PERGAMON

Computers & Education 42 (2004) 25–44

COMPUTERS & EDUCATION

www.elsevier.com/locate/compedu

Optimising ICT effectiveness in instruction and learning: multilevel transformation theory and a pilot project in secondary education

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Abstract

Specific combinations of educational and ICT conditions including computer use may optimise learning processes, particularly for learners at risk. This position paper asks which curricular, instructional, and ICT characteristics can be expected to optimise learning processes and outcomes, and how to best achieve this optimization. A theoretical multilevel framework is developed to specify instructional, learning, and ICT conditions that may transform and optimise both teaching and learning. The empirical part of the paper reports on and analyses a participatory, user-oriented pilot study carried out in Dutch secondary education in the period 1999–2002. The goal was to explore how teachers can develop and practice computer-supported instructional and learning processes that are qualitatively more transparent, more flexible, and more sensitive to differences between learners, than most currently prevalent teaching practices. The pilot also resulted in a multilevel software prototype LINE which was developed to support the instructional management of learners, teachers, and school management. The outcomes of the pilot study are used to specify more transformation conditions which are required within and outside schools to optimise instruction and learning in both qualitative and quantitative ways. Finally, software functions to construct more generalised 'Diagnostic, Instructional, and Management Systems' (DIMS) are modelled and discussed.

Keywords: Architectures for educational technology systems; Improving classroom teaching; Interactive learning environments; Secondary education; Teaching/learning strategies

1. Introduction

In many countries computers are becoming increasingly important tools to support educators in designing, stimulating, and controlling teaching and learning processes and effects (Sinko & Lehtinen, 1999; Smeets et al., 1999). Gradually, a broad array of Information and Communication

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doi:10.1016/S0360-1315(03)00063-0

Technology (ICT) including computer use is being designed, developed and implemented (e.g., Blumenfeld, Fishman, Krajcik, Marx, & Soloway, 2000; Lally, 2000). ICT gains a growing influence in supporting instructional management at different school levels, at different places, and at different times. Within schools, for example, teachers, school leaders, and ICT co-ordinators pave the ways for the involvement of other computer users like learners, parents, and external professionals. Often some of the learners are the local experts in the use of ICT and may support other learners and the teachers.

These 'lower level' educational actors usually provide very useful information about possibilities to improve ICT uses and effects at both lower and higher levels. Mooij and Smeets (2001) carried out qualitative modelling research into ICT uses in secondary schools with varying backgrounds. Their empirical results suggested five successive phases and corresponding models of ICT implementation. After the initial acquisition of hardware and software and some isolated computer use in phases one to three, the educational emphasis of the school shifts towards ICT to support learning processes in more integrated and flexible ways during the fourth phase. Examples of school practice in phase 4 include: consideration of the differences between learners' competencies; the use of indicators of learning progress to differentiate next learning processes; stimulation of ICT professionalisation of the school team; and that the organisation of learning, and learning itself, become more independent of time and place. Phase 5 was not yet found in school practice and was described tentatively. This phase can be characterized by co-ordinated deployment of software, in particular by using applications that bring about school subject integration and continuously integrated instruction and organisational flexibility beyond that achieved during phase 4. More specifically, in phase 5 education is to be restructured from the perspectives of the learners. This process requires a co-ordinated *transformation of teaching and learning processes* by harnessing ICT as an integral part of restructuring both the curriculum and the process of instructional management.

However, from a pedagogical perspective, transformation of education is in itself insufficient to realise phase 5. Even as early as the very beginning of kindergarten, differences in development between children may already be very large (Byrne, 1998; Jewett, Tertell, King-Taylor, Parker, Tertell, & Orr, 1998). A mismatch between a child's characteristics on the one hand, and actual pedagogical or instructional characteristics on the other, may create behavioural, emotional, social, and cognitive problems for this child 'at risk' (Jones, Gullo, Burton-Maxwell, & Stoiber, 1998; Walker, Kavanagh, Stiller, Golly, Severson, & Feil, 1998). Characteristics and processes comparable to those in kindergarten and primary education also occur within secondary education (Schuyt, 1995). For example, in a national survey, Dutch teachers and school leaders in secondary education stated that they had too few differentiated curriculum levels and insufficiently differentiated learning materials, to properly adapt learning processes to the diverse competencies and learning differences between learners (Mooij, 2001). In such a school system, those learners who deviate significantly from the general or subject mean of competencies of the learners in a class, unit, or school are self-evidently at risk.

Learning which is designed to respond sensitively to learners' initial competencies and characteristics, and to provide extra or different kinds of stimulation to relatively high or low functioning learners, may therefore *optimise instruction and learning processes and effects*. Curriculum, instructional, management, and ICT characteristics could act as conditions to improve school practice at different levels, in co-ordinated and empirically controlled ways. This optimising, or quality enhancement, is expected to demonstrate itself in qualitative and quantitative aspects of instructional and learning processes and effects, in particular for the learners who deviate most, relatively speaking, from the other learners within a class or educational unit (Jones, Rasmussen, & Moffitt, 1997; Kemp, 2000; Wegerif, Mercer, & Dawes, 1998).

Integrating educational differentiation or 'inequality' according to the actual differences between learners, could be the best way to implement 'equality of educational opportunities and outcomes' (cf. also Collier, 1994). ICT seems to be promising in assisting educators to provide equal educational opportunities because this technology can assist in the gradual transformation of current educational practice, and at the same time can provide ongoing feedback concerning pedagogical or educational processes and effects. Realising the ultimate goal of 'equality by inequality' requires a consistent, theoretically based, multilevel restructuring approach to operationalising and implementing relevant optimising conditions in school practice and the required ICT. The transformation processes in constructing phase 5 therefore need to be based in both theory and practice, probably through various cycles of qualitative and quantitative research. The research question to guide a first cycle of these developments can be formulated as: *Which curricular, instructional, and ICT characteristics can theoretically be expected to optimise learning processes and outcomes, and how can this transformation be implemented within educational practice?*

To answer this question, I will first construct a theoretical multilevel framework relevant to instructional and learning processes. I will then concentrate on instructional, learning, and ICT concepts and characteristics including computer use to optimise instruction and management of learning processes and outcomes. Information from a participatory, user-oriented, pilot study in Dutch secondary education provides a concrete example of the development of curricular, learning, and ICT conditions in practice. First experiences with a new software prototype lead towards a more general model of software functions, integrating different user functions in a more generalised organisational, multilevel context.

2. Theoretical aspects and conditions

2.1. Education as a multilevel system

When used in the design and evaluation of educational processes, an analysis of the multilevel structure of education can assist in revealing nested or cross-level relationships between many educational characteristics (Cronbach, 1983). For example, a learner can be part of a small group of learners, which in turn is part of a whole class. This structuring allows theoretical multilevel modelling of learning by variables such as the learner's initial competencies and motivation, and instructional characteristics, at the learner level. At the same time, at the small group level, prior learning characteristics of the small group of which the learner is a member may be relevant. Simultaneously, characteristics of the learner's class, the instructional environment of the class, and variables concerning teacher quality, may be at stake at the class level (cf. Blumenfeld et al., 2000; Crook, 1998). Concrete examples of such multilevel processes with different kinds of social, behavioural, emotional, cognitive, and motivational effects for children in kindergarten already are presented by e.g., Jewett et al. (1998), Kounin (1970), Mooij (1999a, 1999b), and Walker et al. (1998). A schematic illustration is included in the lower part of Table 1.

Table 1
Multilevel model of educational structure and level specific characteristics related to learning

Level of educational system	Educational variables or characteristics related to learning, e.g.
10. International	International collaboration and competition, policies, and projects System, organisational, and didactic characteristics across countries
9. National	Guidelines/laws for curricular, cultural, or language characteristics System, organisational, and didactic characteristics at national level
8. Regional/municipal	Social or economic characteristics, willingness to collaborate Organisational or didactic characteristics at regional/municipal level
7. School board	Policy or allocation characteristics, quality of long-term supervision Organisational or didactic characteristics at school board level
6. School	School policy and educational priorities of management Organisational or didactic characteristics at school level
5. Location/part of school	Behavioural rules and order, aggregated results of learning processes Organisational or didactic characteristics at location level
4. Unit of specific location	Collaboration between unit teachers, aggregated learning results Instructional or organisational characteristics at unit level
3. Class/group/form	Teacher–learner interactions, group learning process and results Instructional or organisational characteristics at the group or class level
2. Small group of learners	Learner–learner characteristics and interactions, small group learning style Instructional or organisational characteristics specific to small group level
1. Individual learner	Initial competencies, motivation, learning styles, learning results Instructional or organisational characteristics specific to the level of learner

Multilevel modelling provides for organising and monitoring of individual, small group, and class conditions that may differentially stimulate learning processes of the learners in a class. For example, evaluation of the learning achievement of the individual, the small group, and the class, can be related to the learning progress of the specific actor at a specific level, but also to cross-level processes or effects (Goldstein, 1995). If evaluation of individual learning achievement is based on the learner's own progress, the evaluation may keep its motivating effects for the learner. However, if the individual's evaluation is based on the mean for their class, even motivated learners will become demotivated when they have worked hard initially but, usually, gain the lowest schoolmarks because of this evaluation method (Heckhausen, 1980).

Yet, learning processes and effects are still more complex. Several classes make up an educational unit (for example, all first-year classes, classes 1–3, or a specific combination of school subject departments). Some units represent a location or a separate part of a school building, and different locations combine to constitute a school (see Table 1). The lower-level instructional and learning processes at the individual, small group, and class levels may, for example, also be affected by collaboration processes between the teachers and the pedagogical–didactic climate at the unit, location, or school level. For example, intervention research showed that early specification and checking of rules of conduct by pupils in secondary education, and corresponding co-ordination between teachers in the unit, prevented pupils' antisocial and criminal behaviour (Mooij, 1999c, 1999d). Other potentially relevant variables may include the location management's firmness in enforcing behavioural rules and order, or the kind of educational priorities set by the overall school management. Characteristics or processes at these higher levels may thus interfere with motivational, social, or achievement processes and effects at the learner, small group, or class levels (see also Cronbach, 1983).

At higher levels of the educational system, different schools may be governed by the same school board or governing body. A board can for example be characterized by specific policy aspects or financial resources. Different school boards can be found within the same municipality or region with specific social or economic features, and with specific regional institutions for education, care, health, policing, or justice. A group of regions comprise a whole country. The national level may be characterized by specific curricular, cultural, or linguistic requirements compared to other countries. For example, some countries such as the United Kingdom have a detailed national curriculum with clearly stated educational outcomes for the entire national system. In other countries such as The Netherlands, curricular specifications are left to educational publishers and schools or teachers, while assessment of learning achievement is left to national tests which do not directly measure curricular progress. If evaluation of individual learning achievement is based on a national representative test, one may expect to find that learners who usually achieve scores lower than the norm will experience demotivation and learning problems, and will be at risk.

Finally, the international level is characterized by specific collaborative and competitive processes in the public and private sectors (see Table 1). For example, at the international level, national or governmental educational policies combine with those of the European Union to strengthen specific educational developments in the EU (cf. Ministry of Education, Culture, and Science, 1999).

The level-specific characteristics in Table 1 thus illustrate that many educational features can be relevant in instructional, learning, evaluation, and achievement processes. Moreover, characteristics at or between different levels may interact over the course of time, resulting in rather complex processes and effects which may influence instruction and learning processes and outcomes directly or indirectly (Tymms, Merrell, & Henderson, 2000). How could ICT including computer use be designed to handle this multilevel complexity and, at the same time, to optimise instructional and learning processes and results? A first step in answering this question is to define relevant concepts and characteristics.

2.2. Multilevel instructional, learning, and ICT concepts

A curriculum is usually characterized by a set of *curricular themes* representing content-based concepts and sub-concepts related to specific knowledge, skills or competencies, and attitudes, at specified difficulty levels. A theme and its corresponding instruction of learners should inspire, motivate, and challenge each learner by a careful selection of *instructional activities*. Usually, instructional activities are based in one or more curricular themes and are developed or selected by a teacher, the team, or a publisher or curriculum developer. A theme can also contain *free activities* which are chosen or developed by the learners and evaluated by the learners themselves, or evaluated in co-operation with the teacher.

An *instructional line* denotes a hierarchical arrangement of curricular concepts and sub-concepts corresponding with specific curricular, instructional, and diagnostic or evaluative learning materials representing specific learning activities at a specified difficulty level (cf. Mooij, 2000). Different kinds of *quality indicators* need to be integrated into instructional lines, in order to diagnose and evaluate learning processes and their outcomes for each learner from the beginning of their school career. In practice, different kinds of instructional lines may be assigned to different learners, small groups of learners, classes, or units, depending on the learners' characteristics and the nature of grouping processes in a class, unit, location, or school. In some cases, however, the location level and school level may be identical.

Teachers, coaches, or other professionals from inside or outside the school, work with the set of instructional lines and diagnostics on the one hand, and variations of groupings of learners on the other. They may arrange the support of learning processes in differentiated ways, to integrate and optimise teaching and learning. That is, given the initial competencies of an individual learner, and the mean initial competencies or deviation in initial competencies within a small group, class, or unit, learning progress may take place differently at these different levels because of different arrangements in instructional features. Moreover, variables like the degree of self-evaluation of learning achievement may stimulate learning processes and outcomes, and have different effects on the appreciation and next use of level-specific instructional features. Teachers or coaches will also fulfill an important pedagogical role here.

ICT could then help to design, integrate, record, and regulate the multilevel instructional and learning processes and effects, and assist in assigning learners into groups and to specific instructional lines. Thus the use of ICT could enhance the scope for learners to engage in responsible self-regulation and self-evaluation of learning processes and outcomes, and could also assist in planning and delivery of learning within or outside the school. A schematic overview of these possibilities at the levels of the individual, small group, class, and unit, is shown in the lower part of Table 2.

Furthermore, the location level and school level are characterized by continuous instructional features and middle- and short-term curriculum and organisation development. At these levels, comparable learning aspects as with the lower levels may be in the focus, but usually at a higher level of aggregation. ICT can then be used to design curriculum and instructional features for the school or location; to design and record grouping of learners; and to design, record, and evaluate learning processes and effects both within and outside school (see Table 2).

At the regional level, the school board has a range of tasks which include supervising long-term curriculum and organisation development, and supporting institutional interests within the context of the region. The school board itself may go through a learning process concerning these issues and could use ICT to assist in evaluating and supervising instruction and learning within and outside schools to support long-term school and regional transformation.

At the regional or municipal level, collaboration strategies between different kinds of institutions like educational and health or care institutions may be relevant, resulting in a regional collaborative learning process. ICT could help to design, monitor, and evaluate instruction and learning at intra and inter-regional levels.

At the national level, governmental policies or criteria may stimulate or restrict specific curricular or instructional features. At this level, a *pedagogical–didactic kernel structure* is defined as a set of normed indicators representing diagnostic and evaluative functions, or benchmarks, of instructional lines used within or outside schools. Integrated research on curriculum, instruction, and test development can provide for a psychometrically valid pedagogical–didactic kernel structure and construct its relationships with instructional lines. In this respect, a national learning process is at stake when instruction and learning have to be integrated in a process of continuous

Table 2
Multilevel modelling of instruction, learning, and ICT

Educational level	Level specific concepts and characteristics, e.g.		
	Instruction	Learning	ICT
10. International	Linking and funding research and development projects	International learning and progress	Design/monitor/evaluate instruction and learning processes and outcomes in and between (sets of) projects or countries
9. National	Curricular policy/criteria	National learning and progress	Design/monitor/evaluate instruction and learning processes and outcomes in and between (regional sets of) educational/health/care institutions
	Pedagogical–didactic kernel structure Research and development		
8. Regional/ municipal	Collaboration strategy between e.g., educational and health/care institutions	Regional learning and progress	Design/monitor/evaluate instruction and learning processes and outcomes in and between educational/health/care institutions
7. School board	Supervising long-term curriculum and organisation development	School board learning and progress	Evaluating/supervising instruction and learning processes and outcomes in and out of school
	Supporting institutional interests		Evaluating/supervising long-term school and regional development
	Initiating/supporting regional collaboration		
6. School	Continuous instructional lines and evaluation/grouping	(Mean) initial competencies	Design curriculum/instruction for school/location/units
5. Location	Location/unit assignment and grouping of learners	School/location/unit/ class/small group/ individual aspects of learning processes and effects or outcomes/ results	Design/record grouping at school-unit level
	Middle/short-term curriculum and organisation development	(Self)evaluating instructional effects at school—individual level	Design/record/evaluate learning processes and effects in and out of school at the school/location level
	Integrating external professionals in school		
4. Unit	Instructional lines/diagnostics	(Mean) initial competencies	Design/record curriculum, instruction, grouping at each level
3. Class	Class/small group/individual assignment of learners	Unit/class/small group/individual learning processes and effects or outcomes/results	
2. Small group	Integrating teaching/learning		Record/support learning processes, outcomes, evaluations, in and out of school
1. Individual learner	Integrating external professionals	(Self)evaluating instructional effects at unit individual level	Support self-regulation and self-evaluation
	Coaching in and out of school		

improvement. ICT can also support such a national transformation and learning process, including the evaluation of learning at the regional, institutional, and school levels.

Finally, at the international level, the instructional focus may be directed at linking and funding research and development projects, resulting in an international integration and learning process. Of course, ICT can also play an important role in relevant recording, communication, and evaluation processes (see Table 2). All in all, the multilevel modelling illustrated in Table 2 supports the designing of ICT to optimise instructional and learning processes and outcomes. This potential role of ICT is treated in the next section.

2.3. Multilevel ICT functions to optimise instruction and learning

ICT can play different roles to optimise multilevel instructional, learning, and management processes (Ely, 1999). For example, ICT can help to order and present curricular themes, concepts and sub-concepts; present instructional lines to different learners or groups of learners at different places at different times; and assist in including or evaluating quality or diagnostic indicators in these lines. ICT can also help to assess each learner's initial levels of competence; provide for stimulating individual or shared learning experiences; record and evaluate progress in relation to specified outcomes and group norms; and facilitate timely availability of specific instructional lines and learning appliances for marginal learners or learners at risk. Learners at risk are defined as those learners who deviate significantly from the general or subject mean of competencies of learners in a small group, class, unit, location, school, region, or country. This category includes learners with learning competencies which are considerably in excess of the norm as well as those well below the mean or the norm for the relevant group.

Within a school, input or change of computer-supported instructional lines, integration of external professionals in school processes, adequate grouping of learners, and coaching within and outside the school, may result in improved learning particularly for learners at risk. Recording and analysis of relevant data, and planning and logging of learning activities and materials by a learner or a small group of learners, can be carried out automatically. If necessary, teachers in school can easily communicate or collaborate with external specialists (e.g., educational psychologists, health or care specialists) on actual learning problems, prevention issues, treatments, or evaluation of treatments in school (see the lower part of Table 3). In these ways, educational quality at the level of the school and learning optimisation for each learner can be supported from the beginning of every learner's school career.

At the regional level and below, regional or municipal collaboration between and within different kinds of institutions can result in different kinds of collaboration and learning data or benchmarks. Multilevel analysis can analyse and produce learning and evaluation data, and norms about processes and outcomes between and within regions (Goldstein, 1995) (see the middle part of Table 3).

Finally, at the national and international levels, ICT is functional in constructing the pedagogical–didactic kernel structure and relevant norms or benchmarks in the educational system. A pedagogical–didactic kernel structure is necessary to make educational evaluation processes and outcomes independent of the commonly used age-based groupings or age-based achievement norms. This independence is essential to prevent phenomena like continuous school demotivation, enforced failure of learners at risk, youth criminality, and high drop-out rates (cf. Collier,

Table 3
Multilevel functions of ICT to optimise instruction and learning processes and outcomes

Educational level	Level specific ICT functions, e.g.		
	Input or change features of	Record or use of	Analysis or output of
10/9–1: International/ national—individual	Pedagogical–didactic kernel structure	Pedagogical–didactic kernel structure data/ norms/benchmarks	Pedagogical–didactic kernel structure evalution data/norms
	Educational system	Educational system data/norms	Educational system evaluation data/norms
	Grouping of learners within educational system		Comparing data (longitudinally) between and within nations
8/7–1: Regional/school board—individual	Regional/municipal collaboration between different kinds of institutions	Regional/municipal collaboration data/ benchmarks between different kinds of institutions	Regional/municipal evaluation data/norms
			Comparing data (longitudinally) between and within institutions
6–1: School, location, unit, class, small group, learner	Instructional lines (for learners at risk)	Instructional lines data/norms	Evaluative data (longitudinally) between and within schools/ locations/units/classes/small groups/individual learners
	Integrating external professionals Grouping of learners Coaching in and out of school	Grouping data of learners	Comparing data in and out of school

1994; Mooij, 2001). Alternative forms of evaluation which are designed to foster motivation and achievement include individual evaluation of progress, in the context of considering small group and class or unit mean achievements. Norm-based evaluation can produce additional information about the comparison of the individual's achievement with the mean achievement of the category of same-aged or educational peers.

2.4. Multilevel transformation hypothesis

The multilevel modelling of instructional, learning, and ICT functions in Tables 2 and 3 is expected to enable educationalists to conceptualise an optimising transformation of the educational system with particular benefits for the learning motivation and achievement of learners at risk in particular. Two main arguments can underline this general hypothesis. First, multilevel competence-based learning in flexible groupings, as sketched above, seems to result in qualitatively more supportive and productive learning processes and effects (cf. Mooij, Terwel, & Huber, 2000; Schnotz & Lowe, 2003; Smeets & Mooij, 2001). Second, in the flexible ICT-based school situation, more self-regulative and self-management possibilities will exist for the learners. With a shift from the traditional system to the new optimising system, teachers and other professionals can concentrate more support on slower or less adequate learners, whereas highly able or gifted learners can be stimulated in quite other ways (cf. King et al., 1985).

3. Method

3.1. Participatory, user-oriented design

Recent methodology supports a research strategy in which users, for example teachers and school staff, collaborate with researchers and other specialists to secure validity of innovation processes (cf. Crosier, Cobb, & Wilson, 2002; Kensing, Simonsen, & Bødker, 1998). Wilson (1999) expects that 'use-oriented' strategies '(...) increase the likelihood of successful implementation because they take the end use into account at the beginning design stages' (p. 13). Clark and Estes (1999) address the development of authentic educational technologies by collaboration between, for example, practitioners, technologists, scientists, craftspeople, and artists. They illustrate a developmental cycle of a science-based technology beginning with descriptive and empirical research, followed by the construction of generic technology, then by contextualising the technology which generates new issues for research leading into the next cyle of development, and so on.

I chose a participatory user-oriented design to check the relevance of the above multilevel ICT-theorising in a pilot study in educational practice. It was possible to collaborate with secondary-school teachers and school management to create some of the optimising conditions of Tables 2 and 3, in particular at the lower levels. In general, research and development of curriculum, instruction, learning, and ICT conditions in practice can be expected to start a learning process for all persons involved (cf. Remillard, 2000; Van den Akker, 1999). During this innovation process the transformation and optimising goals and procedures would become concrete and, therefore, be supported by teachers and learners (cf. Borko, Davinroy, Bliem, & Cumbo, 2000). Moreover, the theoretical goals and procedures could be then checked qualitatively against the empirical circumstances. The research and development took place during more than three years (August 1999–December 2002).

3.2. Developmental pilot study: process characteristics

The pilot study was situated in one location (510 learners) out of four locations of a secondary school, in the eastern part of The Netherlands. The location which was already familiar to the researcher, was characterized by a relatively liberal climate for both learners and teachers, with no serious school problems or unusual characteristics. Most lessons were whole-group and rather traditional, while the actual computer and ICT resources were comparable to those in other similar schools. This means that the computer–learner ratio was about 1–10. Teachers and school management already had some experience in experimenting with educational innovation.

Within the location, a steering committee and a development team were convened. The steering committee (management, researcher, software specialist) met about once a month to discuss planning, progress, and next steps. The development team which initially consisted of three teachers and the researcher was extended to include the software specialist after the first year of development. This team met weekly. The teachers were provided with approximately three extra hours per week, in addition to their lesson hours, to do their developmental curriculum work. The initial meetings were devoted to explaining the goal and functioning of instructional lines and the scope for using computers and ICT to enhance learning. Concrete examples were taken from comparable research in primary and secondary education (cf. Mooij, 2000). Next, the teachers developed instructional lines within the framework of a self-chosen project on 'Water and environment'. Different uses of ICT such as multimedia and the Internet were integrated within the curriculum activities, which were designed for small groups of learners (2–4). Occasionally, a member of the school management joined the development team meeting. Every three months, the steering committee received updates and new information from the three teachers.

After one year of development, the resulting computer-supported curricula were used by learners in the first school-year. The 56 learners were from two classes (aged 12–13). Some of these lessons were observed by the researcher, and the new instructional and learning processes were discussed with teachers and learners. Explicit attention was given to the integrated recording, evaluation, management, and controlling functions of software that could support teaching and learning processes in flexible ways, at different levels (cf. Table 2).

4. Results

4.1. Instructional lines and activity worksheets

An overview of the instructional lines as developed by the teachers in the period August 1999–June 2000 is given in Table 4. Initial individual learner levels of competencies in Mathematics and Reading comprehension were assessed at the beginning of the process (see the bottom part of Table 4). The second row from the bottom lists the school subjects to which the curricular activities refer (Biology, Physics/Chemistry, Mathematics, Technology, Care/Well-being). 'Own/free completion' in the last column means that learners can create an activity of their own choice, which should be related to the other activities in the same row.

'Use of water' in the third row from the bottom is a first instructional line represented by five activities on 'living environment' and five activities on 'water management and control'. Each activity was designed to be carried out by a small group of learners. In the same vein, subsequent instructional lines were developed with respect to 'Water as a substance', 'Water and Technology', and 'Water in the environment', respectively. From bottom to the top of Table 4, the activities listed in the columns are related to the respective school subjects.

To aid self-instruction and self-management by learners, the teachers also created worksheets for each activity within the instructional lines. The worksheets contain aspects of preparatory instructional specifics, how these should be carried out, their evaluation, and related project activities. Curricular and learning materials themselves are present in or around the classroom, the school library, or on the Internet. The worksheets thus provided detailed instructional information about the learning processes, materials and sources, tools and equipment or apparatus that could or should be used, and a formative evaluation. An example of a worksheet appears in Table 5 and concerns 'Aquarium as a living environment' (see the respective cell in Table 4).

Table 4
Four instructional lines on 'Water and Environment'

Instructional line	First/second part of line	Cells with prescribed assignments, related to respective school subjects					Own/free completion
4. Water in the environment	4.2. Too less/ much water	Adaptation	Cycle of water	High/low water levels	Water as energy source	Nurturing world-wide	Own completion
	4.1. Organisation of water	Evaporation	Per cent of water in body	Earn by wasting	Cooling water	Water as an element	Own completion
3. Water and Technology	3.2. Water purification	Biological purification	Sewer/ drinking water purification	Make an installation to clean or purify (drinking) water			Own completion
	3.1. At home	Pollution of drinking water	Separation of substances	Water bill, I en II	Supply and discharge, II	Washing machine	Own completion
2. Water as a substance	2.2. Charac-teristics	Surface tension	Density, Temperature	Formulae		Preparing food	Own completion
	2.1. Phenomena	Sweet and salt	Water mixing/ separation	Relationships	Drinking water	Ventilation	Own completion
1. Use of water	1.2. Water management and control	Water in organisms; I and II	Transport; I and II	Costs of water	Supply and discharge, I	Water recreation and safety	Own completion
	1.1. Living environment	Aquarium as a living environment		Aquarium, II (including diagnostics)	Designing an aquarium	Hygiene; if so required, reading diagnostics	Own completion
School subjects		1. Biology	2. Physics/ Chemistry	3. Mathematics	4. Technology	5. Care/ Well-being	6. Own/free completion
Initial competencies	Mathematics	Information from primary education and a special test developed by the teachers (see cell Aquarium, II)					
	Reading comprehension	Information from primary education and from special tests (spelling, vocabulary, speed, studying, reading comprehension)					

Table 5
Learning activity worksheet concerning: ‘Aquarium as a Living Environment’

1. Goal: What will you discover?	How can you make a living environment in a small fresh-water aquarium?
2. Prior knowledge	General knowledge about an aquarium
Concepts	Aquarium; Living environment;
What do you know?	Temperature; Light;
	Oxygen/Carbon dioxide; Food chain
	Ventilation; Filtering
Skills	Set up an aquarium
What can you do?	Carry out an investigation
	Use resources
Understanding	Transfer to an aquarium with salt water
3. What do you need?	The aquarium book; Internet site; Practice material
4. With whom do you collaborate?	Work in a group of two 1. 2.
5. What has to be done?	1. Read “The aquarium as a living environment” chapter in the aquarium book carefully and make notes.
	2. Draft the set-up for a fresh-water aquarium and explain the functions of each piece of equipment.
	3. Describe a chain of food in an aquarium.
6. Who will do what?	1. 2.
7. What do you investigate?	Design an investigation in which you can prove the relationship between the amount of light and algal growth. After checking the plan, you carry out the investigation.
8. Who will do what?	1. 2.
9. How is the time schedule?	Before the activity......................minutes
	During the activity......................minutes
	After the activity.........................minutes
10. Did you complete all tasks?	Study of theory
	Draft the set-up for creating and installing an aquarium
	Describe the chain of food
	Carry out the investigation
11. Evaluation	How was the collaboration?
	What is your opinion of the result?
	What could be done better with this activity?
	Do you have an idea for another activity in this area?

4.2. First software functions

Learners and teachers are the ‘primary’ categories of computer users, so the development of the software first of all concentrated on facilities that were relevant to these users at the lower levels of the educational system. It was decided that the software should support the instruction and self-management of the learners but, in general, the learning activities themselves were not to be completed on the computer (cf. Mooij, 2002). This means that the work on the activities themselves would not generally require the use of a computer. This promoted easy computer access for the processes that required learners to work with computers and facilitated differentiation in didactic working procedures.

The main functions of the software prototype were designed to conceptualise and create instructional lines and sublines, to create groupings of learners, to work with instructional lines by teachers and learners, and to record and check learning processes automatically (cf. Table 2). The software prototype was named LINE ('Learning In Networked Environments': see http://scholen.net/line). An overview of the multilevel software functions in June 2001, and the potential users of this software, is given in Table 6.

The software functions listed in Table 6 refer to administering, recording, organising, and evaluating everyday school information. The functions relate to curriculum content aspects with respect to instructional lines and diagnostics (individual, small group, class, unit, age-normed), flexible grouping of learners, planning of combinations of curriculum contents and learners, support of specific learners, and detailed specifications of learners' progress in specific periods. Such administrative and evaluative activities require a lot of teachers' attention each day, and automatic logging and use of digital databases seem to be of great assistance to them. Moreover, digital availability of this information may assist computer users at all levels of the educational system.

Table 6
Software functions supporting multilevel instructional management (LINE)

Educational level	Instructional features	Potential users
6.–5: School or location	a. conceptualising instructional lines	Schools, (specialist) teachers, parents, external professionals, policy instances, research & development
	b. assigning materials and activities c. assigning diagnostic tools and evaluation d. groupings of learners/teachers e. assigning learners to lines	
4. Unit within the school/some classes and teachers	d. smaller groupings of learners/teachers	Teachers, specialist teachers, learners, parents, external professionals, research & development
	e. assigning learners to lines	
3. Teacher or class of learners	d. smaller groupings of learners/teachers	Teachers, learners, parents, external professionals, research & development
	e. assigning learners to lines f. matching materials to individual learners/(small) groups of learners g. planning instructional lines for individual learners/(small) groups h. checking, coaching and evaluation	
2. Small group of learners	i. networked learning and evaluation	Learners, teachers, parents, external professionals, research & development
	j. start again with learning according to f	
1. Individual learner	i. networked learning and evaluation	Learners, teachers, parents, external professionals, research & development
	j. start again with learning according to f	

4.3. Intermediate evaluation

During an evaluation meeting in June 2001, the participating teachers emphasised the importance of collaboration between learners, the fact that learners were able to choose their own friends in the small group, the relevancy of integrating the computer-supported instructional lines within the regular curriculum, and the urgency of developing the software further. Ten of the participating learners volunteered to express their opinion on working with the new instructional lines. They generally liked this way of working, but they also suggested potential improvements. These included the need to allocate similar amounts of time to different activities, the need for differentiating teacher support, and the importance of integrating the experimental activities into the assessed school curriculum so both teachers and learners would experience them as real school activities. They also noted an occasional confusion about which resources were required for specific activities and how these resources could be accessed as well as the challenges of learning to collaborate within the small group without whole-group instruction.

From a research perspective, the developmental process with computer-supported instructional lines, activity worksheets, and integration of the software, was evaluated positively. Gradually, organisational school aspects became relevant too in the change process. One main educational shortcoming was not easy to tackle, however. The teachers had responded to the challenge of ensuring that evaluation and judgement of learning achievement were sensitive to the learning competencies of individuals but, because of the general lack of normed achievement or progress indicators, it was not possible to estimate in reliable and valid ways in how far a learner's progress was meaningful from a normed point of view. In other terms, evaluation could only be done on a local basis and not by using a pedagogical–didactic kernel structure. This curriculum evaluation problem is characteristic for Dutch education as such (cf. Section 2.3 and Kuhlemeier, Kleintjes, & Van den Bergh, 2001).

4.4. Development in the third year

As a consequence of the intermediate evaluation of the pilot study, educational and software development during the third year was concentrated on diagnostic evaluation and judgement of learner progress. The teachers provided criteria related to different aspects of learning e.g., social, knowledge-related, skill-related, or outcome-related. An instructional activity, or part of this activity, could then be evaluated according to a scale ranging from 0 to 100% correct. This evaluation was conducted by both learners and teachers, which allowed a detailed quantitative evaluation of specific instructional activities or parts of these activities, and also of the agreement or discrepancies between teacher(s) and learner(s). This evaluation procedure seems to be very worthwhile in practice. With the involvement of more learners this procedure can assist in constructing psychometrically adequate including normed evaluation or test procedures, which may also support the development of a pedagogical–didactic kernel structure.

Furthermore, the developmental research resulted in concrete suggestions about more generalised 'diagnostic, instructional, and management systems' (DIMS), to optimise functions of instructional lines and ICT in organisations in general. From a generalised point of view, the content of instructional lines can refer to specific characteristics or items in a specific order e.g., a specific topic or issue in a questionnaire, observation list, or test. Generalising the software functions means that ICT can record or evaluate progress or regress—either locally or normed—in psychological, instructional, work, and management processes, for various types of users, in different kinds of institutions, at different levels such as a learner or a group of learners, teachers, parents, and coaches within or outside the school. The same kind of ICT including relevant data bases can be used in research and development, national and international management, regional institutions, institutional boards, units in institutions, and local or institutional management. These different but related DIMS functions, for different kinds of users, are modelled in the ellipses numbered 1–8 in the centre of Fig. 1 and in the lines to the user categories in the margins of this figure, respectively.

In the upper part of Fig. 1, research and development are functionally related to the creation or evaluation of normed instructional lines or benchmarks, and qualitative and quantitative analysis of multilevel data. Moreover, (inter)national management can directly or indirectly use ICT to collect data and provide feedback about means or normed and other data results with respect to psychological, instructional, work, or management multilevel processes or effects. Furthermore, in the lower part of Fig. 1, the creation and evaluation of local instructional lines and benchmarks is a feature characterising for example the local or total management, the unit, or the teacher or coach. Assignment of normed and local instructional lines or benchmarks can be a characteristic of a teacher or coach, the school management, or the school administration.

The more general meaning and functions of the concept of 'instructional line' in the software interpretation of DIMS can then support the longitudinal integration, recording, transformation, optimising, and multilevel evaluation of different kinds of processes, from different kinds of institutions, at different times, and at different places. For example, the multilevel processes may refer to diagnostic processes and individual health treatments at a very young age; the diagnostics and evaluation of multilevel intra- and inter-institutional interventions by means of common instructional lines in institutions for youth health and preschool, primary education, or secondary education; or the recording and evaluation of combined efforts within and outside the schools to prevent school demotivation or the development of antisocial and criminal youth behaviour. The software design functions of Fig. 1 will be worked out in a next case-study, in close relationship with related practice developments in different institutions (see: http://www.dims.nl).

5. Discussion

This article has concentrated on the scope to optimise instruction and learning through adequate multilevel integration of ICT including computer use for learners, in particular for learners at risk. The research question was formulated as: *Which curricular, instructional, and ICT characteristics can theoretically be expected to optimise learning processes and outcomes, and how can this transformation be implemented within educational practice?*

The answer to this question started with the specification of the multilevel structure of the educational system and relevant learning characteristics and processes (see Table 1). Then the focus was on level specific instructional, learning, and ICT concepts and characteristics (Table 2) which, in combination with specific ICT functions (Table 3), were expected to enable the optimising of instructional and learning processes.

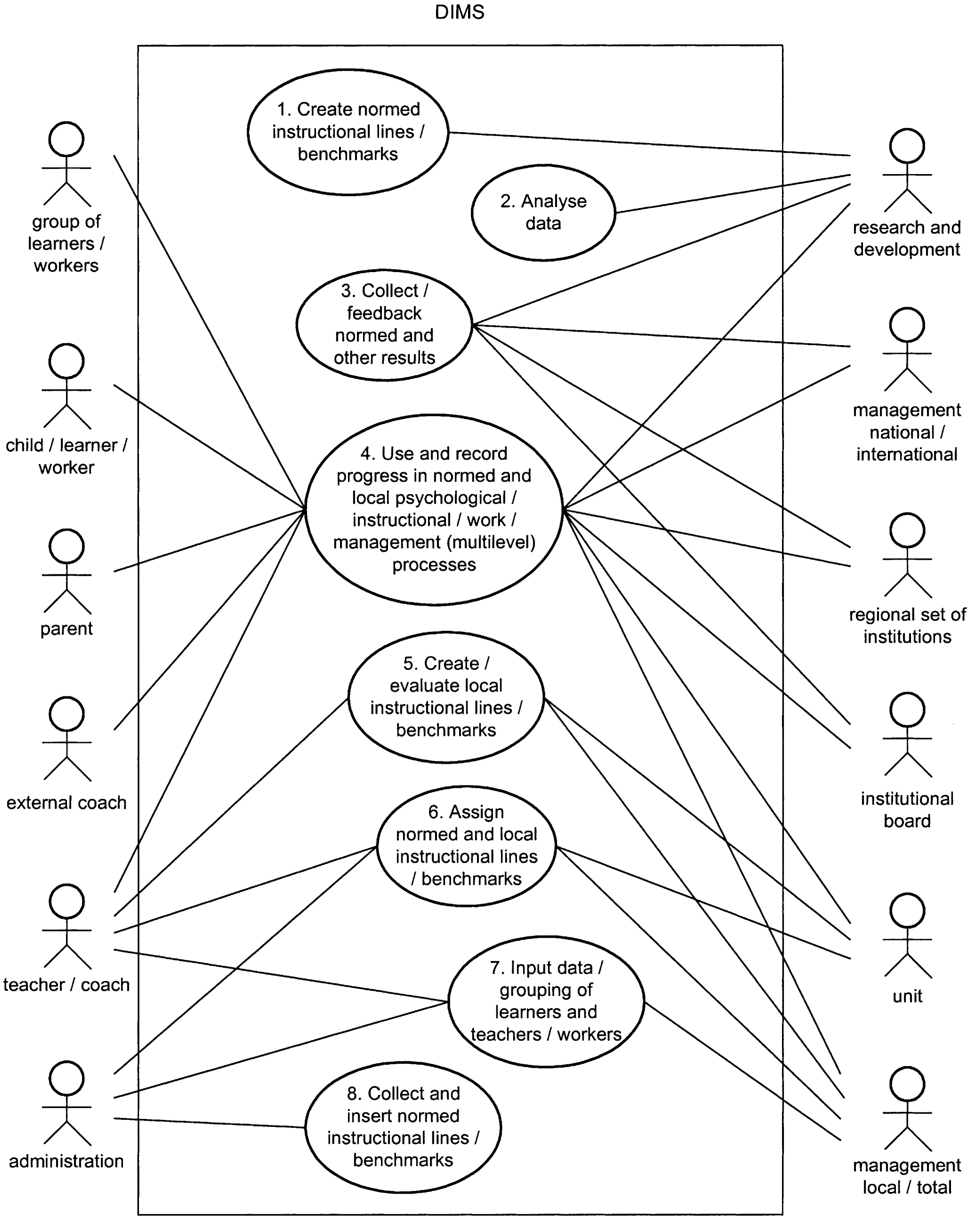

Fig. 1. First model of general 'Diagnostic, Instructional, and Management Systems' (DIMS).

In a first step of a pilot study in Dutch secondary education, collaboration with teachers and school management in the period August 1999–June 2001 led to the development of four instructional lines on 'Water and environment' (Table 4) and a worksheet format (Table 5) to assist the learners' self-regulation and self-management. The pilot was characterized by more flexible teaching and learning processes (particularly for small groups of learners) than one would normally expect to observe in schools. A first prototype of Internet-based software designed to support recording of curricular and grouping information, learner tracking, evaluation, management, and control of integrated instructional and learning processes, was developed and used in the same school. Functions of the software prototype ('LINE': Learning In Networked Environments) were described in Table 6.

Learners and teachers in the pilot study were positive about both changes in educational practice and software use. However, though evaluation of learning achievement was already possible at the levels of the individual, the small group, the class, and the teaching unit, evaluation on the basis of a pedagogical–didactic kernel structure remained a main concern. This situation reflects a general educational problem in The Netherlands. Consequently, in the second pilot step from August 2001–December 2002, research and development were concentrated on the creation of more detailed Internet-based assessment and evaluation functions and their potential integration with local and normed indicators of learner progress. The functioning of the LINE prototype stimulated the development of a more general model of diagnostic, instructional, and management systems (DIMS: see Fig. 1). DIMS should allow for more, and more specific, diagnostic, evaluation, and learning activities, in specific instructional lines, for specific kinds of learners or individual learners. It should also promote the integration of different roles of different kinds of users e.g., learners, teachers, school management, and internal and external professionals, at all different levels. These refinements bring more preventative attention and integrated support for learners at risk, or learners deviating significantly from the mean or the norm in a small group, class, or unit. The DIMS software functions will be further developed and implemented in next research oriented towards prevention of learning demotivation and learning problems, in parallel to the construction of a first architecture of a pedagogical–didactic kernel structure.

All in all, the results of the multilevel theorising, educational innovation in school practice, and software development, seem to be promising from the perspective of using ICT to facilitate educational transformation and optimisation. In this respect, Tables 1–6 and Fig. 1 already reflect a specification process based in an interaction between relevant theory and practice. Teachers and learners in the pilot study experienced real changes in their everyday work and work organisation. These results allow for further concentration on psychometric, diagnostic, instructional, remedial, and multilevel educational and ICT change processes, both in theory and in practice. In the course of this complex process, it will become possible to test the optimising transformation hypothesis concerning the motivation and learning achievement of learners and learners at risk, in quantitative ways (cf. Schnotz & Lowe, 2003).

Finally, it is clear that the process to realise multilevel transformation and optimisation of education can adopt different forms in different countries, depending on national or other circumstances. Moreover, the optimisation as such is dependent on more conditions, for example the support of national or local institutions with innovation or coaching tasks. A helping hand can be given also by the potentially self-disseminating role of ICT, in addition to the improvements as experienced and desired by teachers, learners, school management, and parents. Successful optimising transformation of education will require a long-term, gradually broadening collaboration between those persons and the institutions involved in the innovation of educational practices and instruments, at an increasing number of levels, within and outside the educational system. The present study represents few early steps in taking advantage of the possibly integrative and supportive role of ICT for optimising system transformation (see also Griffin & Beagles, 2000).

Acknowledgements

The empirical part of the project was co-financed by the Dutch ministry of Education, Culture, and Science, and by the school involved in the research. I want to thank Michael Polman (Antenna Foundation Nijmegen, The Netherlands) and Michaël Sperber (ITS Nijmegen, The Netherlands) for their collaboration in modelling software features of LINE and DIMS, respectively. Special thanks go to the teachers and management of the secondary school, and also to Tony Carr (University of Cape Town, South Africa) and Chris Comber (University of Leicester, UK) who proofread the text.

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