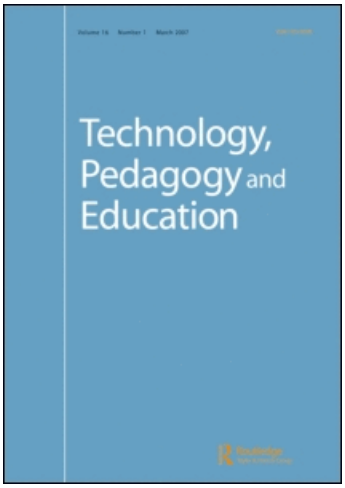

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Using Affordances and Constraints to Evaluate the Use of Information and Communications Technology in Teaching and Learning

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ABSTRACT Evaluating the nature and extent of the influence of information and communications technology (ICT) on the quality of learning is highly problematic, owing to the number and complexity of interacting variables involved in settings for teaching and learning. Yet, for those responsible for allocating large sums of money to the development of ICT in education, it is important to identify, characterise, measure and model more precisely the features and processes through which technology impacts upon teaching and learning activities. This article offers a framework for analysing the effects of ICT in combination with the other factors which may enhance or ameliorate the positive impact of ICT in the classroom and beyond. This framework is applicable to different levels of evaluation, including large scale curriculum development programmes, curriculum and pedagogical change in particular schools, and individual teachers' planning and reflection. Its use in evaluating new ICT-based teaching approaches at classroom level is illustrated and analysed in the context of an in-service teacher education programme in the United Kingdom, and suggestions are made concerning the development of evaluation tools based on the framework.

Introduction

The use of information and communications technology (ICT) as an aid to teaching and learning has been adopted largely as an act of faith (Stevenson, 1997), and reliable, quantitative evidence for its beneficial effects on student learning is currently limited (Haertel & Means, 2000). Yet, if further development of ICT in education is to be justified, hard evidence of its benefits is required (McFarlane, 2000). Many case studies and small scale research projects suggest positive effects on the quality of pedagogy and learning under particular conditions (e.g. National Council for Educational Technology, 1994; Mumtaz, 2000). Larger scale research indicates that

extensive access to ICT produces clear benefits in terms of student motivation (Cox, 1997; Chen & Looi, 1999), but marginal improvements in measurable attainment (British Educational Communications Technology Agency [Becta], 2001). Meta-analysis of such findings is inhibited, however, by a lack of consistency of approach in terms of the variables selected for analysis and the methods chosen for evaluation.

This state of affairs reflects the deep problems in obtaining a clear view of the contribution made by ICT to the effectiveness of teaching and learning. These problems are caused by the sheer number of elements and variables in the pedagogical setting and the complexity of relationships amongst these elements. In order to help overcome the difficulty in evaluating ICT's influence, we first examine the nature of the pedagogical setting, and review some models available for evaluating the contribution of different elements. We then outline a new framework for evaluation, developed from our research into ICT and learning, which extends current models in order to focus on student activity and incorporate the key role of reflective activity. We next provide some illustrations of the application of the model in teacher education and, finally, we draw conclusions concerning the development of more effective tools for the evaluation of ICT's impact in the classroom.

The Pedagogical Setting

There are many factors which may influence the success of a teaching episode. Variables concerning the teacher, students, classroom organisation, resources, subject/classroom culture and norms (rules, routines and expectations) will influence what and how students learn. ICT will not act independently of these; designers incorporate particular pedagogical ideas into software and tasks (Hoyles & Sutherland, 1992; Squires & McDougall, 1994); teachers use the same ICT resources in different ways (Moseley & Higgins, 1999; Wood et al, 1999); student ICT activities depend on the pedagogical approach employed and the resources available (Gardner et al, 1993; Watson, 1993); the role of ICT will be perceived differently in each subject and in each classroom because of the prevailing culture (Olson, 1988; Kennewell et al, 2000b); and students' ICT capability and perception of ICT depend on their access outside school (Kennewell et al, 2000b; McFarlane, 2000; Furlong, 2000).

We take as a premise that, in order properly to evaluate the impact of ICT on teaching and learning, a detailed analysis of the setting is required. A framework is thus needed to help us characterise and measure these variables and enable us to model their influence.

Evaluation Models

In seeking to find out whether ICT makes a difference to students' learning, we need to recognise that ICT cannot be isolated from other features and methods of teaching, which makes an experimental design inappropriate.

> The direct experiment is to run two groups differing only as to whether they had a computer, but since it is part of the complete learning situation, in the control condition the other activities would make no sense without the computer ... The best argument (though indirect) seems to be to show that a package using the computer is effective, and that there is no obvious way to substitute for the role of the computer. (Anderson & Draper, 1991, p. 6)

A framework for evaluating the impact of information technology (IT) needs to consider the aims of the teacher, the principles of the software and an interpretation of what went on in the classroom (Hammond, 1994). In devising such a framework, two fundamental questions need to be considered:

1. What are the problems in trying to measure the contribution of IT to learning;
2. What are the problems encountered in making IT an effective tool in the classroom? (Hammond, 1994, p. 252)

In response to Question One, Hammond (1994) also comments on the limitations of a design involving control groups. The groups cannot be given the same tasks to do; one group may need a longer time to complete activities; they may develop knowledge other than that specifically planned and tested; the need for transfer of knowledge to a manual test setting may disadvantage groups using ICT; and, if ICT is believed to be beneficial, 'is it fair to potentially disadvantage one set of students at the expense of another?' (p. 255).

Question Two raises further issues. There may be 'side effects' of using ICT: if we are to overcome the IT interference factor (Birnbaum, 1990), we may need to develop students' ICT capability, and this may not be valued in the context of the study. There may be a mismatch between features of powerful office software and educational goals (Squires & McDougall, 1996). There may be little difference between ICT and non-ICT groups if insufficient time is allowed for the use of ICT.

Similar points were raised by the *Impact* project (Watson, 1993), where the case studies highlighted positive effects of using IT such as increased concentration and motivation, but also identified negative factors such as:

- teachers having insufficient knowledge of the software and understanding of the principles behind its use;
- students being unable to cooperate effectively;

- students having difficulties in learning to use the software;
- the existence of a minimum threshold to make the use of IT effective. (Watson, 1993, pp. 3-4)

When attempting to compare the effectiveness of different approaches, we cannot hope to control fully all the relevant variables: time, location, culture, resources, teacher, pedagogical approach, didactical strategy, intended learning outcomes, task briefs, task outcomes. What we can do, however, is analyse these features carefully and systematically in each setting.

A starting point for such an analysis is provided by the *Perspectives Interaction Paradigm* of Squires & McDougall (1994). This framework for software evaluation recognises the influence on learning of three main perspectives (software designer, teacher, student) and takes into account three sets of interactions between them:

- *Teacher-student*: a two-way direct interaction. One of the main variables here is the teacher role, which may be 'resource provider', 'manager', 'coach', 'researcher' or 'facilitator'.
- *Designer-student*: primarily a one-way influence, although the designer's perception of a student's characteristics and activities will also be influential implicitly.
- *Designer-teacher*: again, primarily a one-way influence, with the designer's perception of the teacher having some influence.

This framework assists the evaluator to identify the key issues on which judgements must be made in the particular context of the proposed use (predictive evaluation) or actual use (interpretive evaluation) (Squires & McDougall, 1996).

It is clearly inadequate to consider the design of the software in isolation from its pedagogical setting. Squires & McDougall (1994) note that some of the most innovative educational activities occur when teachers and students actually subvert the designer's intention, and these interactions are necessarily complex in nature. They also highlight the problematic nature of using evaluation tools based on curriculum objectives 'when software applications are "high-jacked" for use in education' (Squires & McDougall, 1996, pp. 149-150). Furthermore, software gets used in ways not predicted by the evaluator, and organisational factors have a significant bearing on the degree of integration of the software into the mainstream of classroom experience (Anderson & Draper, 1991).

It may thus be preferable to consider 'how to "measure the learning process" rather than how to "evaluate Information Technology"' (Anderson & Draper, 1991, p. 7). There is a role for a theory of learning in predicting 'what factors or features of the system and the testing situation determine the measurements observed, and thus tell you what measures might be worthwhile', and 'what features of an intervention to change in order to try to improve the values observed' (Anderson & Draper, 1991, p. 7). In this view, however, a reliable measure of learning is independent of the uses to

which it is then put, and the measurement of learning can proceed as follows:

1. Decide what is being measured.
2. Choose the instrument(s) for making the measurements.
3. Summarise the results.
4. Draw conclusions and make judgements.

This takes little account of the role of the teacher in planning and managing the learning process, however, and it is important to consider the teacher's pedagogical knowledge, the integration of ICT into this knowledge, and its application in the particular context being studied (Kennewell, 1997).

Thus, the evaluation of the effects of ICT on learning should not be seen as merely an analysis of the extent to which knowledge is mediated by ICT and how it is mediated. Rather, it should involve characterising the ways in which gaps between potential and actual activity in a setting are bridged by learners with the assistance of teachers, ICT and other resources, and then analysing the contribution of influences on learning attributable to ICT and the way these influences are orchestrated by the teacher. Learning with ICT may result in some dependence of the knowledge gained on the availability of ICT, for instance when dyslexic students learn effective strategies for using spellcheckers rather than learning to spell every word. Thus, the implications of such dependences must also be considered. This is a highly complex task, and we must look for some way of structuring the analysis.

Affordances and Constraints in Didactical Activity

Didactical activity is used here to mean goal-directed actions in relation to tasks which have been designed to bring about learning for a specific group of students. Learning involves a change in students' *abilities;* in this framework, a person's ability is the potential for action in a setting provided by their knowledge, skills, understanding and disposition (Greeno, 1994). These attributes are at least partially dependent on the setting (Greeno & Moore, 1993). The settings which teachers create for learner activity comprise a large number of features; some of these are designed specifically for didactical purposes, whilst others are present as a natural part of the pedagogical culture and environment. Students are expected to carry out tasks with particular goals concerning their *outcome* (such as a piece of writing, a set of short answers to questions, or an artefact) and concerning *learning* (for example, developing the ability to identify the causes of a historical event, compare the reactivity of certain metals, or calculate the mean of a set of numbers). To achieve the task outcomes, students use their existing abilities, together with supporting features of the setting. To achieve learning, some cognitive effort on the part of students is required to overcome the gap between their existing abilities and the intended abilities

in the setting (Salomon & Globerson, 1987). The teacher's role is to orchestrate the supporting features – the visual cues, the prompts, the questions, the explanations, the demonstrations, the collaborations, the tools, the information sources available, and so forth – in an attempt to make it possible, but not trivial, for learners to bridge the learning gap.

The attributes of the supporting features can be classified as affordances (Gibson, 1986) and constraints (Greeno, 1998). The affordances are the attributes of the setting which provide potential for action; the constraints are the conditions and relationships amongst attributes which provide structure and guidance for the course of actions. For example, a doorway affords entrance to a room; a closed door constrains entry. Constraints are not the opposite of affordances; they are complementary, and equally necessary for activity to take place. Of course, by virtue of their support for particular actions in a setting, the affordances and constraints may inhibit other actions which are more desirable. The door that is open may not lead to the room we seek, and it will be more fruitful to walk on down the corridor. Neither type of feature can be considered absolute in nature, however; affordances and constraints must be considered in relation to the abilities of the participants in the activity they support. For example, a narrow doorway will not afford entry to the room for a wheelchair user, and a closed door will be too great a constraint for someone who does not know that the handle must be turned to open it.

ICT is just one component of the setting, but it is particularly important because of the special features that it can bring to the learning and application of other subjects in the school curriculum, such as:

- speed, capacity and range of access to information;
- automatic processing of data;
- ease of amendment of work carried out;
- immediate feedback to the learner. (Teacher Training Agency [TTA], 1998)

The affordances and constraints of ICT are often different in nature from those features of the setting that are directly related to the subject matter being taught. Furthermore, abilities in ICT may influence the preferred techniques and processes selected when applying knowledge of the subject. The introduction of ICT thus changes the relationships in the pedagogical setting sufficiently to warrant a special place for ICT in a framework for analysing teaching and learning in classrooms at present.

When students are working on a task designed to bring about learning, their progress towards the task goal depends on the potential for appropriate action provided by the affordances of the setting, and the structure for appropriate action provided by the constraints of the setting, together with their abilities. These will relate to the subject they are learning, to other generic matters such as literacy and metacognition, and to ICT if it is involved in the activity. For example, in the biology classroom,

the task of describing the heart may be afforded by a large diagram of a heart on the wall, or by the showing of a film. In this scenario, less able pupils may given a constrained version of the task in which they merely have to fill in missing keywords on a printed version of the required description. In a foreign language classroom, a role play activity concerning the purchase of a train ticket may be afforded by a list of useful vocabulary; it may be constrained by requiring all the words on the list to be used appropriately in conversation.

Figure 1 represents the main relationships during classroom activity with ICT:

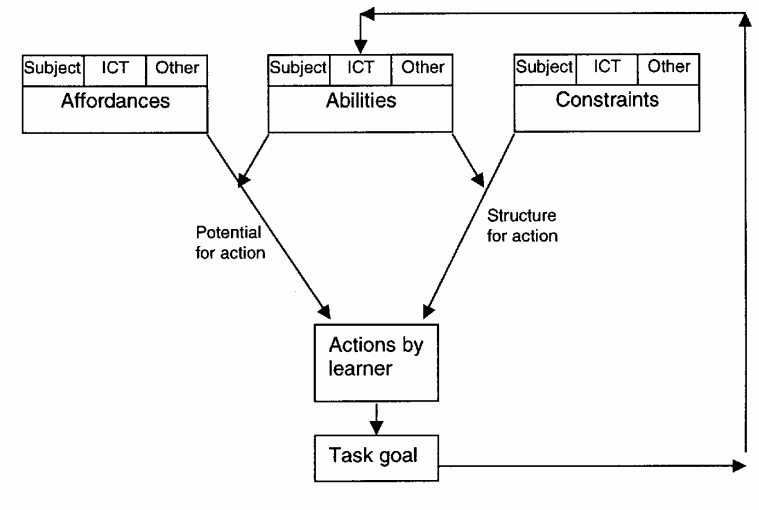

Figure 1. Elements of goal-directed activity.

The role of the teacher is to orchestrate the affordances and constraints in the setting in order to maintain a gap between existing abilities and those needed to achieve the task outcome, a *learning gap* which is appropriate to the development of intended abilities. If students find the task easy, little learning will result and the affordances and constraints need to be reduced. Similarly, if they find the task too hard, other features can be added or the current ones adapted in order to provide more appropriate support. This orchestration involves adding, removing and changing features of the setting as the students become attuned to the features and then focusing their attention on the features during subsequent reflective activity in order to develop conceptual schemes and improve the students' subsequent performance (Greeno, 1998). See Figure 2.

The teacher's intentions for the activity are concerned with reflection and the development of abilities. The framework must incorporate task goals and outcome, however, because:

- the task goals have an important impact on the activity, and may be perceived differently by the student and the teacher;
- the task outcome is important as something concrete be reflected on;
- the task outcome may also provide evidence of learning (or lack of it in some cases).

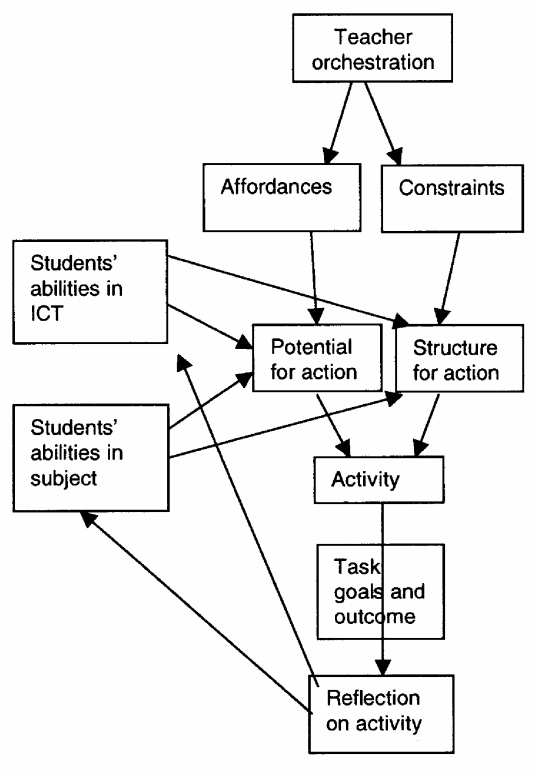

Figure 2. Influences on classroom activity.

Where the teacher has a direct role in the orchestration of the setting, this may be planned in advance (proactive) or may be contingent on the continuous stream of events in the classroom (reactive). Alternatively, the orchestration may be delegated to resources such as an integrated learning system (see, for example, Wood et al, 1999). In this case, reactive orchestration will be limited unless all possible actions by the learner can be anticipated by the resource designers. See Figure 3.

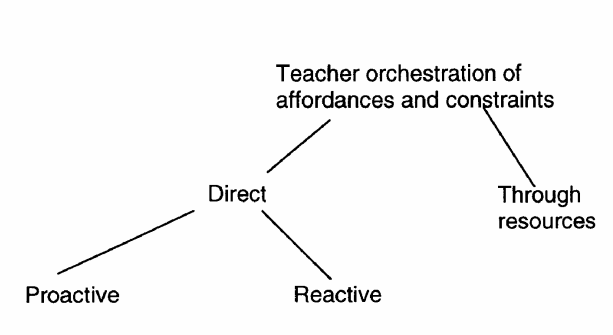

Figure 3. Teacher orchestration of features in the didactical setting.

The role of other students is also important to the learning achieved by a particular individual. This issue will not be considered in depth here, but we assume that if students work collaboratively towards a single product, then their abilities may be considered jointly. When each student works towards an individual product, then the abilities of other students may be considered as affordances and constraints for the activity.

Examples of ICT-based Teaching and Learning

As part of their work towards the expected outcomes for the use of ICT in subject teaching (TTA, 1998), a number of teachers have worked on a teaching activity which involves students carrying out a web search and producing a report on their findings using presentation software such as *Microsoft PowerPoint*. For three different specialist IT teachers who worked with the author as their 'ICT mentor', the student learning objectives involved basic knowledge of data protection law and an understanding of the principles behind the legal framework for data privacy and computer misuse. Following the activity, the teachers were expected to evaluate the contribution that ICT had made to students' learning. Their ICT mentor had a key role in helping them to do this.

Teacher 1

The teacher considered a number of ways of enabling students to obtain information about data protection issues. He judged that a search engine would provide a suitable level of affordance for obtaining information, but that because of the lack of experience in using search techniques, a further constraint should be provided for the students. The teacher thus suggested that students use 'Data Protection Act' as the search term. This immediately produced the two most relevant web sites at the top of the list returned, and

students quickly moved to the second phase of the task. They were required to load up a partially complete *PowerPoint* presentation prepared by the teacher and enter the answers to questions given in the title of each slide in the form of bullet points. They were able to work systematically through the prompts on the presentation slides and use the web sites found to obtain answers which they wrote into the presentation. The teacher then gained the attention of the whole class and displayed a complete presentation containing the desired responses, so that students could check how successful they had been. The students were then asked to write a report about data protection for homework, which would be used for assessment purposes. As many students did not have access to appropriate resources at home, this was allowed to be handwritten.

Teacher 2

This teacher was a colleague of Teacher 1, and they had jointly planned the approach to be taken. Teacher 2, however, imposed a looser constraint on students' web searches, suggesting only 'Data protection' as the search term. This resulted in a wider range of results concerning security as well as privacy issues from all over the world, from which students had some difficulty in selecting relevant information. This process provided less support for the outcome of the first stage of the task; although it provided opportunities for teaching about refining searches and about computer security issues, the time constraint was paramount and the teacher decided that, instead of finding their own answers, they should be given direct teaching using the complete *PowerPoint* presentation so that they would be in a position to produce their reports for assessment.

Teacher 3

This teacher worked in a different school, where the students already had a high level of ability in web searching. They were also judged to have a high level of literacy and metacognitive skills. He thus decided not to provide any constraints on this aspect of the activity, nor to provide any constraints on the use of *PowerPoint*. He produced a *PowerPoint* presentation himself which set out a number of questions concerning issues of privacy and computer misuse, and used it with the whole class both to demonstrate the use of *PowerPoint* as a medium for presentation and to raise the issues on which they were going to research and report. The students were organised to work in groups of three over an extended period of time to carry out the web research and to produce a *PowerPoint* presentation on their findings. They were then asked in turn to present their reports to the rest of the class, with assessment being carried out on their ability to use *PowerPoint* to

present information as well as their explanation of the ideas which they had included.

Discussion of Evaluation Issues

In each of the examples, the teaching involved the same topic, in the same course, using the same resources. The role of the WWW was to afford access to information for which cognitive effort would be required on the part of students in order to produce a reflective report. *PowerPoint* afforded the entry of responses in brief point form; it was for this reason that it was chosen, rather than *Word*. Despite these similarities, the impact of ICT was very different in each case. Teachers 1 and 2 provided constraints on the activity which Teacher 3 did not. First, they constrained the web search activity; next, they specified prompts to indicate the required responses; finally, they required a separate assessment task in order to evaluate the learning which had taken place. These constraints made a fundamental change in the contribution of ICT, and influenced the nature and amount of learning which took place.

For Teacher 2, the results of the assessment task revealed that somewhat less learning had taken place than with Teacher 1. Teacher 2 felt that the students did not have the metacognitive and literacy abilities needed to bridge the learning gap, but the mentor had been present in both teachers' lessons and was able to discuss the effect of the difference in the web search term. Furthermore, the teacher-led presentation to the whole class had not engaged students in the sort of cognitive effort required to bridge the learning gap.

For Teacher 3, the students' presentations, explanations and responses to questions from the teacher and other students revealed considerably greater attainment than for Teachers 1 and 2. This may be partly due to the greater ICT and other abilities of the students, and partly due to the affordances of the media used in the assessment task, namely presentation software and oral communication, rather than written prose. It is currently impossible to quantify the factors involved, but it seemed that the depth of knowledge gained was influenced the most by the combination of the students' metacognitive abilities and a lack of constraint in the learning task. The students were able to set their own constraints and reduce their dependence on the teacher, and their ICT abilities enabled them to increase their recognition of affordances, thus gaining greater value from the ICT resources. The teacher was able to set higher expectations for the students' use of *PowerPoint* presentations than were possible using the 'gap filling' approach of Teachers 1 and 2. As we would expect from the body of research carried out into groupwork with computers (e.g. Hoyles et al, 1994), it also seemed that the constraint of group collaboration, and the affordances of each others' suggestions, enhanced the learning. The group also afforded an audience for individuals' ideas and feedback on their

viability, which helped each individual to bridge the learning gap. There is clearly scope for further analysis of the conditions for effective groupwork using the framework of tasks, affordances, constraints and abilities.

Conclusion

The superficially similar examples described above highlight the context-sensitivity of the impact of ICT on learning. If further cases are considered where the topic and/or resources vary as well, then clearly even more differences will emerge. The nature of ICT is not the only, or even the major, factor in most settings for teaching and learning. Any study which attempts to isolate the quantity of ICT use from other variables is thus unlikely to find a significant effect (see, for example, Watson, 1993) until the effectiveness of the pedagogical approach is taken into account (as was attempted in Becta, 2001). In order to identify a clear link between the use of ICT and the extent of learning, however, much more sensitive measures and instruments are needed. Such tools need to reflect the interrelated affordances/constraints in settings and the way in which they are manipulated relative to the students' prior abilities. At present, we can apply useful measures of abilities in the subject knowledge involved (Kennewell, 2000) and we can also design a variety of measures in the analysis of ICT capability (Kennewell et al, 2000b). The challenge remains to design a metric for affordances and constraints which allows for the relativity of these features to the learners' abilities.

It is clear that we cannot attempt to identify 'the most suitable ICT to meet teaching objectives' (TTA, 1998, p. 6) in any general sense, nor can we characterise how ICT is affecting the learning of the topic concerned without detailed reference to the particular context. Even when a seemingly identical lesson is planned, the variations in the setting lead to different forms of activity, different learning outcomes, and a different effect of ICT.

However, the framework provides a basis for evaluation in which the relative contributions of the features of the setting, the abilities of the students and the actions of the teacher can be analysed. The need for new measurement tools does not prevent us from evaluating qualitatively the influence of ICT on task progress and the achievement of intended (and unintended) learning in terms of:

- task goals;
- intended learning;
- students' abilities in the subject taught, in ICT, in other key skills, and in metacognitive functioning;
- affordances and constraints of the setting, including ICT;
- the teacher's didactical knowledge and pedagogical approach, which affects their orchestation of the setting.

Our framework can be applied to analyse the influence of particular ICT resources in particular settings for teaching and learning. To date, we have used the model for analysis of the role of ICT capability in learning various subjects (Kennewell et al, 2000a); for personal research into the use of computer modelling in the teaching and learning of a particular topic in mathematics (Kennewell, 2000); and to support the mentoring of experienced teachers of ICT in the evaluation of their use of ICT in teaching (see the above case studies). We see potential for developing the framework so as to provide tools at three levels:

- generalisable research concerning the links between teaching and learning with ICT;
- curriculum planning at teacher and school level;
- individual teacher reflection.

Generalisable Research

For large scale evaluations involving use of an ICT resource by many teachers, and for research concerning the general effectiveness of ICT in teaching and learning, the framework can be used at the design stage to identify influences characteristic of the resource. However, in order to find general relationships within the teacher-learner-ICT triad and suggest ways of using ICT effectively, we will need to develop reliable measures of affordances, constraints and their orchestration by the teacher. Some features may be simply characterised as present or absent (e.g. availability of a presentation package); some features will nearly always be present, and either a threshold value can be used, or a scale will be needed to reflect their extent (e.g. access to ICT resources outside lessons). Other features may be categorised and coded (e.g. room layout, student allocation to computers) whilst others will not submit to scoring or coding and a description will be required (e.g. the nature of the teachers' prompts concerning search terms). We will also need valid and reliable means of assessing students' abilities. These are not trivial tasks, however, and we will not pursue the issues further here.

Planning at School and Class Level

For planning purposes, measures are not required and a teacher or group of teachers can use the framework as a model explicitly to:

1. represent their particular resources, classes and curriculum objectives;
2. identify the relevant affordances and constraints;
3. hypothesise ways of orchestrating these in order to achieve the objectives;
4. discuss the likely effects of different approaches and methods;

5. decide on implementation strategies – which may vary according to the teacher and/or class.

Of course, this sort of planning happens already, but is often hampered by the lack of a common understanding of the interrelationships between the many variables. The framework can aid such understanding by providing a structure for representing these relationships.

Evaluation of Teaching Effectiveness

Reflection on a teacher's use of ICT may be similarly restricted by difficulties in sharing an understanding of the relationships involved. The framework provides a means of making these relationships explicit, and individual teachers (on their own, or with a mentor) can use it to highlight strengths and weaknesses and suggest improvements in a way which reflects the context-sensitive nature of teaching effectiveness. The model allows the influence of particular features of the setting to be analysed and provides a structure for alternative scenarios to be considered. For example, Teachers 1 and 2 could analyse Teacher 3's approach and identify how it could be adapted for their own context, or how they might change the features of their own setting in order to provide the conditions required for success. They might, perhaps, plan to develop students' metacognitive skills when they start the secondary phase of schooling so that different approaches are feasible during more advanced courses. Following use in this way for explicit representation during professional development work with a mentor, the process has the potential to be used implicitly as part of teachers' normal pedagogical thinking.

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