Information and communication technologies in higher education: Evidence-based practices in medical education

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Abstract

In contrast to traditional meta-analyses of research, an alternative overview and analysis of the research literature about the impact of information and communication technologies (ICT) in medical education is presented in this article. A distinction is made between studies that have been set up at the microlevel of the teaching and learning situation and studies on mesolevel issues.

At the microlevel, ICT is hypothesised to foster three basic information processing activities: presentation, organisation, and integration of information. Next to this, ICT is expected to foster collaborative learning in the medical knowledge domain. Empirical evidence supports the potential of ICT to introduce students to advanced graphical representations. But the studies also stress the importance of prior knowledge and the need for real-life tactile and practical experiences. The number of empirical studies focusing on the impact of ICT on information organisation is restricted, but the results suggest a positive impact on student attitudes and relevant learning gains. However, again, students need a relevant level of prior knowledge. Empirical studies focusing on the impact of ICT on information integration highlight the positive impact of ICT-based assessment and computer simulations; for the latter this is especially the case when novices are involved, and when they master the prerequisite ICT-skills. Little empirical evidence is available about the impact of computer games. Research results support the positive impact of ICT-based collaboration, but care has to be taken when skills development is pursued.

At the mesolevel, the available empirical evidence highlights the positive impact of ICT to promote the efficiency of learning arrangements. Research grounds the key position of ICT in a state-of-the-art medical curriculum. Recent developments focusing on repositories of learning materials for medical education have yet not been evaluated.

The article concludes by stressing the need for evaluative studies, especially in the promising field of ICT-based collaborative learning. Furthermore, the importance to be attached to the position and qualifications of the teaching staff is emphasised.

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Introduction

Recent reviews of research about the efficacy and efficiency of the integrated use of Information and Communication Technologies (ICT) in education do not always come to optimistic conclusions. The meta-analyses of Kulik (2003) result in statements that the potential of ICT in education is yet not clear and that the findings of evaluative studies are conflicting. Other researchers come to comparable conclusions (e.g., Waxman *et al.*, 2002 and Cox *et al.*, 2004). In relation to medical education, Letterie (2003) presents a more specific analysis of research about the potential of computer-assisted instruction based on the content analysis of studies (MEDLINE and ERIC) set up between 1988 and 2000. He concludes: “Few studies of good design clearly demonstrate improvement in medical education over traditional modalities. There are no comparative studies (…) that demonstrate a clear-cut advantage. Future studies of computer-assisted instruction that include comparisons and cost-assessments to gauge their effectiveness over traditional methods may better define their precise role” (Letterie, 2003, p. 849).

It is important to note that the author could only identify 210 studies that met basic research criteria to be incorporated into the analysis. An additional important critique builds on the statement in the last sentence. Few studies succeed in defining the precise role of ICT in the educational process. Part of the research limitation is the lack of a theory that drives the instructional goals of the ICT-applications. Moreover, the expected outcomes can be extremely varied, which presents an additional difficulty to meta-analysis studies of evaluative research.

Alternative approach

The present contribution revisits part of the research literature while adopting an instructional analysis approach when considering the potential of ICT in medical education. As to the potential of ICT, a distinction is made between mesolevel and microlevel benefits. At mesolevel, we focus on educational benefits that are linked to the delivery of medical education programmes and characteristics of the student population. At microlevel the focus will be on specific variables and processes in the teaching and learning setting. As a consequence, the analysis question is no longer whether ICT results in better medical education, but rather what type of ICT-use – as it is linked to specific variables and processes in the teaching and learning context – results in more effective, efficient, or satisfying education.

The empirical base gathered for this overview has been extracted from MEDLINE and ScienceDirect, by applying the search concepts *medical*, *education*, and *computer* and with a focus on studies published in journals since 2000.

Microlevel issues

At a conceptual level, ICT facilitates the design, development, transfer, delivery, and storage of *information* and facilitates *communication* in the context of instructional processes. We discuss both dimensions separately.

ICT to foster the information processing dimension in learning

Information and information processing are central in most conceptions of learning. Three major phases can be distinguished in the information processing. These phases are clearly delineated in the models of Mayer (2001) and Paivio (1986). Information is presented to the learner, selected by the learner and stored in the sensory memory. Next, this information is organised in working memory, also called short term memory. This results in the construction of cognitive structures, also called schemas or mental models. The organisation process comprises the relating, connecting, comparing, and ordering of the information. At this stage, learners continuously retrieve information from the long term memory. This introduces the third phase in the learning process: the integration of the information with the already available schemas resulting in the further elaboration and organisation of information in our memory. The three major phases (information presentation, information processing, and information integration) are depicted in Figure 1. Below, we discuss how ICT can foster these three basic information processing activities and what evidence is available about the efficiency, efficacy, or satisfaction of ICT in this respect.

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ICT fosters information presentation

Information presentation is a crucial part in the field of medical visualisation. Robb (1999) distinguishes – in the context of medical visualization – between real-time imaging, interactive imaging, 3D imaging, and multi-model imaging. A large number of research and developmental work has been set up in the medical field during the last decade. Current developments especially focus on developing virtual realities and on the validation and credibility of the models being developed.

The potential of ICT to represent information in a variety of ways is both from a practical, theoretical, and empirical point of view important for medical education. The same information can be presented with text, graphics, pictures, video, animations, and audio. From a practical point of view, advanced graphical representations empower medical staff with professional tools to build teaching and learning activities on complex, authentic, and real-life learning materials.

From a theoretical point of view, presenting multiple representations results in the development of a richer schema structure in long term memory. It also helps to take into account individual differences in the processing of information, which is functional, as students differ in the way they prefer types of visual or auditory information. Moreover, both visual and auditory presentation of information, in addition to textual representation, also helps to reduce cognitive load since it helps to reduce the complexity of the information presented (Sweller, 1994).

From an empirical point of view, there is clear evidence that the presentation of graphical information (static graphics or animations) is superior to textual information. Research of Mayer (2003) and Mayer and Moreno (2002, 2003) presents convincing evidence that the graphical representations (such as the heart pump) result in a stronger retention and transfer of the processed information. But what about the research in the medical field?

A review study of Durfee *et al.* (2003) about the use of graphical data in 48 ICT-based radiology courses, indicated that this kind of information is underused in radiology courses "although radiology is in the forefront of incorporating information technology (…) into everyday practice" (p.209).

A research study of Roubidoux *et al.* (2002) on students playing "breast cancer detective", a web-based breast imaging game, pointed out that the graphical nature of the information was preferred by the students and resulted in very positive appreciation of the course and high levels of self-reported learning outcomes.

But despite the large potential of the very advanced computerised imaging approaches a balanced approach might be needed. In a large scale study, involving over a thousand medical students learning anatomy, researchers studied whether ICT-based resources could replace real life cadaver dissections. The results of this quasi-experimental study show that the proportion of students who received both treatments – traditional dissection and computer resources – was significantly larger than in the other conditions (Biasutto *et al.*, in press). Moreover, also the average mark was larger in this condition. This rather unique quasi-experimental study builds on a review of the research literature about the teaching of anatomy. The authors come to the conclusion that real-life dissection remains important to develop the necessary visual and tactile experience base (see also Miles, 2005). The real life experience is considered to be a catalyst to learn in an optimal way from the biomedical computer applications; thus resulting in superior performance.

The power of ICT-supported representations is further growing due to 3D techniques and the Cave Automatic Virtual Environment (CAVE) technologies. When applying the latter tools, students can even walk around within the 3D projection of the biological structure. Kral (2004) presented applications of CAVE technologies to teach pathologies, based on real life patient data. Other exploratory research focuses on virtual reality graphical representations that are distributed via the Internet. Research of Lu *et al.* (2005) demonstrates the potential of ICT-supported representations, but also points at the critical elements, such as too long waiting times for students and the need for extra learning materials to support the viewing process.

A research review of Letterie (2003) focuses on the analysis of research about applications of virtual reality (VR). Based on the review of 150 studies he projects that VR is useful for the training in basic and advanced surgical skills for both medical students and residents. But he immediately adds that this technology is tested to a too limited extent in the medical field. Most studies are too descriptive and rather suggest future directions. This is in line with the opinion of other authors. In the context of medical education, and more particular in surgery education, the use of VR still remains restricted (see e.g., Haluck *et al.*, 2001). An early study of Gallagher *et al.* (1999) pointed out that VR resulted in superior performance of laparascopic surgery skills, but not of venous catheter placement when compared to traditional methods for training these skills.

Next to rich graphical representations, ICT can also help to represent varied representations of information in a more organised way. To support neurology students in assessing neurological disorders, a comprehensive CD-ROM was produced covering about 100 different vignettes (audiovisual case descriptions). A study, involving 401 medical students, resulted in clear evidence about the reported instructional value of the materials (Bain & Biller, 2004). The authors present the vignettes as adjuncts to other instructional approaches and not as a way to replace other approaches, such as bedside teaching. They furthermore point at efficiency issues, for instance in contexts where there is a shortage of neurology specialists or to expand the number of cases students can focus upon.

The empirical evidence put forward stresses the importance of introducing advanced and professional graphical representations in ICT-based contexts. Most authors in the studies stress that it is important for students to learn to work with state-of-the-art medical imaging tools and artefacts. But in the context of the overall development of medical knowledge and skills, real life experiences, observation and practices are needed to develop a rich information representation base in medical students.

ICT fosters information organisation

Medical education relies heavily on the active processing of large amounts of complex and interrelated information. From a theoretical point of view, sensory information only becomes meaningful due to the active organisation of the new information. This organisation implies structuring, comparing, ordering, relating, and analysing of new information. In traditional teaching contexts this is fostered by the continuous active involvement of students in interactive teaching and learning settings.

The organisation of new medical knowledge is also pursued by developing eBooks. The system developed by Lison *et al.* (2004) is a content free solution that supports a variety of teaching and learning strategies. The technical functionalities are linked by the authors to specific knowledge processing activities as illustrated in Figure 2 (Lison *et al.*, 2004, p.168).

Pilot-studies with the eBook solution have especially focused on the feasibility of the system and testing the delivery of a wide variety of contents.

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ICT-tools foster in a variety of ways the organisation of knowledge. In a 3D application, developed by the New York University school of education, students can manipulate 3D representations of the skull, orbital cavity, and meninges. The manipulation activities include among other things rotation, opening up, revealing closing, and positioning. Each manipulation enriches the further construction of schema. There is one condition: students have to master basic prior knowledge about the anatomical structures in view of learning from this tool. This is a typical tool that can serve as a base for developing computer simulations in which students have to manipulate the simulated reality in view of diagnosing diseases or follow procedures to treat illnesses. We discuss this type of ICT-applications in the next paragraphs.

Pallikarakis (2005) designed and evaluated a web-based distance learning course about medical image processing. This package pursues the acquisition of the conceptual base of the medical image processing field. Concepts can be studied at three levels of complexity, for example: a first level with a general description, a second level with more detailed explanation, and a third level revealing the complicated mathematical proofs. Evaluation of the package revealed large satisfaction levels, projected usefulness of the learning content and efficiency in time spent for learning the content. In line with the remark about the need for sufficient prior knowledge to be able to develop organised knowledge as a result of the learning experience, the latter example reflects a very detailed and structured breakdown of the knowledge components.

Empirical evidence that is restricted to studying the impact of information organisation is hardly found. Most packages offer additional functionalities that go beyond information organisation (see next paragraphs). However, the available studies suggest positive student attitudes and report relevant learning gains. But – as it was stated earlier – developers have to be aware of what they expect from students as a prerequisite level of prior knowledge.

ICT fosters information integration

In the third phase of the information processing activities, students organise their knowledge to a further extent and link the new knowledge in an active way with knowledge already available in long term memory. ICT-applications that especially foster this type of activities force students to use and re-use information that has been stored earlier in their long term memory. Use and re-use of information is observed when student solve problems, answer questions, apply their knowledge on cases, etc. This cognitive processing activity occurs in ICT-based learning environments when students apply and test their knowledge. Under this umbrella we especially distinguish (1) tutorial ICT-applications that have an embedded evaluation of student learning, (2) computer simulations, and (3) game-based approaches.

ICT with a focus on assessment and evaluation

In the multimedia guide to cardiopulmonary resuscitation, medical students take tutorials (organising information) and test questions in basic and advanced life support (Clark *et al.*, 2000). Research results comparing the web-based version with traditional approaches resulted in better “basic knowledge” about resuscitation, but not in significant differences on practical test scores. In a comparable study of Mehrabi *et al.* (2000), the computer based training module, presenting new information and consequently assessing this with quizzes, resulted in significantly higher scores as compared to lectures. Mullins *et al.* (2001) set up a study to research the feasibility of ICT to test medical students on radiology clerkships. The study results support the efficiency of this approach in terms of time gains and low costs. Furthermore, questions and repetition of concepts were also found to be key elements that helped students to build up their knowledge about acid and base physiology, as presented in a study of Rawson and Quinlan (2002), in which the embedded questions scaffold the learning of novices by accentuating the relevant features of the cases.

Assessment of complex skills present challenges to traditional educational contexts: they require extensive staff involvement, discussions about objectivity, and available training time. In this context, ICT-solutions are put forward as ways to support this assessment. Hulsman *et al.* (in press) studied the use of standardised video cases to test video examination of communication skills by computers. The study involved 200 medical students and resulted in an acceptable reliability of the test approach (G = .66) and high interrater reliability (G = .93). Although the researchers indicate that more research is needed to validate the approach, the study illustrated its feasibility.

Another study focussing on assessment and evaluation compared a face-to-face tutorial with the use of a computer-assisted package (CAI) in radiology education (Kim *et al.*, 2002). Central in both approaches was the continuous assessment of the students. The authors hardly found significant differences that were pedagogically meaningful and concluded that both models were effective teaching formats, but they suggest that the CAI-approach might be more efficient since the students spent less time studying and no experienced staff was involved.

Considering the importance of high quality graphical information as the base for teaching in medical education, also the assessment procedures are pressurised to build on state-of-the-art technologies when representing questions and problems. Grunewald *et al.* (2004) developed an Internet-based application to assess radiological knowledge that builds on 1650 pathologic cases and 550 anatomy cases. Users can select among other things the characteristics of the target population, the difficulty level, and the number of questions.

The available research evidence helps to confirm the efficiency of ICT-supported assessment approaches.

Computer simulations

The example of the CAI-package in radiology education (Kim *et al.*, 2002) discussed earlier, is also a typical illustration of a computer simulation in which students have to manipulate the simulated reality in view of diagnosing diseases or following procedures to treat illnesses. The developers and researchers of this CAI-package carried out a study in which student performance on a computer simulation to treat cardiac dysrhythmias (Advance Cardiac Life Support Simulator) was compared to the study of text based materials. Initially the students in the text-based condition performed significantly better after the treatment period, but one week later there was no longer a significant difference. The decline in knowledge gain was larger in the text-based condition. The authors explain the initial better learning performance (right or wrong questions) in the text-based condition by referring to the inexperience of students with learning in ICT-based learning environments. But – and this is more important – the students were novices in this knowledge domain and were confronted with a larger level of complexity in the ICT-based environment. Prior knowledge is a critical asset for students when studying complex knowledge. The researchers suggest therefore looking for a balanced mixture of both teaching approaches.

Nackman *et al.* (2003) studied the use of simulation software – with a computerised life-sized mannequin – in the surgical education of students during their clerkships. They could conclude that the simulation software significantly improved skills. The researchers add in their research report an important remark to their conclusions. They refer to the fact that the approach was effective "in a clerkship that already emphasised (…) case-based learning" (Nackman *et al.*, 2003, p.214). This remark points at the context in which ICT-based medical training approaches might be effective. It stresses the congruency between the variety of teaching models being adopted.

Di Giulio *et al.* (2004) developed a simulator for upper endoscopy. In their randomised controlled trial with their system (N = 420), they could put forward evidence that medical students in the experimental condition performed more complete procedures, needed less assistance and obtained more positive remarks from the instructor. It is important to note that the target population comprised novice trainees.

Engum *et al.* (2003) studied a simulation package aimed at developing intravenous catheter placement skills and compared this with traditional approach. Both groups developed their skills in a significant way. But student satisfaction was lower in the computer condition. The researchers suggest a blending of the efficient computer condition and the face-to-face teaching context.

Meier *et al.* (2005) researched the impact of using a simulation-based curriculum of situations commonly encountered during on-call situations during a surgical internship. The implementation of the simulation significantly increased the confidence of interns as compared to unsupported transition from medical school to surgical internships.

Pulling together the results of these studies, we can conclude that simulations are effective. However, this is especially the case when novices are involved and when they master the prerequisite ICT-skills.

Computer games

In view of the integration of medical knowledge, interactive computer games are presented as potentially relevant tools. Students have to interpret complex situations, apply their knowledge, put forward hypotheses, test them in the game settings, and receive immediate feedback. Howell (2005) gives an overview of ICT-based interactive games and related evaluative research; some of them relevant for (para)medical education.

A typical example is the computer assisted board game to manage patients with breast cancer. Students can – depending on the adequate application of the work-up procedure – decide to send the patient to physical examination, mammography, ultrasound, or office procedures (Mann *et al.*, 2002). Playing the game resulted in significant learning gains about the work-up procedures. It is to be remarked that – as compared to the earlier studies – the learning gains put forward are clearly related to skills development.

ICT to foster the communication dimension in learning

A variety of communication models can be supported with ICT. In current practices, we especially observe ICT-applications that support teleteaching and collaborative learning approaches.

Communication with teachers and experts

In the context of medical education, real-time teaching via the Internet is a recurrent approach to teleteaching. Teaching activities can for example be enriched with viewing real life surgeons at work.

Feasibility studies, such as the one of Filler *et al.* (2000) show how the technology is sufficiently adequate to be applied in this context. Another study, focusing on the distance education delivery of a postgraduate course via the Internet, resulted in high satisfaction levels, but also revealed critical issues, such as drop-out and low participation levels (Jenkins, *et al.*, 2001). The study revealed that the computer literacy levels of the potential students are critical.

Dugas *et al.* (2000) studied an emergency medicine online course during which students had to submit answers to questions. This student input was displayed on a large video screen and discussed in real time by an expert. An evaluation of the approach with 138 students resulted in high scores for acceptance and learning success.

The projected benefits of teleteaching are large and especially stress economical benefits. However, it is striking that the medical education research literature especially publishes initiatives and projects, but hardly evaluation results.

Communication between students: collaborative learning

Collaborative learning is promoted for a number of reasons in the medical domain. Ortega *et al.* (2003) refer to the importance of clinical reasoning and problem solving skills. A meta-analysis of 122 studies focussing on collaborative learning with ICT as compared to individual learning with ICT, indicates that the collaborative setting results in more effective learning (Lou *et al.*, 2001). Research suggests that adding a communication dimension to the information dimension in medical ICT applications results in better performance. Numerous article focus on the potential of collaborative learning in medical education (see e.g. Wiecha & Barrie, 2002). But few evaluation studies have actually been published.

In the study of Romanov and Nevgi (in press) two ICT-conditions were compared: a simple web-based course and an alternative design that was enriched with general discussion groups and special discussions about lectures. Learning performance increased significantly when third year medical students could work together.

De Wever, Van Winckel, and Valcke (2005) analysed the use of asynchronous discussion groups involving students during a semester of clinical rotation in paediatrics (N=49). In the electronic discussions, students worked with real life cases in order to enhance professional reflection and critical thinking on patient management and as an exercise in evidence based medical practice. Student input in the discussions was analysed to determine the level of knowledge construction. In a quasi-experimental study, part of the students was expected to adopt specific roles (e.g., moderator). Significant differences in the levels of knowledge construction were observed between groups that were moderated by a student and groups moderated by the instructor ($z = 3.96$, $p < .01$). Student moderated groups resulted in higher cognitive involvement as reflected in the quality of the student input; students' messages are 1.75 more likely to reflect higher levels of knowledge construction. The results do not question the importance of the instructor being available and being involved. They especially point at the significant value of ICT to foster discussions between students in a distributed setting.

Although the research literature about collaborative learning in ICT-based environments presents convincing results about the efficacy of this kind of ICT-applications (see also Valcke & Martens, 2005), few research studies have been reported in medical education. Nevertheless, the limited number of available studies presents overall a positive picture. There may be limitations when it comes to the actual development of skills; for example, in surgical training.

A study of Rogers *et al.* (2000) indicated that skills acquisition was superior in an individualised computer-assisted (CAI) environment as compared to a peer teaching supported CAI-setting. It is important to stress that this study was set up with novices.

ICT at mesolevel

ICT and the flexibility in medical education

Flexibility is a central concept when ICT is put forward to deliver medical education in environments in which course delivery is constrained due to time, place, and pacing limitations of the target audience. Gunewald *et al.* (2003) present their radiology website explicitly as a solution to solve problems in relation to flexibility in access to and use of educational materials. Students can choose time, place, and pace of learning.

In the study of Durfee *et al.* (2003), it was clear that due to the use of the Internet, the radiology courses could be delivered in a very flexible way with a variation in student numbers, number of times of offering the course, and a required versus an elective nature of the course. Accessibility was also a major advantage quoted by 96% of 4th year medical students playing an interactive web-based breast imaging game (Roubidoux *et al.*, 2002). Greenberg *et al.* (2003) discuss a study in which they provide in-service medical trainees with online research articles to update their knowledge and skills about diagnostic radiology, in view of the residency review committee requirements. Results from a pretest-posttest design study underpin the significant learning gains.

A very specific implementation of ICT in a teleteaching context is found in developing countries. Mukundan *et al.* (2003) describe a telemedicine system that was introduced on the Solomon Island. A small scale evaluative study underpinned the flexibility and efficiency of the teaching model. The authors stress the low-cost and sustainable nature of the teaching approach.

Medical education is often hindered by the combination of clerkships and continuous face-to-face training. The distributed nature of the clerkships makes it difficult for students to attend lectures. In a rare evaluation study of the use of videoconferencing to cope with these difficulties, researchers could indicate that the videconference based lectures were as effective to deliver the didactic lectures in a surgical clerkship as the conventional teaching approach. But, the videoconferencing approach was significantly more efficient due to time gains and reduction in travel costs (Stain *et al.*, 2005). In the study of De Wever *et al.* (2005), discussed above, the ICT-based collaborative learning environment was also implemented in a context where medical students could not come to the university for face-to-face meetings. The efficiency of the approach was appreciated by the students.

Johnson *et al.* (2004) studied student satisfaction with a web-based courseware system that was meant to foster just-in-time education and expected to be an efficient solution to promote flexible delivery of medical education. Overall, the system was considered as efficient and effective. End-users raised some concerns about the quality of technical instructions and feedback.

The study of Masiello *et al.* (2005) focused on the readiness and attitudes of students to take online microbiology courses. On average, the students mastered the prerequisite ICT competencies and expressed positive attitudes towards the system to use it in a flexible way. But – and this is crucial – the actual learning experience with the system resulted in a more negative attitude towards the learning management system. The critiques centred on functionalities such as reading from screen and replacing lectures with the computer system.

ICT in the medical education curriculum

ICT is also put forward in medical education because it can provide students opportunities to get acquainted with technologies they need in their professional lives (De Wever *et al.*, 2005; Stromso *et al.*, 2004), which are necessary to keep up with the rapid growth in medical knowledge (Hagdrup *et al.*, 1999). Nattestad *et al.* (2002, pp. 127-128) emphasise the importance of ICT skills in order to avoid becoming "a clinician who is unable to access or handle new electronic technology (and) therefore (is) left with the significant risk of being unable to provide optimal evidence-based care".

What is the evidence to support the need for ICT skills in the medical education curriculum? Logan and Price (2004) validated the curriculum of medical informaticians, revealing some neglected areas in the current curriculum. But is ICT also considered as essential in a curriculum of general practitioners and clinicians? A national study in the United Kingdom revealed that the IT-skills of medical students are not well developed in view of their professional qualifications (Murphy *et al.*, 2004). Respondents were clearly in favour of a national IT curriculum for the medical field (with a strong focus on health informatics). Researchers also tried to look for explanations for this current state of affairs. They point at the critical IT training level of teaching staff.

Learning repositories

A particular innovative area in the application of ICT in medical education is related to the implementation of learning repositories. Geueke and Stausberg (2003) describe a large repository that consists of a large set of re-usable learning objects (see e.g.

http://mmedia.medizin.uni-essen.de/portal/). These learning objects can be used in other educational contexts and are described by adding metadata to them. In this way, teaching staff can easily trace relevant learning materials to be used in their context. Thus far, no evaluative information is available about this new development.

Conclusions

Current ICT-related research has shifted its focus from a media-oriented research paradigm to a stronger focus on particular objectives to be pursued. Whereas earlier studies especially focused on the question whether a specific ICT application resulted in a certain learning impact, we perceive that the research has now taken a new direction. The major question is now: under what circumstances, in what particular learning environment, with what type of students, and in view of what kind of learning tasks, does ICT have an impact (Jacobsen, 2001)? The critical conclusions, put forward on the base of earlier research reviews about the use of ICT in medical education, have therefore to be reconsidered in the light of the former remark (see also Clark, 1992; Friedman, 1994; Keane *et al.*, 1991).

The discussion presented in this article points out that the expected outcomes of ICT-use in medical education are extremely varied. Studies focus on learning performance and distinguish between knowledge and skill acquisition. Students' satisfaction and their attitudes and confidence levels are also considered as impact indicators. Specific studies – and this is especially true when it comes to the mesolevel perspective – focus on efficiency gains: are ICT-based learning environments faster, more flexible, and independent from time and place constraints? Given the innovative nature of a variety of ICT-applications, studies also report on the feasibility of the new teaching and learning provisions. As stated by Letterie (2002, 2003) the attention paid to economical indicators is observed to a lesser extent.

A large number of studies focus on the information component of ICT, while less light is shed on the communication component. Moreover, in addition to descriptive studies, more evaluative studies of ICT-tools are wanting, focussing on the efficiency and the impact on students' learning. In this respect, ICT-based communication is a promising field, as networked technology can serve as a powerful environment to support collaborative learning.

A final element in the context of this discussion is that ICT is but one component in the context of medical education. ICT cannot be alienated from the broader teaching and learning context. A key factor in this context is the teaching staff. Ward *et al.* (2001, p. 795) point out some implications and dangers of the integrated use of ICT in education. They conclude that "all of these aspects relate to the skills and attitudes of the teaching staff themselves. (…) investment in staff training in these novel educational methods is needed".

References

BAIN, M.E. & BILLER, J. (2004) Essential Neurology: Audiovisual Patient Vignettes on CD-ROM as a Teaching Aid for Medical Students, *Seminars in Cerebrovascular Diseases and Stroke*, 4, pp. 139-143.

BIASUTTO, S.N., CAUSSA, L.I. & CRIADO DEL RIO, L.E. (in press) Teaching anatomy: Cadavers vs. computers?, *Annals of Anatomy*, in press.

CLARK, L.J.R., WATSON, J., COBB, S.M., REEVE, W., SWANN, I. & MACFARLANE, P.W. (2000) CPR '98: A practical multimedia computer-based guide to cardiopulmonary resuscitation for medical students, *Resuscitation*, 44, pp. 109-117.

CLARK, RE. (1992) Dangers in the evaluation of instructional media, *Academic Medicine*, 67, pp. 819-820.

COX, M., ABBOTT, C., WEBB, M., BLAKELEY, B., BEAUCHAMP, T. & RHODES, V. (2003) *ICT and attainment - A review of the research literature*, ICT in Schools Research and Evaluation Series, 17 (London, DfES/BECTA).

DE WEVER, B., VAN WINCKEL, M. & VALCKE, M. (2005) Discussing patient management online: Asynchronous discussion groups for preregistration house officers, *Manuscript in preparation.*

DI GIULIO, E., FREGONESE, D., CASETTI, T., CESTARI, R., CHILOVI, F., D'AMBRA, G., DI MATTEO, G., FICANO, L. & DELLE FAVE, G. (2004) Training with a computer-based simulator achieves basic manual skills required for upper endoscopy: a randomized controlled trial, *Gastrointestinal Endoscopy*, 60(2), pp. 196-200.

DIKSHIT, A., WU, D., WU, C. & ZHAO, W. (in press) An online interactive simulation system for medical imaging education, *Computerized Medical Imaging and Graphics*, in press.

DUGAS, M., DEMETZ, F. & CHRIST, F. (2000) Emergency medicine online course integrating into curriculum of computer-based training, *Anaesthesist*, 49(10), pp. 881-886.

DURFEE, S.M., JAIN, S. & SHAFFER, K. (2003) Incorporating electronic media into medical student education, *Academic Radiology*, 10, pp. 205-210.

ENGUM, S.A., JEFFRIES, P. & FISHER, L. (2003) Intravenous catheter training system: Computer-based education versus traditional learning methods, *The American Journal of Surgery*, 186, pp. 67-74.

FILLER, T.J., JEROSCH, J. & PEUKER, E.T. (2000) Live interdisciplinary teaching via the internet, *Computer Methods and Programs in Biomedicine*, 61, pp. 157-162.

FRIEDMAN, C.P. (1994) The research we should be doing, *Academic Medicine*, 69, pp. 455-457.

GALLAGHER, A.G., MCCLURE, N., MCGUIGAN, J., CROTHERS, I. & BROWNING, J. (1999) Virtual reality training in laparoscopic surgery: a preliminary assessment of minimally invasive surgical trainer virtual reality, *Endoscopy*, 31, pp. 310-313.

GEUEKE, M. & STAUSBERG, J. (2003) A meta-data-based learning resource server for medicine, *Computer Methods and Programs in Biomedicine*, 72, pp. 197-208.

GREENBERG, S.B., LONG, M.J. & KLEIN, S.G. (2003) RadioGraphics: A Web-Based Model for Radiology Resident Self-Education, *Academic Radiology*, 10, pp. 1321-1323.

GRUNEWALD, M., HECKEMAN, R.A., GEBHARD, H., LELL, M. & BAUTZ, W. (2003) Compare radiology: creating an interactive web-based training program for radiology with multimedia authoring software?, *Academic Radiology*, 10, pp. 543-553.

GRUNEWALD, M., HECKEMANN, R.A., WAGNER, M., BAUTZ, W.A. & GREESS, H. (2004) ELERA: A WWW Application for Evaluating and Developing Radiologic Skills and Knowledge, *Academic Radiology*, 11, pp. 1381-1388.

HAGDRUP, N. A., EDWARDS, M., CARTER, Y. H., FALSHAW, M., GRAY, R. W. & SHELDON, M. G. (1999) Why? What? and How? IT provision for medical students in general practice, *Medical Education,* 33, pp. 537-541.

HALUCK, R.S., MARSHALL, R.L., KRUMMEL, T.M. & MELKONIAN, M.G. (2001) Are Surgery Training Programs Ready for Virtual Reality? A Survey of Program Directors in General Surgery, *Journal of the American College of Surgeons*, 193 (6), pp. 660-665.

HOWELL, K. (2005) Summary of Games for Health Research [available online at: http://torch.cs.dal.ca/~sage/games_for_health_research.pdf, accessed 28 August 2005].

HULSMAN, R.I., MOLLEMA, E.D., OORT, F.J., HOOS, A.M. & DE HAES, J.C.J.M. (in press) Using standardized video cases for assessment of medical communication skills: Reliability of an objective structured video examination by computer, *Patient Education and Counseling,* in press.

JACOBSEN, D. M. (2001) *Building Different Bridges: Technology Integration, Engaged Student Learning, and New Approaches to Professional Development*, Paper presented at AERA 2001: What We Know and How We Know It, the 82nd Annual Meeting of the American Educational Research Association, Seattle, WA: 10 - 14 April 2001.

JENKINS, J.M., COOK, J., EDWARDS, J., DRAYCOTT, T. &. CAHILLA, D.J. (2001) Medical education with the Internet: a pilot training programme in reproductive medicine, *British Journal of Obstetrics and Gynaecology*, 108, pp. 114-116.

JOHNSON, T.R., ZHANG, J., TANG, Z., JOHNSON, C. & TURLEY, J.P. (2004) Assessing informatics students' satisfaction with a web-based courseware system, *International Journal of Medical Informatics*, 73, pp. 181-187.

KEANE, D.R., NORMAN, G.R. & VICKERS, J. (1991) The inadequacy of recent research on computer-assisted instruction, *Academic Medicine,* 66, pp. 444-448.

KIM, J.H., KIM, W.O., MIN, K.T., YANG, J. & NAM, Y.T. (2002) Learning by Computer Simulation Does Not Lead to Better Test Performance Than Textbook Study in the Diagnosis and Treatment of Dysrhythmias, *Journal of Clinical Anesthesia*, 14, pp. 395-400.

KRAL, F. (2004) Using CAVE technologies for educating and training residents, *Otolaryngology - Head and Neck Surgery*, 131(2), p. 210.

KULIK, J.A. (2003) Effects of using instructional technology in elementary and secondary schools: what controlled evaluation studies say (SRI-International) [available online at: http://www.sri.com/policy/csted/reports/sandt/it/Kulik_ITinK-12_Main_Report.pdf, accessed 28 August 2005].

LETTERIE, G.S. (2003) Medical education as a science: The quality of evidence for computer-assisted instruction, *American Journal of Obstetrics and Gynecology*, 188, pp. 849-853.

LOGAN, J.R. & PRICE, S.L. (2004) Computer science education for medical informaticians, *International Journal of Medical Informatics*, 73, pp. 139-144.

LOU, Y., ABRAMI, P.C. & D'APOLLONIA, S. (2001) Small group and individual learning with technology: A meta-analysis, *Review of Educational Research*, 71(3), pp. 449-521.

LU, J., PAN, Z., LIN, H., ZHANG M. & SHI, J. (2005) Virtual learning environment for medical education based on VRML and VTK, *Computers & Graphics*, 29(2), pp. 283-288.

MANN, B.D., EIDELSON, B.M., FUKUCHI, S.G., NISSMAN, S.A., ROBERTSON, S. & JARDINES, L. (2002) The development of an interactive game-based tool for learning surgical management algorithms via computer, *The American Journal of Surgery*, 183, pp. 305-308.

MASIELLO, I., RAMBERG, R. & LONKA, K. (2005) Attitudes to the application of a Web-based learning system in a microbiology course, *Computers & Education*, 45, pp. 171-185.

MAYER, R.E. & MORENO, R. (2002) Animation or an aid to Multimedia Learning, *Educational Psychology Review*, 14(1), pp. 87-99.

MAYER, R.E. & MORENO, R. (2003) Nine Ways to Reduce Cognitive Load in Multimedia Learning, *Educational Psychologist*, 38 (1), pp. 43-52.

MAYER, R.E. (2001) *Multimedia learning* (New York, Cambridge University Press).

MAYER, R.E. (2003) The promise of multimedia learning: using the same instructional design methods across different media, *Learning and Instruction*, 13, pp. 125-139.

MEHRABI, A., GLÜCKSTEIN, C., BENNER, A., HASHEMI, B., HERFARTH, C. & KALLINOWSKI, F. (2000) A new way for surgical education - development and evaluation of a computer-based training module, *Computers in Biology and Medicine*, 30, pp. 97-109.

MEIER, A.H., HENRY, J., MARINE, R. & MURRAY, W.B. (2005) Implementation of a Web- and simulation-based curriculum to ease the transition from medical school to surgical internship, *The American Journal of Surgery*, 190, pp. 137-140.

MILES, K.A. (2005) Diagnostic imaging in undergraduate medical education: an expanding role, *Clinical Radiology*, 60, pp. 742-745.

MUKUNDAN, S., VYDARENY, K., VASSALLO, D.J., IRVING, S. & DIVI OGAOGA, D. (2003) Trial Telemedicine System for Supporting Medical Students on Elective in the Developing World, *Academic Radiology*, 10, pp. 794-797.

MULLINS, M.E., WILL, M., MEHTA, A. & NOVELLINE, R.A. (2001) Evaluating Medical Students on Radiology Clerkships in a Filmless Environment: Use of an Electronic Test Prepared from PACS and Digital Teaching Collection Images. *Academic Radiology*, 8, pp. 514-519.

MURPHY, J., STRAMER, K., CLAMP, S., GRUBBC, P., GOSLAND, J. & DAVIS, S. (2004) Health informatics education for clinicians and Managers - What's holding up progress?, *International Journal of Medical Informatics*, 73, pp. 205-213.

NACKMAN, G.B., BERMANN, M. & HAMMOND, J. (2003) Effective Use of Human Simulators in Surgical Education, *Journal of Surgical Research*, 115**,** pp. 214-218.

NATTESTAD, A., ATTSTROM, R., MATTHEOS, N., RAMSEIER, C., CANEGALLO, L., EATON, K. ET AL. (2002) Web-based interactive learning programmes, *European Journal of Dental Education*, *6,* pp. 127-137.

ORTEGA, E.M., BURGUN, A., LE DUFF, F. & LE BEUX, P. (2003) Collaborative environment for clinical reasoning and distance learning sessions, *International Journal of Medical Informatics*, 70, pp. 345-351.

PAIVIO, A. (1986) *Mental representations: a dual coding approach* (Oxford, Oxford University Press).

PALLIKARAKIS, N. (2005) Development and evaluation of an ODL course on medical imaging processing, *Medical Engineering & Physics*, 27, pp. 549-554.

RAWSON, R.E. & QUINLAN, K.M. (2002) Evaluation of a computer-based approach to teaching acid/base physiology, *Advances in Physiology Education*, 26(1-4), pp. 85-97.

ROBB, R.A. (1999) Visualization in biomedical computing, *Parallel computing*, 25, pp. 2067-2110.

ROGERS, D.A., REGEHR, G., GELULA, M., YEH, K.A., HOWDIESHELL, T.R. & WEBB, W. (2000) Peer teaching and computer-assisted learning: An effective combination for surgical skill training?, *Journal of Surgical Research*, 92(1), pp. 53-55.

ROMANOV, K. & NEVGI, A. (in press) Learning outcomes in medical informatics: Comparison of a WebCT course with ordinary web site learning material, *International Journal of Medical Informatics*, in press.

ROUBIDOUX, M.A., CHAPMAN, C.M. & PIONTEK, M.E. (2002) Development and evaluation of an interactive web based breast imaging game for medical students, *Academic Radiology*, 9, pp. 1169-1178.

STAIN, S.C., MITCHELL, M., BELUE, R., MOSLEY, V., WHERRY, S., ADAMS, C.Z., LOMIS, K., WILLIAMS, P.C. (2005) Objective assessment of videoconferenced lectures in a surgical clerkship, *The American Journal of Surgery,* 189, pp. 81-84.

STROMSO, H. I., GROTTUM, P. & HOFGAARD LYCKE, K. (2004) Changes in student approaches to learning with the introduction of computer-supported problem-based learning, *Medical Education*, *38,* pp. 390-398.

SWELLER, J. (1994) Cognitive load theory, learning difficulty and instructional design, *Learning and Instruction*, 4, pp. 295-312.

URIBE, D., KLEIN, J.D. & SULLIVAN, H. (2003) The Effect of Computer-Mediated Collaborative Learning on Solving Ill-Defined Problems. *Educational Technology, Research & Development*, 51(1), pp. 5-19.

VALCKE, M. & MARTENS R. (in press) The problem arena of researching computer supported collaborative learning, *Computers & Education*, in press.

WARD, J., GORDON, J., FIELD, M.J. & LEHMANN, H.P. (2001) Communication and information technology in medical education, *The Lancet*, 357, pp. 792-796.

WAXMAN, H.C., LIN, M.F. & MICHKO, G.M. (2003) *A Meta-Analysis of the Effectiveness of Teaching and Learning with Technology on Student Outcomes* (Illinois: Learning Point/NCREL)

WIECHA, J. & BARRIE, N. (2002) Collaborative online learning: a new approach to distance CME. *Academic Medicine,* 77 (9), pp. 928-929.

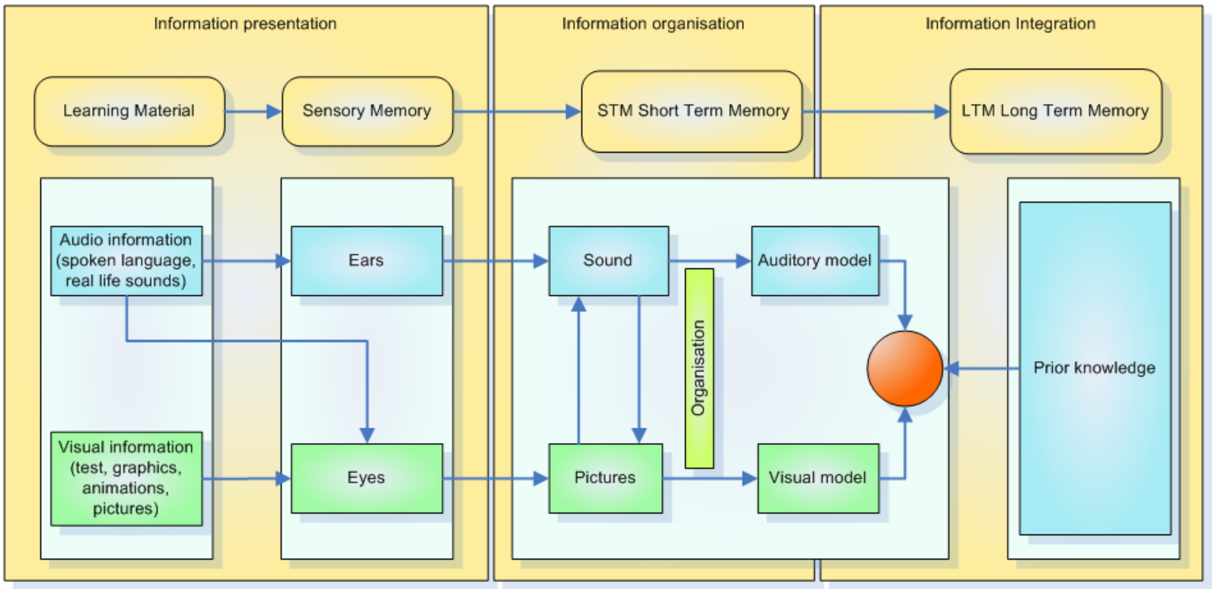

Figure 1: Information processing activities

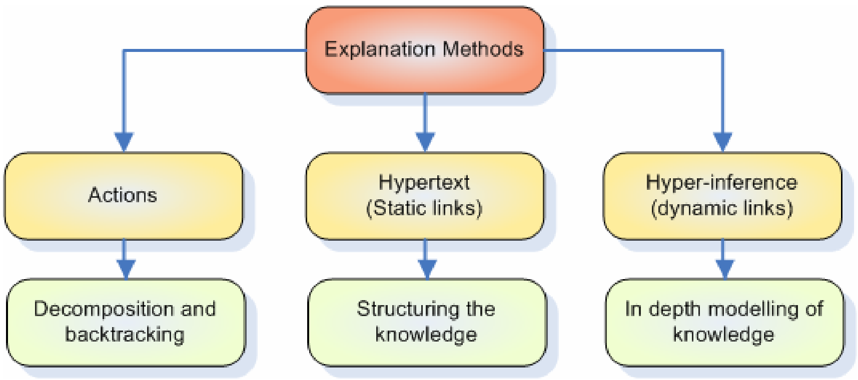

Figure 2: Knowledge processing activities (Lison *et al.*, 2004)