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Variety in views of university curriculum schemes for informatics / computing / ICT

A comparative assessment of ICF-2000 / CC2001 / Career Space

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Abstract: Various recognized international professional organizations have recently developed university curricula concepts and models for the broad field which is referred to as computing, informatics or I(C)T (= Information and Communication Technology). The outcomes show a significant diversity, a little maybe because of the difference in terminology but much more so because of a variety in views and approaches. If one would assume a strongly grown maturity of the field paralleled by paradigmatic convergence, after so many decades of development, this is a surprising result. In order to gain more insight in this matter this paper presents an assessment exercise for three of such curriculum schemes. They are compared on a series of characteristic features as well as judged against a set of general guiding principles. The assessed schemes are ICF-2000 (by IFIP in commission of UNESCO), CC2001 (by ACM and IEEE-CS) and Career Space (by a European consortium of ICT industry in partnership with the European Commission).

Key words: Curriculum models, curriculum guidelines, curriculum assessment, university, higher education, informatics, computing, I(C)T

1. INTRODUCTION

In 1997 a Working Conference was organized by the Working Group on university education of the International Federation for Information Processing (IFIP). This conference brought together a selected group of experts from all over the world. The conference theme was *"Informatics*

(computer science) as a discipline and in other disciplines: what is in common?". Indeed its focus was on the search for a common vision of the core concepts in education and training in a field that over the past decades has developed, matured, extended, and linked with many other knowledge domains.

This Working Conference was very productive, identified a common core and gave rise to an editorial paper [1]. It summarizes the varying views on the informatics field and comments on the fragmented approach to its teaching. It argues that informatics indeed can not be forced into a 'monistic' view of normal science such as the 'queen of sciences', physics. However, rather than working with more or less isolated paradigms, informatics requires a *'pluralistic' view* in which several paradigms coexist. The editorial paper advocates a more integral, generic and coherent approach, and it presents preliminary notions in a search for a shared identity for the informatics field. It proposes to build and extend on the earlier work of Denning et al. in 1989 [2].

What does this all mean for the university educational arena which meanwhile shows a broad spectrum of informatics studies and educational programmes, varying from generalized to more specialized contents, from theoretical to more applied programmes, and from monodisciplinary to multidisciplinary approaches? Do we observe anything in common, a reasonable level of coherence, and complementary efforts? Is the diversity in focus transparent? These questions are particularly relevant in relation to the recent publication of three major international curriculum efforts:

- *ICF-2000* ('Informatics Curriculum Framework 2000'), for 'informatics' (by IFIP in commission of UNESCO)
- *CC2001* ('Computing Curricula 2001'), for 'computing' (by ACM = Association for Computing Machinery and IEEE-CS = Computer Society of the Institute of Electrical and Electronics Engineers)
- *Career Space* ('Curriculum Development Guidelines / New ICT curricula for the 21st century'), for ICT (by a consortium of eleven major ICT companies within the European Union).

Note about the three terms used that they are linked to different traditions and communities:

- *'Informatics'* has its roots in academic Europe and is common in IFIP
- *'Computing'* is used in the US to cover 'computer science', 'computer engineering', plus 'information systems' and 'software engineering'
- *ICT* (or just IT in the US) has a more applications oriented connotation and is preferred by industry.

In this paper they are considered to be interchangeable umbrella labels.

It is the aim of this paper to *critically analyse* the three curriculum schemes within the context as sketched above of commonality, coherence,

complementarity, argued diversity, and transparency. Therefore we start with a short description of the origins and backgrounds of the three. We then proceed with a first assessment exercise in which we compare the curriculum schemes within a full spectrum of characteristic features, extracted by the authors from the accumulation of the three schemes. A second assessment exercise presents a first-order judgement of the curriculum schemes against a set of eleven principles that guided the CC2001 work. The paper concludes with a discussion on the outcomes and some recommendations.

2. CURRICULUM SCHEMES: ORIGINS AND BACKGROUNDS

In 1998 IFIP was requested by UNESCO to carry out a curriculum project. IFIP's Technical Committee 3 (on Education) adopted the project which was executed by members of Working Group 3.2 (on Higher Education), complemented with input from other IFIP Technical Committees. The result [3] could in a way be considered as a successor of an earlier (1994) IFIP/UNESCO curriculum framework, which however was much narrower in scope (only computer science). *ICF-2000* has its origin in the 1997 IFIP Working Conference mentioned above in that it takes a broad and generic view on the field. It is not a model curriculum but instead offers a *curriculum framework*, designed to cope with the diverse demand for different categories of professionals acting or interacting with informatics. Tailor-made implementations can be constructed from the framework in a straightforward way. An important asset of ICF-2000 is that it contains source links to prominent and current informatics curricula (see also [4]).

The US has a long tradition of developing model curricula for computer science (CS), computer engineering (CE) as well as for information systems (IS). The Curriculum'68 report for CS by ACM was the first in a series. Approximately every decade a new version of the model curriculum has been published: 1968, 1978, 1991, and now the latest report. The 1991 report was a breakthrough, being the result of a cooperation between ACM and IEEE-CS elaborating CS and CE, combined in 'computing'. Before the two professional societies had followed their own tracks, in which IEEE-CS had published a report already in 1977 on both CS and CE. The present and forthcoming results under the title *CC2001* represent another *breakthrough* in the ambition to include also IS and SE (software engineering). The first volume (on CS) has been published [5], contains a detailed specification of the curriculum core and includes rather precise guidelines for varying when implementing the curriculum as well as sample curricula. Other reports (on CE, SE, IS, and an overview document) are scheduled for the future.

Career Space is an initiative - with support of the European Commission - of a consortium of eleven major ICT companies: BT, Cisco Systems, IBM Europe, Intel, Microsoft Europe, Nokia, Nortel Networks, Philips Semiconductors, Siemens AG, Telefónica S.A., Thales; furthermore EICTA (European Information, Communications and Consumer Electronics Industry Technology Association) is involved. A project was set up to put in place a clear framework for students, educational institutions and governments that describes the roles, skills and competencies required by the ICT industry in Europe. The first step was to develop generic skills profiles covering the main job areas for which the ICT industry is experiencing skills shortages [6]. The second step was to develop *new ICT curriculum guidelines* [7] for which the generic skills profiles are a point of reference. In the latter project input came from individual experts from over twenty European universities and technical institutions. The guidelines are intended to assist the design of courses to match the skills profiles and needs of Europe's ICT industry.

3. FIRST ASSESSMENT EXERCISE: COMPARISON OF MAIN CHARACTERISTICS

The *overview* on the following pages compares the three curriculum schemes along a set of twelve characteristic features. This set has been inferred by the authors as topical for each of the schemes after a thorough study of all three. Actually the overview serves *two functions*:

– it can be read as three parallel stand-alone encyclopedic stories
– it shows the differences and similarities among the curriculum schemes.

Note

Although we have made a good effort to present a neutral overview, a certain bias towards ICF-2000 may have slipped in, if only because of the deeper and first-hand authors' knowledge of ICF-2000. If that happens to be the case, clearly this is not at all intentional.

ICF-2000	***CC2001***	***Career Space***
Characteristic feature 1 Umbrella terminology		
Informatics, 'traditionally' referring to a diverse, yet related family of domains: CS = computer science, CE = computer engineering, SE = software engineering, IS = information systems, I(C)T, AI = artificial intelligence, …	*Computing*, originally covering CS and CE, according to Computing Curricula 1991 and [2]. The CC2001 report suggests to include also the areas of SE and IS, and maybe others.	*ICT*, Information and Communication Technology, which essentially has a very broad connotation. However, by primarily focussing on ICT industry, the scope is less broad.

2 Developing organizations and experts		
The responsible (world) organization is *IFIP*, in particular its Education Technical Committee (TC3). The work was done by a group of IFIP linked experts.	*ACM* and *IEEE-CS* have produced the 1st volume (CS). The work was done by many experts, with a clear *US base*, though, both in the people and in its context.	A European consortium of *11 ICT companies* (BT, Cisco Systems, IBM Europe, Intel, Microsoft Europe, Nokia, …) has taken the initiative, in partnership with the *European Commission*.
The project has been commissioned by *UNESCO*, meant to benefit students and institutions in both developed and developing countries.	Additional volumes are to be prepared in consultation with other US based professional societies (SWEEP, AIS, AITP).	Input was given in a working group by individual experts from over twenty European universities and technical institutions.
3 Status, level of detail and links to other curriculum schemes		
The project has been completed in 2000. The comprehensive report offers a rather *global* specification, but includes *links* to various distinguished detailed schemes, such as the CC2001 predecessor (CC1991), IS'97 and ECDL (European Computer Driving Licence).	A 1st volume (on CS) is available since Dec. 2001. Other volumes (on CE, SE, IS, …) are foreseen, while an overview document is to complete the series. The CS report is *very detailed* and self contained, not referring to schemes other than its predecessor CC1991.	In 2001 a concise and global report has been published. This contains a set of rather *open-ended* recommendations and does not include any reference to other well-known schemes. The report builds, however, on an earlier Career Space report called 'Generic ICT skills profiles' [6].
4 Goal and function		
ICF-2000 offers a *framework* for the *design* of curricula to be implemented in a specific context, given institutional, societal and cultural factors. More specifically it allows institutions or countries with a less developed informatics education to leapfrog to the state-of-the-art.	CC2001 offers a set of *detailed* curriculum *guidelines*, giving a distinct choice from a selected number of model implementations. More specifically it meets the needs of many US colleges and universities for significant guidance in terms of individual course design.	Career Space offers a set of *global* curriculum development guidelines and *recommendations*, but is not very explicit at implementation. Underlying goal is to narrow the ICT skills gap 'for tomorrow' (and decrease today's shortage) as identified by the ICT industry [6].
5 Paradigmatic view on the field (see also feature 1)		
'Informatics' is viewed broad and generic, basically to be *analysed/decomposed* into domains such as CS, CE, SE, IS, AI, … This is apparent in its *top-down methodology*: all	*'Computing'* is viewed broad and generic, basically to be *synthesized/composed* from the domains CS and CE (plus - intentionally - SE, IS, …). This relates to its *bottom-up approach*, yielding separate	*ICT* is viewed broad and generic, but basically as a *merger* of electrical engineering and informatics, added with business knowledge and behavioural skills. This originates from the *ICT*

domains are included a priori, advancing coherence and consistency implicitly. This is conditioned by an open and intensive interaction between the scientific communities.	volumes on the different domains, by the end resulting in a compiled overview document. This requires an explicit mechanism to advance coherence and consistency.	*industry's approach*, trying to solve the ICT skills gap. The report's suggestion that this will also meet the needs of organizations that use ICT intensively does not show.

6 Orientation on demand and supply

ICF-2000 is driven by both *demand* and supply, with a *focus* on the former. It starts from *work force requirements*, identified at a global level. This is done deliberately because of the inevitable difficulty to specify sustainable precise profiles, also in dialogue with industry. Eight professionals' categories are distinguished under three main umbrellas: *I(nformatics) users* A1 instrumental *I(nformatics) appliers* B1 conceptual B2 interfacing B3 researching B4 directing *I(nformatics) workers* C1 operational C2 engineering C3 researching To clear this up a little: - *Instrumental I-users* use I-technology/applications in their work: internet, word processing, graphics, etc. - *I-appliers* apply I-knowledge/skills in areas different from informatics: a teacher in computer supported education (*conceptual*), a lawyer in software contracts (*interfacing*), a physicist in computational science (*researching*), an information (policy) manager (*directing*) - *I-workers* are I-specialists	CC2001 is primarily driven by *supply*, expressed by *academic requirements*: the identified body of knowledge, undergraduate core material, learning objectives, and detailed course descriptions. This supply orientation also is apparent in the process that resulted in CC2001/CS. *20 focus groups* supported that process, of which: - 14 on knowledge areas (typically a supply theme) - 6 on pedagogical issues across the curriculum: 1 Introductory topics/courses 2 Supporting topics/courses 3 The computing core 4 Professional practices 5 Advanced study and undergraduate research 6 Computing across the curriculum. Only pedagogy focus group 4 addresses the demand side explicitly. In a chapter dedicated to *professional practice* a few mechanisms are suggested: - Capstone projects - Professionalism, ethics, and law courses - Practicum / internship/ co-op programmes - Team-based implementation courses. Elsewhere the report recommends in order to 'complete the curriculum': familiarity	Career Space is driven by *demand*, using a set of ICT core generic *skills profiles*, as identified by the ICT industry consortium. The curriculum report refers to *13 profiles* in the areas [7]: *Telecommunications* 1 Radio frequency engineering 2 Digital design 3 Data communications engineering 4 Digital signal processing applications design 5 Communications network design *Software & Services* 6 Software & applications development 7 Software architecture and design 8 Multimedia design 9 IT business consultancy 10 Technical support *Products & Systems* 11 Product design 12 Integration & test / implementation & test engineering 13 Systems specialist. In [6] each skills profile is described by a vision / role / lifestyle, as well as by tasks, associated technologies, required skills and career opportunities. A confrontation with the *supply side* reveals a rather large mismatch of many

in *operations* (e.g. network operator), systems *design* (e.g. software engineer), or *research* (e.g. postdoc). The supply side enters when a best fit to the intended categories of professionals is made through *graduate profiles*, specified in units with targeted competencies and each referring to various curriculum sources.	with applications, communication skills, working in teams, project courses. CC2001 pays measured attention to demand side issues and includes professional practice in its sample curricula. But the report is also clear on who is to 'rule' the curriculum, namely academic educators.	running ICT curricula with these profiles. *Note* Five profiles from [6] have not been included in [7]: ICT marketing management, ICT project management, Research and technology development, ICT management, and ICT sales management. The reason for this is not quite clear.
7 Curriculum core		
The curriculum core is taken from [1] and has *12 themes*: 1 Representation of information 2 Formalism in information processing 3 Information modelling 4 Algorithmics 5 System design 6 Software development 7 Potentials and limitations of computing and related technologies 8 Computer systems and architectures 9 Computer-based communication 10 Social and ethical implications 11 Personal and interpersonal skills 12 Broader perspectives and context (including links with other disciplines). These twelve core themes constitute each ICF-2000 curriculum. For the eight categories of professionals, however, their relative weight is different (highlighted in so-called theme finger-prints). The core themes are manifest in the *curriculum units* by	The curriculum core is taken from *13* out of 14 *knowledge areas* that span the full CS body of knowledge (no 14 is Computational science). Below we list the core topics, in decreasing order of their % contributions (in brackets) to the curriculum: - Programming fundamentals (19) - Discrete structures (15) - Architecture and organization (13) - Algorithms and complexity (11) - Software engineering (11) - Operating systems (6.5) - Social and professional issues (6) - Net-centric computing (5.5) - Intelligent systems (3.5) - Information management (3.5) - Programming languages (2) - Human-computer interaction (2) - Graphics and visual computing (2). The CS report is *strict* on the core: any curriculum implementation should contain the *full core* as a minimum.	The curriculum core is very *open-ended*. It is considered to be the university's task to specify those global core components in depth. The recommended *4 core components* and their % contributions (in brackets) are: - *Scientific base*, covering the fundamental principles and concepts relevant to ICT industry (30) - *Technology base* with a broad overview of technologies, their functions, advantages and constraints (30) - *Application base and systems thinking* (specialized), giving rise to in-depth knowledge and skills in specialized fields, problem solving skills, and workplace driven application knowledge for particular job profiles (25) - *Personal and business skills*, through team projects, commercial simulations, negotiation, presentation, etc., throughout the curriculum (15). The Career Space report indeed is very *liberal* on the core, guiding to components

specific patterns. And the units can be leveled at four *competency orientations*: - Awareness (know or use) - Application - Design and modelling - Conceptualization and abstraction.	*Note* This is only about the CS core and body of knowledge. Completion with CE, SE and IS is not trivial, at least if a merger with the CS results is intended.	that are only roughly estimated in student's effort and specified at a high level of abstraction.

8 Curriculum structure and components

The curriculum 'atom' is a *credit point* (cp), standing for about *8 hours of study*. The curriculum is composed of *units* ranging from 2-4 to 9-11 cp. Each unit has a short specification of targeted competencies and references to well-known model curricula. ICF-2000 does *not* combine the units to larger *courses*. The units are clustered in four *'graduate profiles'*: - BIP or *Basic Instrumental* I-Profile (20 cp = 160 hours) - BCP or *Basic Conceptual* I-Profile (40 cp = 320 hours) - MIP or *MInor* I-Profile (80 cp = 640 hours) - MAP or *MAjor* I-Profile (160 cp = 1280 hours). Each profile is 80% generic, 20% specific. These profiles build one upon the other and meet the needs of the eight professionals' categories A1-C3 (feature 6): - BIP is meant for *all students*, a 3% part in a 3-year bachelor programme (A1) - BCP + BIP, a 10% bachelor part, offers a flexible fit for a large volume of *students in non-informatics studies* (B1) - MIP + BCP + BIP is for students in a *non-informatics bachelor* who want to incor-	The curriculum 'atom' is the conventional *lecture hour* (lh) which should be interpreted as *4 hours of study* in order to include out-of-class study. The curriculum is composed of *units* ranging from 1 to 14 lh. These units are contained in *courses* that in the report are assumed to have a typical size of: 40 lh = 160 hours. Courses are *clustered* in different arrangements, each specifying - by a particular implementation strategy - a full component of a model undergraduate *(bachelor) CS* programme. Three *course levels* are distinguished: introductory, intermediate and advanced. The advanced courses go well beyond the core, but within the 14 knowledge areas. CC2001/CS contains a considerable set of detailed CS *course descriptions*. The report recommends to *complete* the undergraduate CS curricula with *non-core requirements* in: - Mathematical rigor - Scientific method - Applications familiarity - Communication skills - Team working (projects) - Employment empowering.	Career Space does *not* define a *metrics* to measure curriculum components in terms of curriculum 'atoms' or other units. Nor does it specify course contents. Career Space applauds the European *'Bologna' approach.* It adopts the higher education structure of a 1st cycle programme of 3-4 years (*bachelor* degree) and a 2nd cycle programme of 1-2 years (*master* degree). The report suggests a *hierarchical* generic structure for 1st cycle ICT curricula, embracing the full core: - Year 1: *general core* modules - Year 2: *area-specific* core and *elective* modules - Year 3-4: *specialization* and *advanced* topics, plus about 15% of the curriculum for *practical work* experience (industry placement of 3 months) and *bachelor project* thesis work (3 months). The *2nd cycle* should contain *advanced* topics in the same *four core areas* as for the 1st cycle. And again an industry placement, plus a master thesis (in total up to 40% of the curriculum).

porate informatics in their study (up to almost a quarter) with a certain degree of *specialization* (B2-B4) - MAP + MIP + BCP + BIP, adding up to 2400 hours, about half a *bachelor* programme in *informatics*, including a 20% specialization, 10% electives and 12.5% required projects (C1-C3).	The *sample curricula* show room for elective courses (around 10%) and a capstone project (also around 10%). The size of the core is 280 lh = 1120 hours. For the other components mentioned the size depends on the implemented model.	The report observes a need to *cluster* the 13 skills profiles (feature 6) into, for example, *three separate curricula*: - Information Technology (skills profiles 1, 2, 4 and 10) - Computer Science (profiles 6, 7 and 9) - Integrated curriculum (other skills profiles).

9 Transfer of subjects and concepts from other disciplines

In each graduate profile *20%* has been reserved for units that are *discipline specific*. These are meant to be interdisciplinary in approach. Besides ICF-2000 refers to a wide variety of *non-informatics subjects* that may be relevant for a specific curriculum implementation. This, however, has not been further detailed. The ICF-2000 body of knowledge is restricted to informatics; no other disciplines elements are included.	CC2001 recommends to *include* in the CS curriculum: - Discrete mathematics - Selected additional maths. subjects (calculus, etc.) - Science/scientific method - An application domain. The CS body of knowledge *includes* two strictly spoken *non-computing* areas: discrete structures and computational science. It is not clear what this 'inclusive' approach implies when the CS body of knowledge will be completed with CE, SE and IS, for which other non-computing areas are relevant.	Career Space draws heavily on *non-ICT* areas, supposing a *strong link* and cohesion with the ICT domain itself. This holds for the following components: - Scientific base - Application base - Personal and business skills. The report does not present any further detail as to what content is to be incorporated and how the integration with the ICT domain can be achieved.

10 Transfer to other disciplines' curricula

Inherent to its design of four graduate profiles, ICF-2000 addresses the issue of *'Informatics for all'* explicitly. Implementation is possible at *three levels*: - for virtually all students BIP should be compulsory - in many bachelor programmes BCP should be required - on top of that MIP preferably would be chosen as an option by many students.	CC2001 contains a chapter on *'Computing across the curriculum'*, which refers to a key NRC report [8]. This report identifies computer-specific *skills*, fundamental and enduring computing *concepts*, and general *intellectual capabilities*, that all should be included in general undergraduate education. CC2001 recommends *three course models*: general fluency, multi-disciplinary, single discipline specializing.	Career Space does *not* address the issue of *'ICT in any other study'*.

11 Variety in implementation		
Implementation variety with a broad scope is an essential quality of ICF-2000. This is effected by the *framework's degrees of freedom*, such as the: - diversity in the links with the professionals' categories - graduate profile options - discipline context - competency orientations - built-in spread in individual unit sizes - curriculum sources. The report contains a separate chapter on *implementation factors* (institutional, societal, cultural, available resources, etc.) and suggested *strategies*.	Implementation variety is considered necessary, shaped primarily by the suggested *strategies*: - at *introductory* level: imperative-, objects-, functional-, breadth-, algorithms-, and hardware-first - at *intermediate* level: topic-based, compressed, systems-based, and web-based. CC2001 suggests *three sample CS curricula*, i.e. for research-oriented universities (in the US), single discipline focused universities (e.g. in Europe), and liberal arts colleges with a small CS department (in the US). The report concludes with a chapter on relevant *institutional factors*.	Implementation variety is very large because of the *global* level of specification and the *liberal* approach to curriculum design. With an explicit focus on the ICT industry's needs, Career Space advocates a close *collaboration* between *stakeholders* inside and outside the university. They should all be involved in design, control and operation of the university education process, in four steps: - set up entry requirements - define outcomes (graduate qualifications) - define the education and assessment process - implement curriculum quality control.
12 Updating mechanism		
Ongoing updating is considered essential. ICF-2000 has been designed in such a way that this is *relatively simple*. New versions of model curricula can replace earlier ones by just updating references in ICF-2000. Also new curricula may be added to the framework with relatively little effort. An updating mechanism is proposed, however not effective, since there is no active core group of committed IFIP or other experts working on the project any more.	Ongoing updating is advocated rather than what happened before, once a decade. It is *not clear* from the report how this will be *established*. Also, it is unknown how the *future* curriculum development for CE, SE and IS, and the overview document, will *influence* the current CS outcomes. Presupposing better overall coherence and consistency as a final result, it is hard to imagine that there would be no impact on the CS body of knowledge, its core and curriculum content.	Career Space does *not* address the *necessity* of updating explicitly, maybe because the dominant current interest is implementation anyway. But of course regular feedback and updating is a must. It is not clear from the report whether Career Space will organize such a follow-up.

4. SECOND ASSESSMENT EXERCISE: SCORES ON GUIDING PRINCIPLES

The *overview* below judges the three curriculum schemes against a set of eleven principles that guided the CC2001 work. We have chosen this set because it reflects a *state-of-mind* that in our view is more or less generic. It seemed appropriate to conform to this set, at least in a first attempt. However, to facilitate a really generic approach to all three schemes we had to make two *'editorial' changes* in the CC2001 guiding principles:

– the term 'computer science' has been replaced by the more generic term 'computing' (in this paper synonymous to 'informatics' and to ICT)
– all specific references to CC2001 have been substituted by a generic reference to 'curriculum scheme'.

The overview shows a set of scores for each of the curriculum schemes on a scale varying from + + to − −. The scores indicate the extent to which the *principles apply* to the scheme and are assigned by the authors. The motivation for the scoring is attached to each principle and is rooted in the descriptions of the characteristic features in the previous section.

Notes

– Like in the previous section we note that there may - unintentionally - be bias (or misinterpretation) in the results, since our judgement has not been validated with the developers of CC2001 and Career Space. Hence, what we see here should be considered as provisional, first-order.
– For CC2001 the score sometimes is split into an actual one (referring to the CS report published so far) and - in brackets - a future perspective one (assuming all anticipated reports being available).

Guiding principle	***ICF-2000***	***CC2001***	***Career Space***
1/ Computing is a broad field that extends well beyond the boundaries of computer science.	+ +	− [+ +]	0
Motivation *[refer to characteristic features 1, 3, 5]* This becomes manifest definitely in ICF-2000. CC2001 in its present version is restricted to CS, so naturally does not go beyond CS (scoring a −), but when the additional volumes appear CC2001's score perspective is + +. The Career Space report so far shows a limited scope on ICT, but certainly broader than CS.			
2/ Computing draws its foundations from a wide variety of disciplines.	+ / −	+ / −	+ / −

Motivation *[refer to characteristic features 7, 9]* All three schemes conform to this principle with compulsory curriculum components that treat relevant issues from other disciplines, either on themselves or integrated with areas of the computing discipline. Hence, the principle is visible (score +), but in none of the schemes this has led to a level of elaboration that could yield a clear-cut implementation (score −).			
3/ The rapid evolution of computing requires an ongoing review of the corresponding curriculum.	+ + / 0	+ + / −	0
Motivation *[refer to characteristic feature 12]* ICF-2000 and CC2001 both are outspoken on this principle (score + +), but the score is reduced by the lack of an operational guarantee. For ICF-2000 which by its design actually offers simplicity for updating, the score is lowered to 0. For CC2001 where updating is complicated by the expected interference with the forthcoming curriculum developments for CE, SE and IS, the score is lowered to −. Career Space is not explicit on this principle.			
4/ Development of a computing curriculum must be sensitive to:			
- changes in technology	+	+	+
- new developments in pedagogy	−	−	− −
- the importance of lifelong learning.	−	−	−
Motivation *[refer to characteristic features 6, 11, 12]* All schemes account for adaptation to changes in technology, partly by allowing flexibility in the exploitation of the curriculum, partly by an ongoing updating mechanism. Pedagogical issues are addressed in ICF-2000 and CC2001, however in a rather conventional context: nothing 'to the point' about competency-based, problem-based, project-based learning, and nothing about e-learning, portfolio learning and learning communities. Career Space is poor in this respect, paying almost no attention to pedagogical issues (score − −). None of the schemes incorporates operational mechanisms in view of (the preparation for) lifelong learning; indeed they all concentrate on the traditional undergraduate track.			
5/ The curriculum scheme must go beyond knowledge units to offer significant guidance in terms of individual course design.	−	+ +	− −
Motivation *[refer to characteristic features 3, 4, 8, 11]* CC2001 excels on this principle. ICF-2000 does not score well, but indeed it does not aim to offer such detail. It deliberately leaves such an elaboration to those who implement, at the same time choosing for institutional flexibility and appropriateness for some dynamic change. Career Space is even 'worse' and clearly does not comply with this principle at all. Note that if one would invert principle 5 (that ICF-2000 and Career Space seem to do), all scores should be negated (− becomes + and vice versa), turning round the overall picture.			
6/ The curriculum scheme should seek to identify the fundamental skills and knowledge that all computing students must possess.	+	− [+]	−

Motivation *[refer to characteristic features 5, 6, 7]* CC2001 in its present version is only about CS, which implies a limited view on the fundamental skills and knowledge (scoring a −). The CC2001 approach as such, however, arouses expectations of a more inclusive picture when the other volumes are available, hence a + in perspective. For ICF-2000 principle 6 is a major driver (scoring a +). Career Space scores a −, because it also has to grow towards more inclusiveness and does not offer much guidance.			
7/ The required body of knowledge must be made as small as possible.	+	+ [−]	0
Motivation *[refer to characteristic features 7, 9]* ICF-2000 uses a restricted set of 12 core themes for the broad field 'informatics', containing no elements from other disciplines. CC2001/CS also uses a limited body of 14 CS knowledge areas (of which 2 would be more appropriate within mathematics). Future completion with CE, SE and IS undoubtedly will lead to a substantial enlargement into a broadly covering body of knowledge. Therefore the score (a + for CS), will probably go down in perspective (set to a −). Career Space is open-ended and refers to a really small number of core components, of very global quality however; it does not incorporate any structure that could be considered a body of knowledge.			
8/ The curriculum scheme must strive to be international in scope.	+	0	0
Motivation *[refer to characteristic features 2, 3, 4, 11]* Career Space has a European base, although all ICT companies involved are also present outside Europe. CC2001 is predominantly US-based, but incidentally makes an excursion outside North America. ICF-2000 probably is principally most global in scope, facilitated by its linking to distinguished curriculum schemes from whatever continent or country.			
9/ The development of the curriculum scheme must be broadly based.	0	0	+
Motivation *[refer to characteristic features 2, 6]* This principle implies participation by various constituencies from higher education as well as industry and government. Career Space satisfies this approach best: its origin is in industry, a number of universities has supplied input, and the European Commission is involved. CC2001 and ICF-2000 both have a broad basis, but only in academia.			
10/ The curriculum scheme must include professional practice as an integral component of the undergraduate curriculum.	+	0	+ + / 0
Motivation *[refer to characteristic features 6, 8]* All three schemes appear to have applied this principle seriously. The strongest advocate is Career Space which actually considers professional practice as the main driver for arranging the curriculum (score + +). However, the report does not offer much guidance for its implementation (score lowered to 0). The different scores for ICF-2000 and CC2001 stem from the difference in orientation: demand (professionals) versus supply (academia) driven.			
11/ The curriculum scheme must include discussions of strategies and tactics for implementation along with high-level recommendations.	+	+	+

Motivation *[refer to characteristic features 8, 11]*
All three reports contain a separate chapter in line with this principle and give guidance with recommendations. The implementation space as such, however, differs among the three curriculum schemes from micro- to macro-level variety.

5. DISCUSSION

We may *conclude* as follows.

- ICF-2000, CC2001 and Career Space are all substantial curriculum efforts of recognized organizations and committed experts, aiming at impact in an international context.
- These curriculum schemes show similarities, but also distinct differences.
- Strong points of one scheme could set aside weak points of another scheme. For example, the focus on the demand side in Career Space could compensate the missing attention for demand aspects in CC2001; or the deep level of elaboration of CC2001 could support ICF-2000 and Career Space in which this is lacking; or the broad top-down view on the field of ICF-2000 could contribute to CC2001 and Career Space.
- The schemes share a long term ambition, namely a coherent educational programming with diversity in a matured and broad field of informatics/computing/ICT, linked to a wide variety of other disciplines.
- A separate track approach has been dominant so far, but international interaction around the three schemes could - in the long run - create a mutually beneficial way of working, a quality impetus and increased international transparency for both students and employers.
- The two assessments offer useful first-order instruments for bringing the process further of increasing transparency, maturity and quality of higher education in informatics/computing/ICT, building on a variety of views, perspectives, interests and needs.

Two earlier conferences have already offered a good opportunity to share visions on university informatics/computing curricula from the ACM/IEEE-CS and IFIP perspectives: the 1997 IFIP/WG3.2 Working Conference referred to in the introduction [1] and the 7th IFIP World Conference on Computers in Education WCCE2001 in Denmark. At this conference both CC2001 and ICF-2000 were presented and discussed. A try-out comparative analysis of the two (see [4]) gave rise to a lively debate and a better understanding of qualities and complementarity of the various activities.

In that context we end this paper with the following *recommendations*.

- The two curriculum assessments introduced in this paper should be upgraded from exercise level to acknowledged quality. First this concerns the assessment items themselves for which input from CC2001 and Career Space could lead to a broadly-based agreement on the instruments.

Secondly the results should be validated by CC2001 and Career Space on both the characteristic features and the guiding principles scores.

– It would be an interesting discovery tour with a probably large added value to join forces in common projects at themes that definitely need further development and implementation in all initiatives. One could think of: 'informatics for all/computing across the curriculum', search for a shared identity of the field (merger of paradigms, common core), shift from knowledge-oriented towards competency-based learning, etc.
– In two other areas collaborative efforts seem to be relevant. The first one is on curriculum updating and innovation, which is required in all initiatives but - as it seems - not yet effectively incorporated. The second one is on curriculum implementation in institutions or countries with a less developed higher education programming on informatics/ computing/ICT, for example in developing countries.

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