A META STUDY ON IC TECHNOLOGIES IN EDUCATION.
Towards a multidimensional framework to tackle their integration

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A *survey of literature about educational uses of IC Technologies in mathematics education was done by a team issuing from five French laboratories working in various fields. A quantitative analysis of a corpus of 662 papers and two qualitative analyses of a sub-corpus helped to specify "dimensions" for the analysis of this very varied mass of innovation and research. Then, cluster analysis performed on each of the dimensions led to informative partitions. The method of analysis and the picture resulting from the partitions are offered as means to tackle the complex integration of IC Technologies into teaching and learning.*

Introduction

This paper originates from a call by the French Ministry of Education to make use of existing published works to answer questions about educational use of Information and Communication (IC) Technologies. The opportunity of doing a meta-study was appealing to us because of the mass of published works existing in this field, contrasting with a general lack of precise understanding of what really happens when introducing IC Technologies. We thought that it was interesting not to do another research project, but to try to see what synthesis could be drawn and how it could be drawn[1].

The ministry's questions were: "How are IC Technologies used inside the educational system? Do they change the nature of learning? Do they modify the notions and the methods? What is their influence on students and teachers?" As for us, we were concerned by the discrepancy between promising IC Technologies and their difficult integration in schools. Our view was that teaching and learning involve complex processes, that bringing in elaborate technology adds even more complexity and that technologies proposed for educational use are quite varied. For these reasons we did not expect that a meta-study could bring the ministry's questions direct answers. Our aim was to build tools for the understanding of integration rather than to collect findings on objective changes brought by technologies.

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[1] A complete documentation on this research, including the material for the statistical analysis is available on the Internet: http://www.maths.univ-rennes1.fr/~lagrange/cncre/rapport.htm. A longer version of this contribution is also available for download. The longer version presents detailed numerical data summarised here.

Aims and approach

Building a methodology for analysing innovation or research, and using this methodology to identify trends in a corpus of works were two aims that we thought about together. A classical meta-study “translates results to a common metric and statistically explores relations between study characteristics and findings” (Bangert-Drowns & Rudner, 1991). Because of the above complexity and because of the diversity of the characteristics and findings of papers in the field of IC Technologies, we did not try to define a single metric. It appeared to us that looking at the integration of technology requires a plurality of perspectives or approaches and that a first stage of this “meta-work” would consist in a precise identification of these perspectives. Our methodology was to conceive of possible perspectives or factors (that we named “dimensions”) using our knowledge of research work. Then we had to analyse writings on the introduction of IC Technologies. As a writing focuses on a necessarily limited number of perspectives, we wanted to be able to identify in which dimension(s) its contribution is and what specific approach and results it brings into this(these) dimension(s).

We had to make the dimensions operational by identifying each of these by a set of adequate questions. In our mind, this identification could not be done only from a theoretical reflection but had to be drawn from the existing literature. This is why we decided to carry out a qualitative analysis of a corpus as large as possible, covering the diversity of fields defined by a specific technology: (dynamic) geometry, computer algebra and other algebraic software, arithmetic and graphical calculators, computerised learning environments… We chose also to consider French publications in order to specify our own cultural and institutional context and also as many papers as possible from other countries to identify alternative approaches.

Methodology

The specification of the dimensions was the goal of a first stage analysis and a statistical analysis of a corpus in each of the dimensions was the goal of a second stage analysis. In the first stage analysis, we considered a whole range of publications regarding the nationality of the author(s), the type of work, the type of software and hardware used, the domain of knowledge… We decided to cover years 1994 to 1999, which appeared to include enough diversity. We used a variety of international sources as well as French works. This resulted in a corpus of 662 published works.
The exploitation of this "first stage" corpus was:

1. a quantitative identification of the repartition with respect to nationality, mathematical field, school levels, type of study,
2. a qualitative classification of questions (or "problématiques") that we did on a topical subset (we chose Computer Algebra), in order to establish the various dimensions in the approach of the use of technology,
3. the selection of a corpus for the "second stage" analysis.

The selection for the second stage analysis was necessary because not all papers in the first stage corpus had sufficient matter. The selection was to be large enough to respect the diversity of approaches and to avoid biases, but we had also to consider that the second stage analysis was expected to take several hours working on each paper. The principles of selection were:

- to have publications with sufficiently developed "problématiques", methodology and findings,
- to avoid papers too close in their analysis and findings,
- to have a distribution of nations, types of hardware and software, domains and levels similar to the initial corpus.

We selected 79 papers, judging this selection to be a good compromise between in depth analysis and respect of diversity. For each of these papers, one of the participants of the project established a detailed review. The exploitation of this "second stage" corpus was:

1. a qualitative analysis of a dimension (we choose the cognitive dimension) in order to get a first evaluation of the diversity of the approaches in this corpus
2. a statistical classification giving informative partitions of the corpus with regard to the various dimensions.

A quantitative identification of the corpus

We started this study with the hypothesis that the great variety of types of publications in the field of the use of IC Technologies gives evidence of a lively field but also makes difficult the search for convergent findings. Of course we had also an intuition of what this variety could be. Thus, the simple quantitative findings reported in this paragraph were intended to provide evidence of the diversity of the publications as well as provide a check of the conformity of the corpus as compared to what we thought of the general production.

<u>Type of analysis and mathematical field.</u> Research publications were not a majority (37%). This is relevant for our aim to analyse the use of IC Technologies as a whole, looking at classroom innovation, and speculation as well as at research studies. Geometry is well represented. Few papers are about arithmetic and algebra alone, probably reflecting the smaller amount of writings about the pre-college level, outside geometry, in the corpus. A number of papers do not specify a mathematical field, focusing on the support of technology in “general” mathematical learning.

<u>Type of technology.</u> Varied technologies were represented. Their repartition shows that, although simple and graphical calculators are everyday instruments for many students all over the world, papers tend to focus on "smarter" technologies, like computer software or symbolic calculators. Emergent technologies (Internet, etc…) although very present in discourses are rarely addressed by papers in our corpus. We thought this repartition was not a misleading picture of the varied writings about the introduction of IC Technologies in the period of time that we considered.

Countries. Our corpus represented also a great variety of countries. Of course there was a bias towards France because it was easier to get hold of publications in France like thesis, professional teachers' journals and congress and professional meetings reports that we wanted to include beside papers from international journals. The part of all the "Latin" and "Latino-American" world appeared to us reduced compared to what we had expected, a bias that we attributed to the sources we had in hand.

Two qualitative pictures

As indicated above we did two qualitative analyses, firstly to have a general picture of the publications in the initial corpus before selecting the second stage corpus, and secondly to get an evaluation of the diversity of the approaches in this latter corpus.

A qualitative classification of "problématiques" in the first stage corpus

To prepare for the second stage analyses, we considered the "problématiques". The "problématique" of a publication is the field of connected problems or questions that the publication addresses. This idea of "problématique" is important in our research because it aims at the study of the way questions are posed in the field of IC Technologies. A reason for the discrepancy between the favourable opinions on their use and their poor integration lies in the difficulty of addressing appropriately the problems really involved in a given experiment.

For each publication in the first stage corpus, we established a small text summarising its "problématique". An analysis of the "problématiques" of the whole corpus would have been too time-consuming for a qualitative picture. So we decided to restrict this analysis to a specific field: the educational use of Computer Algebra Systems (CAS). We chose this field because it appeared with a high percentage, reflecting the great number of papers written in this field. Another reason was that the corpus included all the papers issued from a journal dedicated to CAS educational use, the IJCAME. As this journal encourages research papers as well as articles about teaching issues, activities for class use and opinions, we were particularly sure of having a variety of papers in this field. The CAS sub-corpus also included thirty percent of publications on CAS use from a great variety of other journals or books.

We found that the publications of the CAS sub-corpus could be classified into five types of "problématique" that we summarise below.

Technical descriptions of possibilities of CAS (53 %). These papers stress the capabilities of CAS that they find relevant for educational use. Optimism is a very common feature of these papers and only a few articles stress the need for students' training to avoid pitfalls.

Descriptions of innovative classroom activities (13 %). These papers go farther, presenting actual CAS use in classrooms. Presentations of national projects for experimenting and integrating CAS (like French or Austrian projects) and of new curricular projects influenced by CAS capabilities are examples of these.

Papers starting from assumptions (18 %). These papers are more research-oriented studies, with hypotheses, experimentation and conclusions. Hypotheses come from general views on mathematics teaching and learning and on technology and are often backed by a theoretical cognitive approach.

Papers starting from questions about the use of CAS (31 %). In contrast with the above papers they do not presuppose advantages of this use. They present innovations, experimentation or examples of use not for themselves, but as a tool to address the questions.

Papers focusing on integration (7 %). These papers address the issue of the conditions for CAS to be used, such as paper and pencil in the everyday practice of teaching and learning in existing school institutions.

This classification reflects the diversity of reflection, research and experiment on the use of IC Technologies. The papers with a mere technical approach of possible use of IC Technologies (type 1) prevail. The mass of papers produced in this approach is representative of the interest raised by a technology like CAS among a part of the teachers. Papers arguing in favour of classroom innovations (type 2) are much less common, but seem useful especially when they report on long-time experiment of students' use of CAS. A weakness is that they generally do not discuss the teacher's options.

Among research papers, our classification distinguishes publications starting with assumptions on expected improvements resulting from students' use of CAS (type 3) from others starting with questions about this use (type 4). Ten years ago, in the first stream of research about CAS use, many papers were of type 3. In the period 1994-1999, the papers of type 4 are nearly twice as frequent as papers of type 3. We can take it as an indication that at this stage of development of research about IC Technologies, formulating and trying assumptions on improvements is no longer very productive. The assumptions and questions have in common their focus on the epistemological and semiotic dimension: they generally consider the mathematical knowledge at stake in technological settings and the possible effects of its computer implementation. Type 3 and 4 papers share also a common interest for a "cognitive" dimension: the assumptions of improvements and the question about the use of IC Technologies are generally based on a theoretical framework about the student's functioning and learning processes.

The last class (type 5) gathers a minority of papers explicitly addressing the issue of integration, which implies a study of questions like those in type 4 papers, but with a specific approach of an ecologically sustainable use. Questions on tasks, procedures and conceptualisation, as well as on CAS as an instrument exist in the type 4 papers. In the type 5 publications they appear as not to be missed dimensions that we briefly characterise below:

- The "instrumental" dimension of IC Technologies distinguishes a technological artefact and the instrument that a human being is able to build from this artefact.

While the artefact refers to the objective tool, the instrument refers to a mental construction of the tool by the user. The instrument is not given with the artefact, it is built in a complex instrumental genesis and it shapes the mathematical activity and thinking. (see Trouche, 2000).

- The “institutional” dimension investigates to what extent content to be taught as well as tasks and procedures (or "techniques") are affected by the institution in which they are taught. Institution has to be understood in a broad sense: a specific classroom with a specific teacher may be considered as an institution as well as a general school level for a country (see Lagrange, to appear).

So this classification helps to consider the varied types of "problématiques" and dimensions that can be used to analyse the use of IC Technologies. It helps also to look at the selection we did for the second stage corpus. Because they generally lack sufficient data and analysis, we could not integrate most of the papers of type 1 and 2 in the second stage corpus.

A qualitative analysis of the theoretical frames in the second stage corpus

As most publications in the second stage corpus are research papers, they generally offer a theoretical basis for their analysis. We chose to look qualitatively at this basis as means for preparing the quantitative analysis by showing convergence and diversity in the mass of papers that we selected.

As expected from the above study of "problématiques", we found a strong convergence of the theoretical frames in the predominance of cognitive approaches. Where constructivist views prevail, papers very generally base their analysis on theories of the student’s functioning and learning processes. Within this general picture, diversity appears through more local theories, attached to specific research trends, such as for instance, the “process / object” approach, or the emphasis put on Piagetian processes of assimilation and equilibration. It appears also in specific theoretical constructs issued from the research on the use of IC Technologies like the notion of cognitive tool and conceptual reorganisations. Specific environments such as for instance dynamic geometry software, graphic calculators, CAS… tend to focus on specific approaches.

In spite of this diversity, we could find convergent elements of an evolution. This evolution reflects the progress of global educational research, especially towards socio-constructivist, socio-cultural and anthropological approaches, showing how the research on IC Technologies depends on the global context. Beyond this dependence, the evolution of the theoretical approaches of the use of IC Technologies marks also a sensitivity towards specific dimensions and provides for specific elaboration.

A specificity of research on the use of IC Technologies is a special sensitivity to the role played by perception in cognitive processes. It is interesting to notice that, even within the short period taken into account, some convergent evolution seems to occur in the way perception and visualisation are approached. Some texts remain still in what we could call the “naïve phase”: the visual potential of technology is emphasised, illustrated by judicious examples, but is seen as a means for improving mathematics understanding and conceptualisation, per se. Most texts in the corpus are situated beyond this naïve attitude. The cognitive power of visualisation tools, the underlying cognitive processes, have become a matter of investigation. In some papers, this leads to the opposition of perceptive and conceptual approaches.

Nevertheless, most recent texts tend to present the relationships between perception and conceptualisation in more dialectic ways. For instance, accessing geometrical knowledge is no longer presented as resulting from the rejection of some perceptive apprehension of geometrical objects, but from the ability of relying efficiently both on spatial and geometrical competencies. More emphasis is put on the characteristics of problems and situations which can foster the dialectic interplay between these competencies of different nature and thus contribute to the development of geometrical expertise (Laborde 1998). The same sensitivity and evolution can be observed as regards the role played in conceptualisation processes by the interaction between the different semiotic registers of representation and as regards the "contextualisation of knowledge" (Noss and Hoyles, 1996).

From this qualitative analysis, we see that even in a specific dimension like the theoretical cognitive framework, diversity makes research advances not easy to synthesise and that relying on such synthesis for a development of the field will be difficult. A useful convergence can be found in the consistent evolutions noticed above.

The quantitative second stage analysis: data and method

Eight dimensions for the analysis of the integration of technology were derived from the above qualitative analysis. Five were briefly described above: the general approach of the integration ("problematiques"…), the epistemological and semiotic, the cognitive, the institutional and the instrumental dimensions. Three other dimensions were considered: the "situational" dimension which refers to the changes that the introduction of technology brings into the didactical situations, the dimension of "human-machine interaction" which analyses students' activity and interaction with the technological tools and the teacher dimension which looks at the teacher's beliefs and at the way (s)he organises the classroom activity.

For each of the dimensions a set of questions was designed resulting in a questionnaire of 96 questions. The answers to the questionnaire for each publication of the second stage corpus was assumed to give a picture of how this work takes each specific dimension into account. The identification of trends in writings about the introduction of technology could then be carried out through a statistical procedure. This procedure was designed on the basis of a cluster analysis. Applying this procedure to each dimension, we obtained specific partitions, data to explain clusters and one or two papers at the centre of each cluster.

The quantitative second stage analysis: results and interpretation

In this section we will detail and discuss the results of the "instrumental" partition as an example of the data that the procedure handles and of the type of insight that it provides for. Then we will draw more briefly on other partitions.

The "instrumental" partition

The instrumental approach was briefly introduced above. It is a rather new approach; older studies took into account neither the learning processes attached to the use of the tool, nor their evolution over time. This approach may be relevant for investigating how students make use of technologies, how the way they use it evolves over time under the influence of evolution of their knowledge in mathematics and about the technology. This approach may also be relevant for investigating how the teaching takes into account the construction of the instrument and its relationships with the learning of mathematics. Several points of our analysis are concerned with this approach.

The types of questions attached to this dimension in the questionnaire are:

- is time evoked as important (q1)?
- are features of the technology or constraints of the technology evoked (q2)?
- are possible organisations of students' work taken into account in the analysis (q3)?
- is the distinction social/individual part of the analysis (q4)?
- are the instrumentation processes part of the analysis (q5)?

This partition is made of six clusters but only three of them are informative.

<u>Cluster 1</u> (14 papers from 8 countries, 6 Anglo-american and 5 French papers)

This cluster gathers papers that take into account

- the availability of technology, its features (type q2),
- the organisation of work (type q3),
- the social dimension (type q4),
- but not always the time (types q1 and q5).

Two papers, which are very different under several aspects, are in the centre of this cluster and may thus represent it.

Chacon P.R. & Soto-Johnson H., 1998, *The Effect of CAI in College Algebra Incorporating both Drill and Exploration*
This paper dealing with the use of CAS in college algebra emphasises the role of permanent availability of technology for all students. Students having permanent access to technology acquire a better ability to analyse graphical representations and symbolic expressions. Just partial availability may imply frustration and antagonism toward technology. The paper calls for the integration of technology not only in activities but also in the course and for considering the interrelationship of the procedural knowledge developed about technology and mathematical knowledge.

Pratt D. & Ainley J., 1997, *The Construction of Meanings for Geometric Construction : Two Contrasting Cases*.

The paper describes a two-year experiment in which pupils from primary school had laptop computers. They used Logo and a dynamic geometry environment (Cabri) on their own, deciding themselves about their projects. The pupils used mainly Cabri as a drawing tool rather than as a construction tool and were not eager to produce drawings whose shape is preserved by the drag mode. Only explicit teacher interventions in specific tasks made the pupils move from a drawing activity to a construction activity.

Although these two papers deal with different technologies, school level, and mathematical topics, they share key features with other papers of the cluster, like empirical data in a long-term experiment of students' activities, fine-grained observations, accounts of the characteristics of technology, the fact that positive results of IC Technologies are not taken for granted but questioned through empirical data. Their balanced findings differ from more general papers which are imbued with optimistic appreciation.

Cluster 2 (6 papers, 4 American, 1Australian, 1 French)

Papers of this cluster all focus on the importance of time in the instrumental process (types q1 and q5) and do not consider the organisation of teaching (types q2, q3 and q4). Five of the six papers deal with geometry. The centre of this cluster is

Goldenberg P., 1995, *Ruminations about Dynamic Imagery (a strong plea for research)*
This paper analyses how the continuous transformation of diagrams in geometry may completely change geometrical properties (a geometrical theorem may become a property of a function) and conceptualising processes of students. This cluster gathers papers which do not consider the classroom but mainly analyse features of the technology and their implications on possibilities of action and on conceptualisation. From this analysis, they find that, even with technology, instant mathematical conceptualisation cannot happen and thus time is necessary for students to understand the mathematical implications of the use of the instrument.

Cluster 3 (8 papers, 4 French, 2 Austrian, 1 English, and 1 American).

The only explicit type in this cluster is time (q5) but it is considered in very different manners among the papers. Half of them consider that technology provides a wealth of opportunities for a "more conceptual" use of time while the other half is doubtful and claims that this issue of time deserves more reflection. The two central papers reflect this dichotomy of the cluster.

Kuntz G., 1998, *Une transformation oubliée qui sort de l'ordinaire : l'inversion.*
This paper reports on a teaching experiment at high school level on geometrical transformations using a graphic package. In the author's view, the use of technology makes classroom time more conceptually productive. Students' mathematical activity is reported as dense and involving deep mathematical ideas. Even the constraints of the computer representation are, in the author's view, pedagogically beneficial.

Mayes R., 1994, *Implications of Research on CAS in College Algebra*.
This paper describes a curriculum in algebra based on DERIVE, aiming at developing abilities in modelling, problem solving and conceptual understanding. In the author's hypotheses, DERIVE was crucial to allow "a reduction of the amount of time spent doing tedious manipulations…" An experimental group and a control group are contrasted. This comparison gives no evidence of significant difference among computation and manipulation skills and a marginal improvement in problem solving competence. The only difference is the critical point of view developed by the experimental group: "they felt the increased burden of problem solving and multiple approach".

In our interpretation of the instrumental dimension in this paper, the issue of time becomes central when the author's initial hypothesis is that technology is able to save time for conceptualisation and when the results are students feeling an increased burden and claiming for more "hours credit". We have to recognise that more complex problems generally associated with a "conceptual" introduction of IC Technologies bring students heavier cognitive load and technology does not, by itself, solve this difficulty. As the author concludes, time and explicit intervention of the teacher on strategies (or "techniques", as the institutional approach now calls them) would be essential for conceptual improvements. So Mayes is representative of a trend in this cluster: an evolution towards a more balanced view of the influence of technology upon conceptualisation and towards the necessity of a careful organisation of time in order that students benefit from technology.

Discussion

The above presentation of the "instrumental" partition shows that each cluster contains papers from varied countries and fields. We can see also that papers in a cluster share common concerns for key variables in the dimension. Their findings are varied but are clearly influenced by these concerns. Looking at the interpretation, we see that instrumentation is a big issue with at least three main entries. The time that technology could save or not is probably the more naive entry (cluster 3), but, seriously questioned, it provides interesting discussions. The time requested by a real mathematical instrumentation is another entry (cluster 2) raising deep interrogations on the nature of conceptualisation. It is otherwise interesting to see that papers focusing on the instrumental dimension (cluster 1) do not consider time as the main variable. Our interpretation is that in the experimental settings, the technology was always available; time constraints are not so important in such a case.

A synthesis of partitions

Looking at other partitions, we found that the largest clusters focus on the students, providing a mass of interesting data and results on the learner, certainly insufficient in themselves for a study of the integration but also a basis for this study. We found especially that the evolution of the cognitive theoretical framework generally used for the analysis of the introduction of technology is sustained by these data and results.

Large clusters are also centred on the epistemological dimension. This is evidence of the attention paid to the relationship between the content knowledge at stake and the new teaching means provided by IC Technologies. On the other hand evidence appears that epistemological relevance is not sufficient in itself when no attention is paid to instrumental constraints and ecological viability.

One of the clusters starts with varied postulates converging on the fact that technology enhances teaching or learning. A wider and more varied set of clusters questions this claim and investigates to what extent technology improves learning. With this posture, researchers consider the students' difficulties in the use of technologies as well as the demands that technology brings into the educational system. These clusters call for a wider approach which should include the instrumental, institutional and teacher dimension. References to these dimensions are sparse, although promising as we could notice in the detailed analysis of the "instrumental" partition. A similar analysis of the "institutional" partition should point out the questions of the tasks offered to the students (tasks especially designed to be solved with technology or "ordinary" tasks), of new instrumental techniques and their mathematical productivity, of the teacher's organisation of classroom activities, as important for the future.

Biases and limits

The most obvious sources for biases were ourselves, the researchers, because we came from five different research teams working in various fields of the use of IC Technologies. At the beginning, this brought many distortions in the coding, and we had to discuss every item of the questionnaire. From the observation of statistical indicators, we are now reasonably confident that the initial heterogeneity was overcome. A critical circumstance is that we were researchers from a single country and "cultural" biases may exist. Another limitation was that we could not analyse methods for learning mathematics on CD-ROM or on the Internet because we found only short presentations which were not sufficiently informative.

Conclusion

We saw the huge literature on the use of IC Technologies for teaching and learning mathematics as data representative of the efforts of a big and varied community of teachers, innovators and researchers. We had the intuition that knowledge about integration could be derived from an analysis of this data. Starting from a corpus as large as possible we got a first picture of what this literature is. Technical presentations and reports on innovative classroom use make the bigger part of this corpus. Because they look at the new applications appearing day after day, these papers are potentially interesting contributions on the use of up to date technology. On the other hand, the qualitative study of papers in the CAS sub-corpus shows that the ideas in these presentations and reports are generally weakly supported by reflection and experimentation and cannot address the complexity of the educational situations. Looking qualitatively at the more research-oriented second stage corpus, we saw a slow evolution towards attention to more varied aspects of educational use of IC Technologies and more dialectical cognitive approaches. So the difficult integration can be seen through this picture: innovations present a wealth of ideas and propositions whose diffusion is problematic; research struggles to tackle the complexity of the integration of evolving technologies.

Our aim was to build a framework as a method to look at research and experimentation. This framework was done using several dimensions which arose from a theoretical reflection, that the qualitative study of the global corpus helped to specify into a questionnaire. A statistical procedure was used to identify clusters of studies sharing a common concern in one of the dimensions. Then, looking at outcomes in each cluster, we could identify concerns and findings. In practice, this framework should help innovators or researchers to characterise a project or a field of research by means of the questionnaire and then to get insight on its specific contribution by looking at its position in the partitions. In our mind, this method is a tool to grasp the complexity of the introduction of technology or, more precisely, to tackle the integration of IC Technologies with a "multidimensional problématique".

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