback on their own teaching.
- engage in a constructive dialogue about others' teaching, for example by evaluating the teaching by making use of the TDS-phases (devolution, action, formulation, validation and institutionalization).
- evaluate how a problem-oriented lesson that was focused on activating students contribute to achieving the Intended Learning Outcomes.
- outline how one's own and others' teaching can be developed and improve.
- identify key didactic problems in university teaching.

Planning the lesson exercises

After planning the lesson exercises, the participants are able to:

- plan a lesson that is problem-oriented by formulating a set of Intended Learning Outcomes and implementing an appropriate level of student activity that is carried by dialogue.
- give and receive constructive feedback to and from group members while planning the lesson.

Preparation for Friday

For those of you giving your lesson exercise on Friday: you must plan your lesson with specific focus on (in addition to the previous days' focuses):

- Dialogue and interaction

In your planning group discuss how to accomplish the following in your lesson:

- Choose a problem or question that engages the students in dialogue
- Prepare specific questions that can keep the dialogue going
- Consider how much time you wish to spend on the dialogical parts of the lesson and how you end them.

Communicative approaches in teaching:

	Interactive	Non-interactive
Focus on science veiw (authoritative)	**Presentation** "Q & A"	**Presentation** "Lecture"
Open to different conceptions (dialogical)	**Probing Prompting Encouraging**	**Review**

	Interaktiv	Non-interaktive
Focus on science view (authoritative)	**I-R-E triads**	Presentation "Lecture"
Open to different conceptions (dialogical)	**I-R-P-R-P-R-P chains**	Review

I stands for Initiation: Teacher asks a question
R stands for "Response": Students answer
E stands for "Evaluation": Teacher evaluates
P stands for promt: Teacher promts

The Tension Between Authoritative and Dialogic Discourse: A Fundamental Characteristic of Meaning Making Interactions in High School Science Lessons

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ABSTRACT: In this paper, we draw upon a framework for analyzing the discursive interactions of science classrooms (Mortimer & Scott, 2003, *Meaning Making in Secondary Science Classrooms*, Maidenhead, UK: Open University Press), to probe the movement between authoritative and dialogic discourse in a Brazilian high school science class. More specifically, we argue the point that such shifts between communicative approaches are an inevitable part of teaching whose purpose is to support meaningful learning of scientific knowledge. We suggest that a necessary tension therefore exists between authoritative and dialogic approaches as dialogic exchanges are followed by authoritative interventions (to develop the canonical scientific view), and the authoritative introduction of new ideas is followed by the opportunity for dialogic application and exploration of those ideas. In these ways, one communicative approach follows from the other, authoritativeness acting as a seed for dialogicity and vice versa. We discuss how this analysis, in terms of shifts in communicative approach, offers a new and complementary perspective on supporting "productive disciplinary engagement" (Engle & Conant, 2002, *Cognition and Instruction,*

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20, 399–484) in the classroom. Finally we consider some methodological issues arising from this study. *Sci Ed* **90:**605–631, 2006

INTRODUCTION

In recent years, there has been a gradual development of interest in studies of how meanings are developed through language and other modes of communication in the science classroom. Different studies have highlighted, from various points of view, the importance of investigating classroom discourse and other rhetorical devices in science education (see, e.g., Candela, 1999; Halliday & Martin, 1993; Kelly & Brown, 2003; Kress, Jewitt, Ogborn, & Tsatsarelis 2001; Lemke, 1990; Mortimer, 1998; Mortimer & Scott, 2003; Ogborn, Kress, Martins, & McGillicuddy, 1996; Roychoudhury & Roth, 1996; Scott, 1998; Sutton, 1992). This "new direction" for science education research (Duit & Treagust, 1998) signals a move away from studies focusing on individual student understandings of specific phenomena toward research into the ways in which understandings are developed in the social context of the science classroom.

The importance of language for learning has also been recognized in a number of curriculum development initiatives. For example, in the UK, the Qualifications and Curriculum Authority (QCA, 2003) strongly identifies "dialogic teaching" with effective whole-class instructional approaches, drawing on the comparative, cross-cultural research of Alexander (2001) as a basis for doing so. In North America, there is a powerful movement toward "inquiry-based" science lessons, in which the students work collaboratively on open-ended activities and are encouraged to talk their way to solving problems (see, e.g., Kelly & Brown, 2003; Roychoudhury & Roth, 1996). On both sides of the Atlantic, moves are being made to engage students in the patterns of talk, or modes of "argumentation," which are characteristic of science (see, e.g., Driver, Newton, & Osborne, 2000; Duschl & Osborne, 2002; Kelly, Brown, & Crawford, 2000).

The notion of dialogic discourse seems to be a central part of all of these initiatives. Duschl and Osborne (2002), for example, claim that argumentation must be dialogic as it "requires the opportunity to consider plural theoretical accounts and the opportunity to construct and evaluate arguments relating ideas and their evidence" (p. 52). Kelly, Crawford and Green (2001) show the potential importance of dissenting voices in the discursive construction of physics explanations by students working in small groups. Ritchie and Tobin (2001, p. 295) suggest that genuine consensus in science can only be achieved through dialogic discourse.

Despite this widespread interest in dialogic discourse, the fact of the matter is that dialogic interactions are notably absent from science classrooms around the world (Alexander, 2001; Fischer, Reyer, Wirz, Bos, & Hollrich 2002; Wells, 1999). In the book *Meaning Making in Secondary Science Classrooms*, we (Mortimer & Scott, 2003) developed a framework for characterizing different kinds of discursive classroom interactions and present examples (rare as they may be) of dialogic discourse, as played out in real classrooms, contrasting these with more authoritative passages.

The purpose of this paper is to extend those kinds of analyses and to develop the argument, with exemplification, that any sequence of science lessons, which has as its learning goal the meaningful understanding of scientific conceptual knowledge, must entail *both* authoritative and dialogic passages of interaction. Indeed, from the perspective that we take, we see a *tension* between authoritative and dialogic approaches as being an inevitable characteristic of meaning making interactions in science classrooms. In order to explore this tension between authoritative and dialogic discourse, we have collected and analyzed data from a series of high school science lessons taught in Brazil. In addition, we discuss some methodological issues which emerge from that analysis, setting out the range of criteria to be used in identifying authoritative and dialogic approaches.

The general theme of extending the range of interactions in science classrooms is one which has been explored in various studies over recent years. A common issue in these studies is that the participant structures (Phillips, 1972) of science classrooms should change so as to "overcome the barriers of traditional classroom participant structures wherein the teacher does most of the talking and students participate by responding to teacher questions and receiving evaluation of their responses" (Cornelius & Herrenkohl, 2004). The aim of the proposed new participant structures is to produce what Engle and Conant (2002) call "productive disciplinary engagement." Engle and Conant give a list of features of students' discourse that can be considered as evidence of their greater disciplinary engagement: more students make substantive contributions to the topic under discussion; these contributions are in coordination with each other; few students are involved in "off-task" activities; students express passionate involvement and they re-engage and continue to be engaged in the topic over a long period of time (Engle & Conant, 2002, p. 402). By disciplinary engagement, the authors mean "that there is some contact between what students are doing and the issues and practices of a discipline's discourse" (p. 402). Productive disciplinary engagement sees the students making intellectual progress that can be inferred by, amongst other things, an improvement in the quality and sophistication of arguments and the development of new ideas and disciplinary understandings.

Engle and Conant advance four principles for fostering productive disciplinary engagement: problematizing content, giving students authority, holding students accountable to others and to disciplinary norms, and providing relevant resources. Problematizing content involves the teacher in encouraging student questions, proposals, and challenges rather than just expecting answers and assimilation of facts and procedures. Giving students authority means encouraging students "to be authors and producers of knowledge, with ownership over it, rather than mere consumers of it" (Engle & Conant, 2002, p. 404). Holding students accountable to others and to disciplinary norms involves students in considering the points of view of others, not necessarily to accept them but to be responsive to them. The students are expected to consult others in constructing their understanding in a domain and to respect disciplinary norms, as for example in giving evidence for their claims. All of these points resonate with Resnick's (1999) notion of "accountable talk" in the classroom. The authors situate the fourth principle at a different level in that it supports the embodiment of the other principles. "Resources supporting productive disciplinary engagement may be as fundamental as having sufficient time to pursue a problem in depth or having access to sources of information relevant to it" (Engle & Conant, 2002, p. 405). These resources might include books and Internet sites but also things such as students' questions and their familiar ways of discussing them. According to Warren, Ballenger, Ogonowski, Rosebery, and Hudicourt-Barnes (2001), these familiar ways of thinking "constitute invaluable intellectual resources which can support children as they think about and learn to explain the world around them scientifically" (p. 548).

Framed in terms of fostering the communication of physics principles, Van Zee and Minstrell's (1997) notion of "reflective discourse" is highly relevant to the achievement of productive disciplinary engagement. Van Zee and Minstrell contrast reflective classroom discourse with the discourse of traditional classrooms in which the authority of the teacher is central and define reflective discourse as classroom discussions in which three conditions are frequently met. These conditions are that (i) students express their own thoughts, comments, and questions; (ii) the teacher and individual students engage in an extended series of questioning exchanges that help students better articulate their beliefs and conceptions; (iii) student/student exchanges involve one student trying to understand the thinking of another (Van Zee & Minstrell, 1997, p. 209).

Central to all of these studies is the goal of engaging students with disciplinary ways of thinking and doing so without ignoring their existing or everyday ways of thinking which are considered to be a fundamental resource in this enterprise. This goal is also central to the dialogic/authoritative tension that we see underpinning meaningful learning and as such there are considerable overlaps to be explored between the present study and the literature outlined above. For example, Van Zee and Minstrell's conceptualization of "reflective discourse" maps directly onto what Bakhtin refers to as "internally persuasive" discourse, which we redefined as dialogic discourse. Cornelius and Herrenkohl (2004) explicitly consider the Bakhtinian notion of persuasive discourse as one of the fundamental tools for empowering students and fostering their productive disciplinary engagement in science classrooms. In suggesting that an effective balance between authority and accountability should be maintained in science classrooms, Engle and Conant (2002) get very close to our intention of exploring how a suitable balance between authoritative and dialogic discourse can contribute to students' meaning making of scientific concepts.

We shall return to these links with the existing literature in the final part of this paper and review them in the light of the data and arguments which we present. In the following sections, we shall first of all outline the framework which we have used in analyzing the classroom discourse. We then present the analysis of data, focusing on the movement between authoritative and dialogic communicative approaches.

THE FRAMEWORK

Following Vygotskian principles, we consider that science teaching entails a kind of "public performance" on the social plane of the classroom. This performance is directed by the teacher who has planned the "script" for the performance and takes the lead in "staging" (Leach & Scott, 2002) the various activities of the science lessons. Central to the teaching performance is the job of developing the "scientific story" on the social plane of the classroom (Ogborn et al., 1996) and the support given to students in internalizing the new scientific ideas which are being introduced. Of course, the teacher cannot exert absolute control over the ways in which the interactions are played out with students in the classroom (Candela, 1999; Erickson, 1982), and as such the teaching and learning performance may develop along unexpected pathways.

The framework which we outline here was developed to analyze the speech genre (Bakhtin, 1986) of science classrooms and, in particular, the ways in which the teacher acts to guide meaning making interactions on the social plane of high school science classrooms. The framework is the product of an ongoing research program conducted over a number of years (see, Mortimer, 1998; Mortimer & Scott, 2000; Scott, 1998) and a detailed description of its development is set out elsewhere (Mortimer & Scott, 2003). Suffice it to say, for the purposes of this article, that the framework is based on a sociocultural perspective on teaching and learning (Mortimer & Scott, 2003) and has been developed through a series of detailed case studies. The case studies focus on the interactions and activities of sequences of high school science lessons in England and Brazil, in which conceptually demanding science topics (such as "air pressure," "energy," and "the particulate theory of matter") were taught to students aged 12–16 years. From the analyses of these data and from the insights gained from various aspects of sociocultural theory, the framework was developed through an iterative process of application and refinement.

The analytical framework (Mortimer & Scott, 2003) is based on five linked aspects, which focus on the role of the teacher, and are grouped in terms of teaching focus, approach, and action (see Table 1).

Central to the framework is the concept of "communicative approach" which was first developed by Mortimer and Scott (2003), and provides a perspective on *how* the teacher

TABLE 1
The Analytical Framework: A Tool for Analyzing Meaning Making Interactions in Science Classrooms

	Aspect of Analysis	
(i) Focus	*1. Teaching Purposes*	*2. Content*
(ii) Approach	*3. Communicative approach*	
(iii) Action	*4. Teacher interventions*	*5. Patterns of interaction*

works with students to develop ideas in the classroom. The different classes of communicative approach (see next section) are defined in terms of whether the classroom discourse is authoritative or dialogic in nature and whether it is interactive or noninteractive (Mortimer & Scott, 2003, p. 33). The different communicative approaches are put into action through specific patterns of interaction and teacher interventions. A common pattern of interaction (p. 40) is the triadic I-R-E form (see next section), whilst a common form of teacher intervention (p. 42) involves marking key ideas, possibly by use of repetition. The different communicative approaches are also linked to specific teaching purposes (p. 28), such as developing the scientific story, and to the nature of the thematic content (p. 28) which is the focus of the teaching. The content might be everyday or scientific; descriptive, explanatory, or generalized; empirical or theoretical, in nature.

In this paper, we shall focus our attention on just three aspects of the framework. These are the communicative approach, teaching purposes, and patterns of interaction and we say a little more about each of these in the following sections.

COMMUNICATIVE APPROACH

The communicative approach focuses on questions such as whether or not the teacher interacts with students (either taking turns in the discourse or simply presenting material), and whether the students' ideas are taken into account as the lessons proceed. In developing this aspect of analysis, we have identified four fundamental classes of communicative approach, which are defined by characterizing the talk between teacher and students along each of two dimensions, *dialogic–authoritative* and *interactive–noninteractive*.

The Dialogic—Authoritative Dimension

The distinction between authoritative and dialogic functions has been discussed by Wertsch (1991), and was used by Mortimer (1998) in analyzing discourse from a Brazilian classroom. It is based on the notions of authoritative and internally persuasive discourse, as outlined by Bakhtin (1981), and on the functional dualism of texts introduced by Lotman (1988) (quoted by Wertsch, 1991, pp. 73–74).

According to Vice (1997), Bakhtin uses "dialogism" in two different senses. In a broader sense, dialogism is a universal property of language where *any* discourse is dialogic because every word or utterance responds to previous utterances and anticipates the responses of others. "Utterances are not indifferent to one another, and are not self-sufficient; they are aware of and mutually reflect one another" (Bakhtin, 1986, p. 91). In addition, any true understanding, or meaning making, is dialogic in nature because we lay down a set of our own answering words for each word of the utterance we are in process of understanding (Voloshinov, 1929/1973, p. 102).

The other sense of dialogism in Bakhtin's work is a more restricted concept, related to the historical and cultural environments in which language is shaped. In this case, the author makes a distinction between *authoritative* and *internally persuasive discourse* (Bakhtin,

1981) and it is this distinction which we draw upon in defining the concept of communicative approach.

We certainly agree that when a teacher makes an authoritative presentation, then the meaning making process must be *dialogic* in nature as the students try to make sense of what is being said by laying down a set of their “own answering words” to the words of the teacher. At the same time, and according to our own definition, we are clear that in authoritative discourse the teacher’s *purpose* is to focus the students’ full attention on just *one* meaning. It is in this sense that we have chosen to use the word “authoritative” (whilst acknowledging the underlying dialogic nature of the interaction). Additionally, we have chosen the word “dialogic” to contrast with an authoritative communicative approach, in order that we can draw upon the dialogic meaning of recognizing others’ points of view. Thus, according to our definition, we are clear that in dialogic discourse the teacher recognizes and attempts to take into account a range of students’, and others’, ideas.

Following on from these perspectives, we define dialogic discourse as being that which is open to different points of view. At different points in a sequence of science lessons, dialogic talk inevitably takes on a different character. Thus at the start of a lesson sequence, the science teacher might elicit students’ everyday views about a particular phenomenon. Later on in the sequence, the teacher might encourage students to discuss how to apply a newly learned scientific idea in a novel context.

In the first situation the dialogic discourse involves collecting students’ everyday views. A fundamentally important point here is that this kind of dialogic interaction can be played out with different levels of *interanimation* of ideas (Bakhtin, 1981). At one extreme the teacher might simply ask for the students’ points of view and list them on the board. Here the discourse is open to different points of view, but there is no attempt to work on those views through comparing and contrasting. The teacher’s approach involves a low level of interanimation of ideas. On the other hand, the teacher might adopt an approach which involves trying to establish how the ideas relate to one another (*John thinks that this might be the case, but Susan seems to be suggesting something different. Nancy what do you think?*). Both of these approaches are dialogic in the sense of allowing the space for different ideas to be represented, but the second approach clearly involves a higher level of interanimation of ideas. It might be the case that the teacher simply collects ideas at the start of a teaching sequence (low interanimation) and then, later in the sequence, compares and contrasts these ideas with the school science point of view (high interanimation).

In the second situation, the dialogic discourse might involve the students in working together to apply a new (to them) scientific idea to construct an explanation for a novel problem. Here we might imagine the students agreeing on some points and disagreeing on others, but working together to understand any points of difference (*Oh! I see what you mean!*) as they develop their explanation. The agreeing and disagreeing on points of view constitutes an ongoing, dialogic interanimation of ideas.

In *general* terms we can say that dialogic discourse is open to different perspectives. There is always the attempt to acknowledge the views of others, and through dialogic discourse the teacher attends to the students’ points of view as well as to the school science view. Within dialogic discourse, there is the possibility of different levels of interanimation of ideas, as in Table 2.

By way of contrast, *authoritative* discourse does not allow the bringing together and exploration of ideas. Here the teacher focuses attention on the school science point of view. If ideas or questions, which do not contribute to the development of the school science story, are raised by students, they are likely to be reshaped or ignored by the teacher. Alternatively, if a student idea is perceived by the teacher as being helpful to the development of the scientific story, it is likely to be seized upon and used. In these ways, authoritative discourse

TABLE 2
Dialogic Discourse and Interanimation of Ideas

DIALOGIC discourse	LOW level of interanimation of ideas	Different ideas are made available on the social plane. For example: teacher lists student ideas on the board.
	HIGH level of interanimation of ideas	Different ideas are explored and worked on by comparing, contrasting, developing.

is *closed* to the points of view of others, with its direction having been set in advance by the teacher. More than one voice may be heard, through the contributions of different students, but there is no exploration of different perspectives, and no explicit interanimation of ideas, since the student contributions are not taken into account by the teacher unless they are consistent with the developing school science account.

The Interactive—Noninteractive Dimension

An important feature of the distinction between dialogic and authoritative approaches is that a sequence of talk can be dialogic or authoritative in nature, independent of whether it is uttered individually or between people. What makes talk functionally dialogic is the fact that different ideas are acknowledged, rather than whether it is produced by a group of people or by a solitary individual. This point leads us to the second dimension to consider in thinking about the communicative approach: that the talk can be *interactive* in the sense of allowing for the participation of more than one person, or *noninteractive* in the sense of excluding the participation of other people.

Four Classes of Communicative Approach

Combining the two dimensions, any episode of classroom talk can be identified as being either *interactive* or *noninteractive* on the one hand, and *dialogic* or *authoritative* on the other. We can represent this combining of the two dimensions in Table 3.

The four classes, as they appear in the classroom, can be exemplified as follows:

a. *Interactive/dialogic*: Teacher and students consider a range of ideas. If the level of interanimation is high, they pose genuine questions as they explore and work on different points of view. If the level of interanimation is low, the different ideas are simply made available.
b. *Noninteractive/dialogic*: Teacher revisits and summarizes different points of view, either simply listing them (low interanimation) or exploring similarities and differences (high interanimation).

TABLE 3
Four Classes of Communicative Approach

	Interactive	Noninteractive
Dialogic	*A. Interactive/Dialogic*	*B. Noninteractive/Dialogic*
Authoritative	*C. Interactive/Authoritative*	*D. Noninteractive/Authoritative*

c. *Interactive/authoritative*: Teacher focuses on one specific point of view and leads students through a question and answer routine with the aim of establishing and consolidating that point of view.
d. *Noninteractive/authoritative*: Teacher presents a specific point of view.

Although these aspects were developed in relation to the teacher's role and actions, they can also be used to characterize student–student interactions in the classroom. We shall return to this point in the final section of the paper.

PATTERNS OF INTERACTION

This second aspect of analysis which we shall consider relates to the structure of the interactions between teacher and students in the classroom. The most distinctive pattern of interaction reported in the literature is the three-part exchange structure which Lemke (1990) refers to as triadic dialogue. This pattern was first described as IRF (Sinclair & Coulthard, 1975) or as IRE (Mehan, 1979). For both authors, *I* stands for "*I*nitiation" (normally through a question from the teacher) and *R* stands for "*R*esponse" (normally from the student). In relation to the third move, Sinclair and Coulthard (1975) refer to "*F*ollow-up," while Mehan (1979) and others refer to "*E*valuation." Wells (1999) stresses the point that the third move from the teacher can serve different functions. In some contexts, it has a dominant evaluative function, in others "the third move functions much more as an opportunity to extend the student's answer, to draw out its significance, or to make connections with other parts of the students' total experience during the unit" (Wells, 1999, p. 200). An important contribution of Wells is to show that triadic dialogue is neither intrinsically good nor bad. "Its merits—or demerits—depend upon the purpose it is used to serve on particular occasions and upon the larger goals by which those purposes are informed" (p. 169).

In the following paragraphs, we take an approach similar to that of Wells, by distinguishing between *triadic* IRE patterns and *chains* of interaction which are generated when the third move of the interaction is made to prompt elaboration of the student's point of view.

The *I-R-E* Pattern

As outlined above, this pattern of interaction is played out in "patterns of three" with utterances from teacher–student–teacher and is referred to here as a *triadic* "*I-R-E*" interaction (Mehan, 1979). This pattern of initiation–response–evaluation is distinctive and very common in high school classrooms. As we shall see, most *authoritative* interactions are played out through an I-R-E pattern.

The *Open* and *Closed Chain* Patterns

An alternative form of interaction occurs when, instead of making an evaluation of a student's response, the teacher feeds-back the response to the student, in order to *prompt* further elaboration of their point of view (*that's interesting, tell me a little more*. . .) and thereby to sustain the interaction. In this way the student is supported in elaborating and making explicit their ideas.

This alternative pattern of interaction normally generates interaction chains which take an *I-R-P-R-P-R-* form (where *P* stands for *P*rompt). Here the prompt move by the teacher is followed by a further response from the student [R] and so on. Some chains of interaction are *closed* by a final *evaluation* from the teacher (*I-R-P-R-P-R-E*), whilst others remain *open* without any final evaluation (*I-R-P-R-P-R-*). As we shall see, some teacher prompts involve only single words taken from the student's response, whilst others involve further elaboration by the teacher.

There are other ways in which nontriadic patterns might appear in the classroom. For example, students (rather than the teacher) can initiate a sequence by posing a question. Alternatively, different students can answer the same question from the teacher, generating an I-Rs_1-Rs_2-Rs_3— form, where Rs_n indicates a response from a particular student. In this latter pattern, the response from student 3 (for example) might not necessarily address the initial question posed by the teacher; it might be a comment on a previous student's response. In such cases, the pattern of interactions can become relatively complex.

TEACHING PURPOSES

The third aspect of analysis which we shall consider relates to the teaching purposes. It is clear that as a sequence of teaching progresses, different purposes are addressed by the teacher with each purpose relating to a particular phase of a lesson within an overall lesson sequence. The teaching purposes which we have identified (Mortimer & Scott, 2003) are as follows:

1. Opening up the problem;
2. Exploring and probing students' views;
3. Introducing and developing the scientific story;
4. Guiding students to work with scientific ideas and supporting internalization;
5. Guiding students to apply, and expand on the use of, the scientific view and handing-over responsibility for its use;
6. Maintaining the development of the scientific story.

This list of purposes was developed both from our observations of science lessons in which there were significant and substantive interactions between teacher and students, and from the basic tenets of the Vygotskyan perspective on teaching and learning (see Mortimer & Scott, 2003).

ANALYSIS OF TEACHING EPISODES

As outlined earlier, the aim of the analysis presented in this paper is to explore how shifts between authoritative and dialogic approaches might evolve as a teaching sequence proceeds. In the following sections, we therefore present four teaching and learning episodes taken from a teaching sequence in a Brazilian school with students aged 14–15 years, along with an analysis of each in terms of communicative approach, patterns of interaction, and teaching purposes.

These episodes were part of a sequence of lessons to introduce some basic concepts of thermal physics. The teaching sequence content was organized around the topic of the thermal regulation of living beings. It included the study of heat, temperature, thermal equilibrium, and the balance of energy in organisms. The students in the target class had been introduced previously to the kinetic particle model of matter through an approach based on the interpretation of phenomena such as gaseous diffusion and changes in the physical states of matter.

The lessons involved a combination of work carried out in small groups followed by whole-class discussions led by the teacher. In the small group work the students performed experiments and discussed their observations and findings. The teacher introduced each experiment with a preliminary presentation whose purpose was to contextualize the problem and to locate it within the developing teaching and learning story. In the subsequent whole-class discussion, the teacher and students talked through the ideas and explanations that the students had proposed.

In presenting the episodes, we decided to refine the original transcripts by leaving out the technical marks and adding punctuation for the pauses and interrogative intonations. We have also left out some turns of speech which were not relevant to the theme under discussion, since they referred to issues of classroom organization and maintenance of discipline. The most delicate step in the "reconstruction" of classroom interactions was the translation of the Brazilian transcripts from Portuguese to English.

Episode 1—You Must Justify Your Ideas

This episode took place during the *first* lesson of the teaching sequence. An initial activity involved students immersing one hand in cold water and the other in warm water before plunging them both into a tank of water at room temperature. The purpose of the activity was to show the limitations of the senses in monitoring temperature. During the group work the teacher noticed that students were talking about what was happening in various different ways. In the subsequent whole-class discussion the teacher encouraged the students to explain what they meant by "heat" and "temperature" in the context of this activity.

1. Teacher: So, how do you explain it? What happens when we feel hot and cold?
2. Student 2: Maybe the temperature of the water passes to your hand when you put it in the water.
3. Teacher: What passes to your hand?
4. Student 2: The temperature.
5. Teacher: The temperature? Do you agree with that?
6. Student 5: There was a heat change.
7. Teacher: Heat change. What's that? Can you explain please?
8. Student 3: There was a kind of diffusion. The temperature of the water passes to your hand and from your hand to the water.
9. Student 6: One swops heat with the other Miss.
10. Student?: I think that it's a change of temperature.
11. Student 6: The heat warms the cold water until a point at which the temperature will transfer neither cold nor hot.

Here, Student 2 (turn 2) uses the idea of *temperature* in a way which is closer to the school science concept of *heat*. Students 5 and 6, on the other hand, refer to a "heat change." In turn 11, Student 6 refers to some kind of equilibrium being achieved and in his explanation temperature is something which is able to transfer either hot or cold (probably both). In this way, a range of ideas are presented for consideration. The teacher does not evaluate, or correct, these ideas but simply asks for further clarification and prompts others to position themselves in the debate.

12. Teacher: I don't understand what you're saying. I want to know what changes between the water and hand. . . temperature or heat?
13. Students: Temperature.
14. Student ?: It's heat, a heat change.
15. Teacher: Well, you must justify your ideas.
16. Student ?: It's because the temperature is made by heat.
17. Teacher: Hmm. . . .

Some confusion now arises in the class as one of the students, Student 4, provides a long description of the activity and other students conclude that the hand absorbs heat from the water. To keep the transcription as simple as possible, we decided not to present this part of the talk, which consists of 11 turns. The teacher, after Student 4's intervention, asks whether anybody thinks differently.

29. Student 1: I think there is a heat change because our body is always around the same constant temperature.
30. Teacher: Hmm. . . .
31. Student 1: So, if you put your hand in a bowl of warm water your temperature remains more or less the same, it doesn't change. There is a change of heat. Heat relates to what you feel, so there is a heat change and not a change of temperature.
32. Student 7: That's it. And heat can be cold or hot. It can be a cold or hot heat.
33. Teacher: Do you agree with that? Movement of cold heat and hot heat?
34. Student ?: No.
35. Student ?: Temperature is only a measure.
36. Teacher: But she is saying that. Please Student 7, explain again, because when you were saying hot and cold heat I saw someone looking surprised.
37. Student 7: I think that heat, when we talk about heat it does not mean just a hot heat, it can be cold, cold heat. For instance, in cold water we have cold heat and we felt it cold.

Communicative Approach and Teaching Purpose. Throughout this episode, the teacher adopts a neutral stance in not offering evaluative comments. She prompts the students to present their ideas and asks for elaboration and justification of points of view. She also helps the students to recognize the existence of different possible interpretations of the phenomenon. For example, in turn 36 the teacher gives special attention to Student 7's explanation which is based on the existence of two kinds of heat. Although Student 7's explanation is not fully explored at this point in the sequence, the teacher returns to it later (as we shall see in the next episode). In this way an interactive/dialogic communicative approach is developed by the teacher and the "two kinds of heat" idea, is foregrounded as a theme to be returned to.

With regard to teaching purpose, the interactive–dialogic approach is consistent with the purpose of *exploring and probing students' views* of heat and temperature, prior to any teaching on this topic.

Pattern of Interaction. The teacher starts with a question: "How do you explain this? What happens when we feel hot and cold?" [Initiation] Student 2's reply "Maybe the temperature of water passes to the hand when we put in the water" [Response] is followed by a request for elaboration by the teacher, "What passes to your hand?" [Prompt]. Student 2 restates her idea, and the teacher foregrounds the answer by repeating it, "The temperature?" and opens up debate by asking the whole class "Do you agree with that?"

Up to this point, it is not possible to decide whether by repeating the answer ("The temperature?"), in this way, the teacher is evaluating it negatively or whether he is just making a prompt move to elicit other interpretations. Looking ahead through the episode, we see the teacher making similar responses to all of the ideas proposed by the students, and each response has the same kind of neutral intonation. We can therefore conclude that the function of his questioning was to *prompt* students' elaboration and justification of their ideas rather than to evaluate those ideas. Since the students do not modify their answers when the teacher responds with these questions, we can assume that they have also interpreted the teacher's questioning as a prompt rather than an evaluation.

In fact the teacher makes successive prompt moves, with requests for elaboration (turns 7, 12, 15, 33 and 36), and without (turns 17 and 30), to encourage the students to engage in the debate. In some of these interventions the teacher simply "bounces-back" the student's words: "Heat change. What's that? Can you explain please?" (turn 7). In this way he encourages the student to continue and thereby acts to sustain the interaction. At other points, the teacher stresses the existence of different accounts for the same phenomenon and the consequent need to justify personal ideas: "Please Student 7, explain again, because when you were saying hot and cold heat I saw someone looking surprised" (turn 36). At the beginning of this episode, the contributions from the students are relatively short and strongly connected to the teacher's feedback, but then become longer after turn 14. This change provides evidence of the increasing engagement of the students in the construction of the arguments as the lesson proceeds. We also observe the I-Rs_1-Rs_2-Rs_3-pattern, referred to earlier, in this episode. For example, in turn 7, the teacher's question, "Heat change. What's that? Can you explain please," generates four answers from different students.

In this way the teacher uses *open chains of interaction* (generally with no evaluative feedback) to support an *interactive–dialogic* communicative approach, with a clear purpose of *exploring and probing students' views*. By adopting an interactive–dialogic communicative approach, the teacher sets an appropriate climate for "productive disciplinary engagement" (Engle & Conant, 2002), which becomes apparent as a significant proportion of the class become involved in making substantive (and passionate!) contributions to the discussion (thereby addressing the teaching purpose of *opening up the problem*). Such is the level of involvement that the teacher is eventually forced to intervene and to call the discussion to a close.

Of course in opening up the discourse in this kind of way the teacher is left with the challenge of what to do next; how to move toward the orthodoxy of the scientific point of view. In this way a *tension* is created for the teacher. This tension exists between developing the dialogic approach of encouraging students to make their views explicit on the one hand, and focusing more authoritatively on the accepted scientific point of view, on the other. We shall see how the teacher begins to address this tension in the next episode.

Episode 2: Examining Ideas of Cold and Hot Heat

This episode took place during the next lesson of the teaching sequence. In this lesson the teacher had organized a small-group activity to address explicitly the idea, from the first lesson, that there are two kinds of heat. The activity entitled "Can cold be hot?" involved preparing a system (ice chips with salt) which is colder than melting ice and observing what happens to the reading of a thermometer when it is moved from a beaker containing ice and salt to one with melting ice. The reading of the thermometer actually goes up as it is placed in the melting ice. The episode starts (on completion of the activity) with a whole-class review of the question that had arisen in the previous discussions:

1. Teacher: Now let's return to our question. Last week some groups were talking about there being two kinds of heat. . . hot and cold heat. In fact, this is not a new idea. In the history of science it's been around for a long time.

   Also, we often think about heat in terms of our sense of touch and we have distinct senses of hot and of cold. So, we naturally tend to accept that there are two opposite and separate things—hot heat, which warm objects have and cold heat, which cool objects have.

But, we have to examine these ideas to see whether they can help us understand the notion of heat or not. So, there are two things. The first relates to what we call "cold," or "the cold." There is nothing which is absolutely cold is there? For example, melting ice. . . we think it is really cold, but is it compared to ice plus salt? Is it cold?

2. Student?: No.
3. Teacher: No, it's warm. It's a source of heat. If you put both in contact, pure melting ice will pass heat to the ice with salt. What *is* cold? I can say that it is less hot and the opposite is also true, hot is less cold. Cold and hot are relative ideas, aren't they? It's a matter of comparing things. So, does it help to think about two kinds of heat, one associated with hot objects and the other with cold? There is a second point, an important one. . . .

Communicative Approach and Teaching Purpose. Here the teacher returns to the idea, introduced by Student 7 in Episode 1, that it is possible to have two kinds of heat, both hot and cold. The teacher starts by referring to the historical origins of this idea and makes the link to the students' commonsense ideas. She then refers to the findings of the earlier practical activity and challenges the "two kinds of heat view," giving support to the scientific perspective that "cold and hot are relative ideas."

Hence, initially, the teacher adopts a noninteractive/dialogic communicative approach as she reminds the class of the ideas from the first lesson, comparing and contrasting points of view. The teacher's discourse takes the form of a rhetorical presentation (Billig, 1996), as she brings together different sides of an issue to be debated and thereby reminds the students of the "state of play" of the ongoing classroom talk. However, once the teacher acknowledges and positively appraises the "two kinds of heat" point of view (by making a link to historical perspectives and to the physical sensations of hot and cold) she introduces the scientific perspective. In other words, there is a clear movement toward the authoritative pole of the dialogic/authoritative dimension.

Episode 2 thus constitutes *one* turning point in the flow of discourse of this lesson sequence as the teacher brings together everyday and scientific views and makes an authoritative case for the scientific view that there are *not* two kinds of heat. The teacher has developed the case by engaging the students in an activity ("Can cold be hot?") which offers a vivid example of a "cold object" (melting ice) actually being "warm" in relation to another object (ice plus salt), and the noninteractive/authoritative argument that the teacher develops is based on the shared outcomes of this activity. At this point, the teacher is doing all of the talking and it would certainly be wrong to assume that all of the students in the class have taken on the scientific view. Nevertheless, in subsequent small group and whole-class discussions, there are many opportunities for students to articulate their developing ideas about heat, and the two kinds of heat idea is not raised again, by teacher or students.

An important point to recognize is that the sequencing of approaches taken in Episodes 1 and 2 enabled the direct juxtaposition of everyday and scientific views, and we believe that this is of fundamental importance in supporting *meaningful* learning by students. Thus the students have the opportunity to position the authoritative discourse of the disciplinary knowledge in relation to their everyday views and in so-doing we believe that they are better placed to appropriate this discourse and to make it their own. In simple terms, the students are better placed to see how the different ideas fit together. Drawing on the ideas of Engle and Conant (2002), the teaching approach taken here requires that the students are accountable to the views of others and to disciplinary norms and encourages students to take ownership of the scientific point of view, thereby encouraging productive disciplinary engagement.

Episode 3: What's Going on Between the Ice and Thermometer?

This episode took place during the same whole-class review of Episode 2, staged after the small-group activity "Can cold be hot?" During the activity, the teacher had talked with the groups of students, emphasizing amongst other things that a process of "heat transfer' (one way) rather than "heat exchange" (two ways) was taking place. The students had already been introduced to the particulate theory of matter, but not in the context of thermal phenomena. In the whole-class discussion, the teacher starts by asking the different groups to explain why the thermometer reading goes up when it is moved from one beaker to the other.

1. Teacher: What ideas do the different groups have? Is it right to say that the ice water transfers heat to the thermometer and that's the reason for the mercury going up?
2. Student 1: I don't think that the water transfers heat but that the thermometer measured the heat and the result was the temperature.
3. Teacher: Why not?
4. Student 1: The water doesn't transfer heat, not to the thermometer. The thermometer is just there to measure the temperature of the water.
5. Teacher: Who agrees with Student 1? Who has a different explanation?
6. Student 2: I think there is a transfer of heat because when you put the thermometer into the salt water it was at a lower temperature, than when you move it into the beaker with pure ice the temperature rises, so it is taking heat that is provided by the ice.
7. Teacher: And where does this heat come from?
8. Student 2: From the melting ice.
9. Teacher: Student 3, what did you come up with?
10. Student 3: That there is a heat change.
11. Teacher: Why?
12. Student 3: Because the thermometer measures temperatures and so it must have a heat change. The thermometer has to take in heat to get the temperature of the material which is being measured otherwise it would not measure the temperature.
13. Teacher: Student 4, what did you think?
14. Student 4: I think there is a change.
15. Teacher: Why?
16. Student 4: I think that the thermometer is measuring the temperature but besides this the water is giving heat to the thermometer.

Communicative Approach and Teaching Purpose. The purpose of this whole-class review was for the teacher to guide the students to work with scientific ideas and to support internalization as they considered the process of heat transfer from the ice–water mix to the thermometer, after the thermometer was switched between beakers. During the practical activity itself the teacher had been able to carry out a significant amount of instruction with the individual groups and this is reflected in the responses from individual students. Interestingly, the first response from Student 1, "The water doesn't transfer heat, not to the thermometer" is contrary to the school science view. Although the teacher makes no evaluative comment, she ignored this alternative response and asked for a "different explanation" (turn 5), probably expecting that other students would offer the correct response, which is what actually happened.

Consistent with the teaching purpose for this phase of the lesson, the students were not being asked to present their own ideas or beliefs about a phenomenon but to articulate the scientific point of view with support and guidance from the teacher. Furthermore it is clear from the students' responses that they understood what was being asked of them. In this way the episode sees the teacher checking student understandings and the discourse is firmly (and authoritatively) centered on the school science point of view. There is no interanimation of ideas here as the one contrary view (expressed by Student 1) is ignored. This episode is thereby played out through an interactive/authoritative communicative approach as the teacher addresses her purpose of guiding students to work with scientific ideas and supporting internalization, by probing the students' understandings of the taught school science point of view. There is clear evidence that the students are in process of making the authoritative scientific point of view their own, as they offer complete utterances in explaining that there is heat transfer between the melting ice and the thermometer (Student 2 in turn 6, Student 3 in turn 12, and Student 4 in turn 16).

Pattern of Interaction. Short, closed chains of interaction I-R-P-R-(E) are repeated strikingly throughout the episode within turns 1–5, 5–8, 9–12, and 13–16. The interesting point here is that within these chains the final evaluation (E) from the teacher appears to be missing.

Although there was no *direct* evaluation from the teacher throughout the episode, we can infer from a set of contextualization cues visible in the video that evaluation and confirmation of the science point of view *were* taking place. These contextualization cues include kinesic shifts (related to body movement), proxemic shifts (related to the interpersonal distance between speakers), prosodic shifts (changes in voice, intonation and pitch), and register shifts (Green & Wallat, 1979; Gumperz, 1992). It is also evident, from the video, that the students were absolutely clear that the responses from Students 2–4 were being positively evaluated by the teacher.

A further important point which arises here is that the analysis in terms of communicative approach and patterns of interaction is consistent with what we know about the teaching purpose for this episode. The teacher's intention was to check the students' understandings of the school science point of view. The "understated" evaluation responses from the teacher are consistent with the students providing acceptable responses. Indeed, it is inevitable that the evaluative response would have been quite different (pointing out any shortcomings) if the students' answers had not been acceptable. The interactions of this episode are therefore not to be mistaken for an interactive–dialogic communicative approach where the absence of evaluation by the teacher points toward a teaching purpose of exploring the students' own ideas.

A general methodological point which follows from this is that we should examine how all three aspects of the framework (teaching purpose, communicative approach, and patterns of interaction) articulate with one another in analyzing a particular episode.

Episode 4—What's Happening in the Thermometer?

This episode took place in a whole-class format, in the same sequence of talk as Episode 3, and illustrates how authoritative discourse can develop into dialogic discourse whilst still focusing on school science content. The numbering of turns follows on from Episode 3, thus between the end of Episode 3 and the beginning of Episode 4, 21 turns of speech are not presented.

38. Teacher: Now, what happens to the thermometer when its temperature goes up? What's happening in the thermometer? Does some kind of change take place?

39. Student 3: I think so, because the mercury in the thermometer only goes up and down, expands or contracts according to the temperature. It expands when the temperature is higher. It must have a heat change to go up and down.
40. Student 6: I think that the stuff in the thermometer is made of a material that doesn't take much heat to make it change. That's its property and that's why it's used in a thermometer. It's sensitive to whatever's being measured.
41. Teacher: A good thermometer mustn't take too much heat otherwise it would lower the temperature of the object to be measured, OK?
42. Student 6: There is heat transfer, but the mercury doesn't take much. That's why it's used in thermometers, to measure the energy from the particles.
43. Teacher: There is a small amount of energy [transferred to the thermometer/mercury] but if there was no energy, would it be possible for the mercury to expand?
44. Student?: No, I don't think it would.
45. Teacher: And there *was* an expansion of the mercury, wasn't there?
46. Student 8: Any change in heat, due to its sensitivity, changes its temperature. When you get this thermometer and put it in the surroundings, then it's at 25°. When you put it in ice the temperature decreases so fast because the heat from the ice is higher and the mercury is sensitive to it and so it goes lower.
47. Student 6: And I think that the energy of the mercury will be equal to that of the ice that is moving faster and will make the mercury go up or down.
48. Teacher: Let's consider this situation you have mentioned. It was at 25° and then you put it in the ice and then the temperature decreased. And you are saying that the ice, in this situation, has more heat than the thermometer? Is there any heat transfer in this case? What is the direction of this heat change; heat transfer in this case?

Communicative Approach and Teaching Purpose. This episode starts with the teacher asking, "what's happening in the thermometer?" This prompts a response from Student 3 which is framed tentatively "I think so. . . ," and she goes on to explain what happens to the thermometer in a scientifically correct way. Student 6 builds upon this point, taking the talk in a new direction, by independently commenting on the need for the thermometer to be sensitive. The teacher feeds-back Student 6's idea "mustn't take too much heat" and provides some elaboration by stating, "otherwise it would lower the temperature of the object to be measured, OK?" At this point Student 6 specifically refers to the "mercury" inside the thermometer and introduces the idea of particles for the first time. In this way we see the students working on and developing the original theme of "what happens in the thermometer."

In turn 43, the teacher takes back control and checks the students' understandings by posing the question, "if there was no energy, would it be possible for the mercury to expand?" A student responds correctly (turn 44), and the teacher follows up with a further question. At this point, it looks as though the interactions are returning to an authoritative pattern driven by the teacher. Student 8 thinks differently however, and he intervenes by sketching out a "thought experiment" which involves moving a thermometer from the surroundings and putting it into ice. Student 8 also introduces some confusion (as is often the case in classrooms!) by stating that "the heat from the ice is higher." Student 6 takes the ideas further by re-introducing the notion of particles "moving faster" and points to a thermal equilibrium being achieved, "the energy of the mercury will be equal to that of the ice." Finally, the teacher intervenes (turn 48) and invites the students to reconsider the situation which Student 8 has introduced, posing a whole range of questions which probe the key points raised by the students.

So we see an interesting transition from Episode 3 to Episode 4 as the teacher slackens his control and the students (in turns 39, 40, 42, 46, 47) independently offer points of view and there is a genuine interanimation of ideas. Whilst Episode 3 involves an interactive–authoritative communicative approach where the students simply respond to the teacher's questions, Episode 4 sees the development of a dialogic pattern of communication in which the students begin to pose their own questions, problematizing the scientific themes of the teaching sequence for themselves. Here the dialogic communication emerges from a context in which the students were asked to use scientific ideas to explain what happens to the thermometer when its temperature goes up. The students themselves raised a number of relevant points and this created a space for the emergence of dialogic exchanges within the scientific discourse. There is an important difference between the dialogic communicative approaches of Episodes 1 and 4, in that in Episode 1 the students were making their everyday views explicit whilst here the students are trying to use their newly learned scientific ideas to deal with problems posed by themselves.

Furthermore, the movement in Episode 4 is from an authoritative to a dialogic communicative approach, which is in a reverse direction to that of Episode 2. This demonstrates that the tension between dialogic and authoritative discourse can occur in either direction (generating a move from dialogic to authoritative discourse or vice versa).

Pattern of Interaction. The teacher starts with a question, "Does some kind of change take place?" [Initiation] and responses from two students follow, setting-up an (I-Rs_1-Rs_2-) pattern. The teacher (turn 41) elaborates upon Student 6's idea and prompts a further response from Student 6. At this point (turn 43) the teacher poses an instructional question, "if there was no energy, would it be possible for the mercury to expand?" and runs through a form of I-R-E routine. Student 8 does not respond directly to the teacher's question but introduces his "thought experiment" in posing his own problem.

Overall for this episode, the pattern of interaction follows the kind of chains of interactions, with students independently making contributions, which is consistent with an interactive/dialogic communicative approach. Here we see students assuming the role of "knower" (Candela, 1999), as they support their knowledge claims and generate fresh interactions. An interesting point here is that the direction of development of the content of the discourse is not only influenced by the teacher but also by the contributions of the students. In this way, Episode 4 shows evidence of the productive disciplinary engagement (Engle & Conant, 2002) of students. They are able to present substantial arguments not only in answering the teacher's question but also in posing their own questions and their own hypotheses. Turns from the students are longer and much more elaborated than in the initial episodes and here they are made within a scientific discourse.

DISCUSSION

In this section, we first of all return to discuss in more detail the central theme of the paper which is the tension between authoritative and dialogic interactions in the science classroom. We then make links to the existing literature on "productive disciplinary engagement" (Engle & Conant, 2002) in science lessons. Finally, we explore some general methodological implications for the use of the analytical framework and specify criteria to be used in identifying authoritative and dialogic communicative approaches.

The Tension Between Authoritative and Dialogic Interactions in Science Teaching

Shifts in Communicative Approach. The analysis which we have presented in this paper shows a series of shifts in communicative approach from an interactive/dialogic approach in Episode 1, to a noninteractive/dialogic approach in the first half of Episode 2 and to a noninteractive/authoritative approach in the second half of Episode 2. Thus in Episode 1 the teacher provided the opportunity for students to talk through their existing ideas about "what happens when we feel hot and cold." In Episode 2, the teacher first drew attention to the "two kinds of heat" idea before moving on to state authoritatively that cold and hot are relative ideas and that there is only one kind of heat. As the teacher worked with the class to consolidate the scientific idea of heat transfer in Episode 3 the communicative approach was predominantly interactive/authoritative, but in the same sequence of talk we identified a shift to an interactive/dialogic approach (Episode 4), as the teacher followed the lead of the students in discussing the sensitivity of thermometers.

Through this form of analysis we begin to see the ways in which dialogic and authoritative approaches are intimately connected and how a tension thereby exists between the two. Thus, as the teacher, in Episode 1, opens up the interactions relating to hot and cold heat, she simultaneously sows the seeds for the authoritative resolution of this issue. The fact of the matter is that science is an authoritative discourse which offers a structured view of the world and it is not possible to appropriate the tools of scientific reasoning without guidance and assistance. Learning science, as well as training professional scientists, inevitably involves acquiring the tools of "normal science" (Kuhn, 1962), and the canonical ways of reasoning in science (Anderson, Holland, & Palinscar, 1997). For the teacher in this lesson sequence (and any other science teacher), it is not sufficient to engage students in dialogue about their everyday views of phenomena; there is the additional and central responsibility of introducing the science perspective.

A reasonable question to ask at this point might be "why bother with the initial dialogic approaches if the teacher is bound ultimately to introduce the authoritative science view?" The fundamental idea here is that meaningful learning involves making *connections* between ways of thinking and talking, in this case between everyday and scientific views of basic thermal phenomena. The initial dialogic approaches offer the opportunity for students to express their everyday views and then later to see how these views relate to the science perspective. In addition we would argue, based on our experience of teaching and researching in science classrooms, that dialogic engagement is potentially *motivating* of students (as seen in Episode 1), drawing them into the problem at hand, and legitimizing their expression of whatever ways of talking and thinking they possess. In this way, the initial dialogic approaches address the teaching purposes of "opening up the problem" for the students and allowing the teacher to "explore and probe students' views."

Of course, the authoritative presentation of ideas alone cannot ensure meaningful learning. It is important that students have the opportunity both to make explicit their everyday ideas at the start of a teaching sequence (as in Episode 1) *and* to apply and explore newly learned scientific ideas through talk and other action for themselves (as in Episode 4). Within the context of high school science classrooms, where dialogic discourse is universally rare, there is a tendency for it to fade out altogether as the students appropriate the school science point of view (see, e.g., Amaral & Mortimer, 2004). Thus, the paradoxical situation exists where the most fluent exponent of scientific ideas (the teacher) does all of the talking whilst the novices (the students) have little or no opportunity to speak the scientific language for themselves and to make it their own. We would argue strongly that if we expect students to engage in meaningful learning in the science classroom, they should be allowed to play with the "sharply demarcated" (Bakhtin, 1981) authoritative discourse of science in new situations, expanding its possibilities for application, making links to other areas of science, and constructing meanings that are new for them. Students need to engage in the dialogic process of exploring and working on ideas, with a high level of interanimation, within the context of the scientific point of view.

In these ways, we see transitions between dialogic and authoritative interactions as being fundamental to supporting meaningful learning of disciplinary knowledge as different teaching purposes are addressed (Aguiar & Mortimer, 2003). Thus, now the teacher encourages dialogic discourse to probe students' everyday views; later she adopts an authoritative approach to introduce the scientific point of view; then she prompts dialogic discourse as she encourages students to explore and apply the scientific view, and so the shifts in communicative approach continue throughout the sequence of lessons.

The analysis developed here puts special emphasis on the teacher's role in orchestrating the classroom discourse, but we also consider the students' perspectives, as individuals socially engaged in specific cultural settings, with all their inherent diversity and conflict (Caravita & Hallen, 1994). According to Mercer (1995, p. 50): "appreciating the learner's angle on classroom conversations means recognizing that learners have their own interpretations of events and may be following their own agendas." Thus, the communicative approach cannot always be mapped out in advance by the teacher, since the direction of development of lessons must be consequent upon (for the responsive teacher at least) the interests and concerns of the students.

Although we have presented authoritative and dialogic discourses as constituting, in theory, two poles of a dimension, it is important to recognize their intimate dynamic linkage in practice. The *tension* which we refer to in this article develops as dialogic exploration of both everyday and scientific views requires resolution through authoritative guidance by the teacher. Conversely the tension develops as authoritative statements by the teacher demand dialogic exploration by students. So, both dialogicity and authoritativeness contain the seed of their opposite pole in the dimension, and in this way we see the dimension as tensioned and dialectic, rather than as being an exclusive dichotomy. Following these ideas, we see teaching for meaningful learning in terms of a progressive shifting between authoritative and dialogic passages, with each giving rise to the other.

The Challenge for the Teacher. Given the arguments set out above, an important question to reflect upon concerns why the extent of dialogic teaching in high school science classes is so small, and why therefore there is little of the shifting between communicative approaches which we have drawn attention to here.

One fundamental response to this question concerns the teacher's views of what is involved in teaching and learning. Quite simply, if the teacher sees their job as providing a robust and accurate account of the scientific perspective, then there is no logical reason why they should engage in dialogic interactions with their students. Our experience is that such "transmissive" views, relating to a "conduit metaphor" (Reddy, 1979) of language, teaching and learning, are common.

A further point concerns the knowledge bases which need to be drawn upon to engage fluently in dialogic interactions with students. Here, it is not just a question of knowing and understanding some science, but the teacher also needs to have insights into the kinds of everyday ways of talking which students are likely to bring to their lesson and, crucially, know how to respond to those everyday ideas in attempting to move along the students' ways of talking and thinking. Such interventions by teachers have been conceptualized in terms of developing "passing theories" (Davidson, 1986, quoted in Roth, 2005, p.158) or reconstructions of students' views and this inevitably must be a spontaneous and situated process (Roth, 2005, p. 159) carried out right on the edge of the teaching and learning. For example, in Episode 1 of the present case, the teacher was able to recognize the everyday view of two kinds of heat, draw attention to it, and then develop an appropriate activity to challenge this everyday view, making more plausible the scientific account. This kind of teaching activity constitutes a highly skilled performance, indicative of a high level of insight and expertise.

However, this kind of teaching activity does not simply rely on utilization of different knowledge bases. There is also the "know-how" of being able to engage students in dialogic interactions and to see how these differ from authoritative interactions. Our experiences of using the communicative approach framework with teachers, in both preservice and in-service professional development contexts, is that very often they confuse dialogic teaching with interactive/authoritative approaches. Thus the teacher engages students in lots of interaction and turn taking but these are authoritative in nature as the teacher focuses attention on the scientific point of view, ignoring contributions from students which are not consistent with that view. We believe that the link which we outlined earlier between communicative approach and patterns of discourse can be helpful in supporting teachers to adopt a wider range of teaching approaches (both authoritative and dialogic). Our experience has been that teachers, once provided with the theoretical tools, are quick to see the links between an authoritative communicative approach and triadic patterns of discourse and furthermore recognize the possibilities of an alternative dialogic approach based on chains of discourse. The crucial first step is to provide the tools which allow teachers to reflect upon and then modify their classroom practices.

A further point of concern for teachers, which is likely to militate against them using dialogic approaches in the classroom, is the question of *time.* A common, and absolutely understandable point of view, is that the teacher cannot afford to spend lots of time in listening to what their students have to say. We believe that the key to dealing with this issue is to identify those parts of the curriculum where dialogic discourse will be important, simply because there are big conceptual gaps between everyday and scientific points of view. The fact is that some parts of the science curriculum make bigger learning demands (Leach & Scott, 2002) than others, and it is in the areas of big demand where time needs to be spent in comparing and contrasting points of view. We saw an example of this in Episode 2 where the everyday notion of "hot and cold heat" was addressed dialogically by the teacher. There will be other situations where differences between everyday and scientific views are small (teaching the concept of "speed" springs to mind here) and the science appears to be "just common sense" to the students. In such cases, it would literally be a waste of time to commit lengthy initial parts of a teaching sequence to detailed dialogic interaction. The general point here is that teaching decisions to open-up or close-down instruction in a dialogic or authoritative way must relate to the content matter being taught, and in particular to the degree of difference between everyday and scientific views.

Finally, there is the key question of whether shifts in communicative approach give rise to enhanced student learning. If the answer to this question is "no," then there is no reason for teachers to take arguments for a broader range of teaching approaches seriously. At present, there is a limited body of evidence to suggest that shifts in communicative approach can have a positive impact on measured student-learning outcomes in relation to science concepts (see Leach, Ametller, Lewis, & Scott, 2005). A more significant body of evidence is provided by the kinds of transcripts which are presented in this paper and which illustrate the quality of engagement of the students and their ability to talk the scientific discourse in the classroom. This final point takes us back to the studies referred to earlier on relating to the theme of productive disciplinary engagement.

Shifts in Communicative Approach and Productive Disciplinary Engagement. In our analysis of the lesson sequence, we have so far drawn attention to the shifts between communicative approaches and have developed the case that this pedagogy has the potential to support meaningful learning of scientific conceptual knowledge. In this respect we see clear links with the developing literature on “productive disciplinary engagement” (Engle & Conant, 2002).

In the teaching sequence, the lessons were designed to encourage student involvement by engaging them in tasks that were mediated by classroom talk with their peers and the teacher. In this sense, the lessons exhibit a participant structure that was intended to assure “productive disciplinary engagement” of the students, although the four principles advanced by Engle and Conant (2002) were articulated in a particular way that resembles more the Japanese hypothesis–experiment–instruction method (Hatano & Inagaki, 1991, quoted in Engle & Conant, 2002) than the American learning through inquiry projects (e.g., the Fostering Communities of Learners (FCL), Brown & Compione, 1994).

As outlined earlier, Engle and Conant suggest four principles for fostering productive disciplinary engagement: problematizing content, giving students authority, holding students accountable to others and to disciplinary norms, and providing relevant resources. How are these principles manifested in the teaching sequence presented here?

In relation to *problematizing* content, the teacher acted during the dialogic phases to encourage student questions, proposals, and challenges rather than just expecting answers and assimilation of facts and procedures. As outlined earlier, these approaches to problematizing content were evident both at the start (Episode 1) of the sequence in exploring everyday views and later on (Episode 4) in working with and applying the scientific point of view. Right from the start of the lesson sequence, the students were given the *authority* to develop their own hypotheses in the context of working in small groups and to report their ideas back to the whole class. In Episode 4, we have a situation where the students were given the space and time to present relatively elaborated arguments not only in responding to the teacher’s questions but also in posing their own questions and developing their own ideas. In this way, the students have a degree of agency linked to the expectation that they should provide hypotheses to explain what they observe in practical activities, arguments to support their views, and that they should pose authentic questions. Throughout the lessons there is the expectation that students should *take account* of the views of others and also provide reasons and evidence for their claims (attending to disciplinary norms), as demonstrated in Episode 1 when the teacher declares: “Well, you must justify your ideas.” Finally, for these lessons *relevant resources* include the well-designed activities and texts used to facilitate the emergence of the students’ ways of thinking about heat and temperature and their subsequent evolution. Time is another important resource, as the students are invited to engage with and talk through several activities developing explanations for the phenomena they observed.

In these ways, the principles for fostering productive disciplinary engagement are demonstrated in this specific teaching and learning example. In more general terms, we believe that the notion of shifting between communicative approaches provides a useful and complementary way of thinking through and identifying what might be involved in productive disciplinary engagement in science classes.

An Approach to Discourse Analysis: Methodological Issues

In this final section, we examine a number of broader methodological and theoretical issues relating to the use of the framework (Table 1) in analyzing the discourse of science classrooms.

Taking an Overview. In making our analyses we, first of all, try to get a sense of the overall flow of discourse through a sequence of lessons. This approach of taking an overview follows from the Bakhtinian principle that "any utterance is a link in the chain of speech communication" (Bakhtin, 1986, p. 84). In this sense any utterance provides a response to previous utterances and anticipates the responses of others. In other words, if we want to develop an understanding of the way in which the discourse develops through a specific teaching sequence then it is essential to have an overview of how the constituent events fit together moving forwards and backwards in time.

For example, to understand the purpose of a specific teaching activity in a sequence of lessons it is necessary to determine how this particular activity fits with the whole sequence. The same is true for the communicative approach. For instance, the significance of the discussions in Episode 1 ("You must justify your ideas") becomes clear as we analyze the flow of ideas in the following lesson (where the teacher explicitly addresses the key everyday ideas raised in this episode). In a similar way, an appreciation of the ideas proposed by the students in Episode 3 ("What's going on between the ice and the thermometer?") emerges from the analysis of the previous group activity (where the teacher had talked with individual groups to raise the school science point of view). In this way, our analysis of the discourse of science lessons involves an iterative process of moving backwards and forwards through time, trying to make sense of the episodes as a linked chain of interactions.

A further important methodological issue, following from the analyses presented in this paper, concerns the need to consider a whole set of contextualization cues, and not only verbal language, in deciding on the nature of the discursive interactions. In Episode 3, for example, the absence of explicit evaluation renders the I-R-E pattern invisible in the *written* transcripts. It is only through looking closely at the teacher's body movement and her proxemic shifts toward specific students as they answered her questions, that we can conclude that the teacher was evaluating positively their answers. The general message here is that sometimes we must look beyond verbal interactions to identify patterns of discourse, taking the discursive act as a whole and including all contextualization cues. Gee (1999) makes the distinction between analyses of interactions which focus exclusively upon talk (referring to these as "discourse analyses") and those which also take into account other modes of communication (referring to these as "Discourse analyses"). In Episode 3 the importance of considering the "whole act" (the Discourse with the capital D) is clearly apparent.

Units of Analysis. In analyzing classroom data, it is possible to identify several different units or levels of analysis. One "macro" level of analysis is framed by the organization of the school and the way in which it deals with time scales. So, we take video records from *lessons*, which have clear time boundaries. If we move up from this level, these lessons are part of *sequences* that correspond to larger units of the school science curriculum. If we move down, the lessons (at least in the data presented here) are divided into a set of interlinking activities, which is normally planned in advance. These activities themselves are divided into a set of *episodes* which mark out different phases of the lesson. How do we identify episodes? The central idea here is that each episode addresses a specific teaching purpose and, as argued earlier, the teaching purpose is played out with one particular, or a related set of, communicative approaches and underlying patterns of interaction. Thus we identify the boundary between episodes by looking for changes in teaching purpose. For example, in the data presented earlier, there is a change between Episodes 3 and 4, as the teaching purpose and communicative approach/pattern of interaction change.

Our specific research interest focuses on the ways in which meanings are developed in science classrooms within the "micro" context of interactions between people and between people and various objects and events. In this respect, our analyses involve closely examining the individual *utterances* of the teacher and students. Given the point made earlier that any utterance is a link in the chain of speech communication, we cannot classify a single utterance as being dialogic or authoritative. This is a criterion that applies to a number of utterances that constitute an episode of meaning making. In addition, classification of an episode involves examining the broader picture that is being constructed in a sequence of lessons, as different teaching purposes are addressed. This brings us back to the previous point of needing to take an overview of events in mapping the meaning making processes in a sequence of lessons.

Operationalizing the Concepts of Authoritative and Dialogic Discourse. The theoretical concepts of authoritative and dialogic discourse provide a starting point to the analysis of classroom interactions presented in this paper, but it is only through actually applying the concepts and making such analyses that we can begin to understand more fully these ideas in the context of teaching and learning science concepts.

Through applying the framework to the data presented in this paper and to other data sets, we have developed the following comparison (see Table 4) of the key features of authoritative and dialogic discourse, in the context of school science teaching. In presenting the key features of each kind of discourse in this way, we emphasize the importance of bearing in mind (as outlined earlier) that we see the two forms of discourse not in terms of a dichotomy but as a tensioned and dialectic dimension such that one form of discourse gives rise to the other in supporting meaningful learning.

Contexts for Applying the Framework. An important question that emerges in the discussion of any analytical tool concerns the specific contexts in which it can and cannot be applied. In this paper, our focus has been on science concept learning and the evolution in students' reasoning from everyday to scientific views. Furthermore, all four episodes involved teacher-led lessons. This was not by chance. As we stressed earlier, the analytical framework (Mortimer & Scott, 2003) was developed to analyze the speech genre (Bakhtin, 1986) of science classrooms and, in particular, the ways in which the teacher acts to guide meaning making interactions on the social plane of high school science classrooms. The five linked aspects of the framework were created mainly by focusing on the teacher's performance.

Nevertheless, the framework can also be applied to analyze student–student interactions as the students can take on different roles in the classroom, including that of "teacher." As we demonstrated (Mortimer & Scott, 2003) in analyzing a teaching sequence on the particulate theory of matter, "the asymmetry between the teacher's and students' roles, which is reproduced in this interaction between students, seems to be an inherent sociocultural and institutional characteristic of schools that frames the discourse, even when led by students in the absence of a teacher" (p. 86). We have also used the framework to analyze students' questions (Aguiar, Mortimer, & Scott, 2005) and students' engagement in practical activities. Given these studies, we can conclude that the framework can be applied to analyze both teacher-led lessons and student–student interactions, albeit it in lessons in which the participant structure is open enough to allow students to have a real role in the development of the teaching sequence. As might be expected, the framework does not provide many new insights for those classrooms where the teacher talks all of the time and where the students' participation is limited to filling in the gaps left by the teacher in their discourse.

Related to content, our emphasis in the use of the framework continues to be on teaching scientific concepts. Although we recognize the importance of the epistemic dimensions of classroom talk and also of more open participant structure classrooms that emerge in

TABLE 4
Key Features of Authoritative and Dialogic Discourse

	Authoritative Discourse	Dialogic Discourse
Basic definition	• focusing on a single perspective, normally the school science view.	• open to different points of view
Typical features	• direction prescribed in advance	• direction changes as ideas are introduced and explored
	• clear content boundaries	• no content boundaries
	• no interanimation of ideas	• variable (low-high) interanimation of ideas
	• more than one point of view may be represented but only one is focused on	• more than one point of view is represented and considered
Teacher's role	• authority of teacher is clear	• teacher assumes a neutral position, avoiding evaluative comments
	• teacher prescribes direction of discourse	
	• teacher acts as a gatekeeper to points of view	• greater symmetry in teacher–student interactions
Teacher's interventions	• ignores/rejects student ideas	• prompts student contributions
	• reshapes student ideas	• seeks clarification and further elaboration
	• asks instructional questions	• asks genuine questions
	• checks and corrects	• probes student understandings
	• constrains direction of discourse, to avoid dispersion	• compares and contrasts different perspectives
		• encourages initiation of ideas by students
Demands on students	• to follow directions and cues from the teacher	• to present personal points of view
	• to perform the school science language following the teacher's lead	• to listen to others (students and teacher)
	• to accept the school science point of view	• to make sense of others' ideas
		• to build on and apply new ideas through talking with others

inquiry-based learning environments where authentic controversy and opened problem solving take place, we believe that there is still work to be done in developing tools to help us understand more clearly how conceptual understandings develop through language and other modes of communication.

FINAL COMMENTS

In this paper, we have used part of the framework developed in Mortimer and Scott (2003) to explore the notion of a tension between authoritative and dialogic discourse and what might be involved in meaningful learning or productive disciplinary engagement in the science classroom. In reflecting, in more general terms, upon the value of this approach to discourse analysis we are reminded of the criteria which Gee (1999) lists to establish the validity of such analyses. These criteria include the notions of *agreement*, *coverage,* and *linguistic details*.

In relation to "coverage," Gee (1999, p. 95) argues that "the analysis is more valid, the more it can be applied to related sorts of data" and "this includes being able to make sense of what has come before and after the situation being analyzed." We believe that our approach to discourse analysis meets this criterion of coverage in that it has provided valuable insights into all of the science lessons which we, and others (see, e.g., Aguiar & Mortimer, 2003; Amaral & Mortimer, 2004; Tachoua, 2005; Viiri, Saari, & Sormunen, 2003) have applied it to.

In respect to "linguistic details," Gee (1999, p. 95) states that "the analysis is more valid the more it is tightly tied to details of linguistic structure." He further suggests that part of what makes a discourse analysis valid is that "the analyst is able to argue that the communicative functions being uncovered in the analysis are linked to grammatical devices that manifestly can and do serve these functions." We believe that our approach to discourse analysis meets this criterion of validity insofar as we are able to make the link from patterns of interaction to classes of communicative approach and then to teaching purposes.

Finally, according to the concept of "agreement," Gee (1999, p. 95) maintains that the analysis is more valid or convincing, "the more *native speakers* of the social languages in the data and the *members* of the Discourses implicated in the data agree that the analysis reflects how such social languages actually can function in such settings." Once again, we believe that our analysis meets this criterion and have evidence of this through our widespread professional development work (preservice and in-service) with science teachers. In particular, we believe that our analyses are pitched at a level of detail which resonates strongly with the practices and activities of real teachers and students in real classrooms.

In summary, we have made a case for the value of the framework as a research tool for systematically analyzing the interactions of science lessons, drawing attention to fundamental issues such as the tension between authoritative and dialogic approaches. Furthermore we believe that the framework offers a workable set of tools, which can be helpful to teachers in allowing them to reflect upon and to develop their teaching practices in professional development contexts.

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Friday

Learning objectives

Lesson exercises

After the lesson exercises, the participants are able to:

- carry out a lesson that is problem-oriented by formulating a set of Inteded Learning Outcomes and implementing an appropriate level of student activity that is carried by dialogue.
- receive feedback on their own teaching.
- engage in a constructive dialogue about others' teaching, for example by evaluating the teaching by making use of the TDS-phases (devolution, action, formulation, validation and institutionalization).
- evaluate how a problem-oriented lesson that is carried by dialogue that ensures active students contributes to achieving the Intended Learning Outcome.
- outline how their own and others' teaching can be developed further.

Planning of your lesson

Use the following pages to write down thoughts, plans and reflections concerning the planning of your lesson. Use the pages as a notebook. Jut down thoughts and ideas when you have them.

- Your own ideas for the lesson

- Discussion of lessons with the planning group

- Intended learning outcomes for the lesson

- Overview of main points and didactical phases (TDS)

Time	Content / Main points	Didactical phases	Audio-visuals

Self-reflection on your lesson

To be filled out before you have given your lesson

- What was the greatest challenge in planning the lesson? What would you like feedback on in particular?

To be filled out after you have given your lesson

- How did the lesson go? Did you get through the planned phases? Did the participants learn what was intended? Why – why not? How was the contact with the participants? Was it different than planned? How did the transition between phases go (e.g. starting a student activity, validating the work the students had done)? Other things you noticed?

Feedback on lesson

Here you can write notes on the feedback you receive on your lesson exercise

Friday feedback Team 1 (usually the Danish language team)

www.ind.ku.dk/iup1

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Friday feedback Team 1 (usually the English language team)

www.ind.ku.dk/iup2