Profiling Academic Research on Digital Games Using Text Mining Tools

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ABSTRACT

Academic research on digital games has been conducted for over 30 years. However, the abundance of disciplines conducting research on the topic makes it challenging for the interested to get a holistic and comprehensive account of past digital game studies. Yet, sophisticated text mining tools designed for structured science information resources, such as the ISI Web of Science or INSPEC, make it possible to conduct insightful literature studies that profile and visualize large knowledge domains. The primary aim of this paper is to profile the research literature from the ISI Web of Science on digital games. More than 2.100 studies between years 1986-2006 were found using a set of digital games-related search words. Secondly, the aim is to find out what are the current "hot" research topics and research trends of the near future. Our profiling study demonstrates that digital game research is indeed highly multidisciplinary, covering more than 170 subject categories of the ISI Web of Science. When combining these categories into larger areas of science, it was found that the three most prominent areas are the Social Sciences (including e.g. psychology and communication), the Health Sciences (e.g. experimental psychology, psychiatry and pediatrics), and Information and Communication Technologies and Mathematics (e.g. computer science theory and methods, software engineering). The fields of Engineering and Arts & Humanities are also well represented in digital game research, although to a much lesser amount. The research in ICT (computer science, information systems etc.) seems to have grown the fastest in the last 10 years.

Author Keywords

Digital games, computer games, video games, research profiling, text mining.

INTRODUCTION

Computer gaming has a history of 50 years [5]. The industry really got started in the late 1970's when the first interesting game titles like the Asteroids, Space Invaders, Centipede and Pong were launched to the consumer markets [10]. Digital gaming is now a widely spread phenomenon and at least 70% of the US and Europe households say that they play video games [7, 9]. Furthermore, the game industry has grown to be a significant and growing business [6].

Academic research on digital games has been conducted for over 30 years. Nevertheless, digital game research is still an emerging, disciplinary diverse field [5]. Aarseth [2, p. 1] has characterized this diversity most tellingly: "*Given a field which is interdisciplinary and empirically varied in the extreme, there are a great number of different reasons to do research, and a great number of types of research to pursue. A more or less complete list reads like the A-Z list of subjects from a major university. When faced with the rich and varied world of digital games, it is hard to think of a subject or discipline that could not in some way be used to study the field.*" [2]. Also Eskelinen [8] enumerates the many disciplines in which game studies are conducted and complains that the results of these studies have hardly ever been pulled together as a whole (see the comprehensive books of [17] and [18] for recent exceptions). Eskelinen [8] concludes that this multi-centeredness makes it difficult to create a research domain that is united enough.

However, some researchers have recently proposed a new discipline for the research on digital games that would exist outside of established academic research disciplines [5, p. 10]. For example Raessens and Goldstein [17] promote "computer game studies" and Aarseth [1] speaks for "game studies". Bryce and Rutter [5] state that it still remains to be seen whether or not research into digital games will consolidate into a distinct field. They conclude that it will certainly not happen without actively working toward creating a hierarchy of digital game research and digital game researchers [5]. Furthermore, they also warn that "*by not situating research in what has*

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proceeded, work runs the risk of unquestioningly assuming that this research has no precedents. This is a tenuous assumption and one which, unless critically evaluated, runs the risk of undermining contemporary academic research on digital gaming." [5].

The aim of this paper is to profile all academic research on digital games that can be found from the ISI Web of Science. Our primary purpose is to get a holistic view on digital game studies by utilizing sophisticated text mining tools to profile and visualize the research domain [16]. Secondly, our interest is to find out what are the current "hot" research topics and research trends of the near future.

Our paper proceeds along the following outline. In Section 2 we describe the research profiling method in more detail. In Section 3 we profile the research on digital games. Section 4 is reserved for discussion and Section 5 for conclusions.

RESEARCH PROFILING

Literature reviews are an essential part of any relevant research. They can be done in different scale: from one chapter to whole state-of-the-art review articles. Their purpose is among others to justify the research questions and to present relevant earlier research on the subject.

The search process for relevant literature is iterative as in each search one learns more about the topic under investigation. It is worth of spending time on the design of the search, and save later on time on the actual analysis. This also improves the quality of the review. [15]

Porter et al. [16] propose enhancing the traditional literature review through research profiling. They state that "*This broad scan of contextual literature can extend the span of science by better linking efforts across research domains. Topical relationships, research trends, and complementary capabilities can be discovered, thereby facilitating research projects.*" Thus, this approach seems to suit very well for studying the research on digital games. Research profiling is made possible through modern search engines, electronic science databases and sophisticated text mining tools. These text mining tools are not merely meant for reporting purposes, but they allow the researcher to interact with the literature data in unprecedented ways. Thus, these tools are in a way Decision Support Systems (DSS) for researchers [3]. Table 1 summarizes the key differences between traditional literature reviews and research profiling.

Table 1: Comparison of traditional literature reviews and research profiling. Source: [16]

Traditional literature reviews	Research profiling
Micro focus (paper-by-paper)	Macro focus (patterns in the literature as a body)
Narrow range (~20 references)	Wide range (~20 – 20.000 references)
Tightly restricted to the topic	Encompassing the topic + related areas
Text discussion	Text, numerical, and graphical depiction

The conduct of research profiling can be considered as a problem solving process with a structured set of iterative phases. Borrowing from Simon's [19] seminal work, Porter and Cunningham [15] suggest the process to include the following phases and steps:

Phase A: Intelligence
1. Issue Identification
2. Selection of Information Sources
3. Search Refinement and Data Retrieval
4. Data Cleaning

Phase B: Analysis and Design
5. Basic Analyses
6. Advanced Analyses

Phase C: Choice
7. Representation
8. Interpretation
9. Utilization

In their article, Porter et al. [16] demonstrate more than a dozen ways how research profiling may be used to improve literature reviews. These are summarized in Table 2.

Table 2: Using research profiling in improving literature reviews. Source, adapted from: [16]

Depict the research *context* to target research efforts wisely
- observe related topics within the research domain
- observe related topics beyond the research domain
- gain a "big picture" view on the research activity
- at the "big picture" level, find intersecting interests

Understand the research *community*

- identify a range of information sources
- gain insight into how innovation is progressing from literature distribution patterns
- find active organizations and individuals whose research relates to one's own interests, particularly those working in different disciplines or research domains

Explore *topics* (techniques)

- map (graphically represent) topical interrelationships for a whole research area
- examine how the target topic meshes with other approaches
- generate research opportunities in combining topics, through mapping or in-depth probing
- examine trends to ascertain which topics are hot
- assess the research impact of particular topics
- zoom in to examine promising topics in depth.

CASE: PROFILING DIGITAL GAME RESEARCH

In this section we will depict our research profiling case on digital games. The motivation for this study stems from the other author's initiating doctoral studies on the brand equity [11, 20] of digital games. Neither of the authors have previous background as digital game researchers. Research profiling is an iterative process in which the search terms and understanding of the research field increases during the process [16]. Thus, even with careful design of the search it is difficult to control the founding [15]. In particular, for new researchers possessing scant initial knowledge of the field, it is, at the outset, challenging to start the search. On the other hand, entering researchers may have a more objective view on the field, which helps in seeing the forest from the trees.

Phase A: Intelligence

The first phase, intelligence, includes the identification of the issue, selection of information sources, search refinement and data retrieval as well as data cleaning. Porter [14] recommends writing down some basic questions to which the search results should answer. Search questions should lead the researchers to find the interesting issues of the research area. Research profiling should answer to questions such as "Who?", "What?" and "When?" [14]. For example, what are the main areas of science which study digital games? Who are the prolific authors? Which institutions conduct digital game studies? What scientific areas and disciplines they represent? What are the hot topics or trends in digital game research? When has digital game research been conducted? How has it changed over time?

We studied several science databases (ISI Web of Science, INSPEC, Abi/Infrom ProQuest, EBSCO) and noted that they each produce a different set of results based on their orientation and coverage. We made a choice to conduct our profiling study with one of the most well-known science databases, the ISI Web of Science (ISI-WoS). It is not specialized to certain areas, but covers science, social science as well as arts and humanities. For the sake of clarity and data integrity no other database was selected for the study, as science database contents are not standardized. The ISI-WoS covers more than 230 scientific disciplines and it includes records from over 22.000 journals, 12.000 conference proceedings, 5.500 Web sites and 5.000 books. Around 25 million cited references are added annually. It has more than 20 million users world-wide [21]. One of the limitations of the ISI database is that its coverage starts only from 1986. There has been digital game research already before that [17]. However, we are most interested to find out the latest trends in the past 5-10 years, and thus a year range from 1986-2006 was acceptable.

The root search words [13] were found by reading digital games literature, listing candidate terms, asking advice from digital game research experts, and testing and enhancing the search phrase continuously during the search design process. We wanted to have a broad set of results, although the majority of the hits (around 65%) could be found by using only the two most common words (and their variants) of video and computer games.

The final search phrase used was: (computer-game* or computer-gaming or video-game* or videogame* or video-gaming or videogaming or wireless-game* or wireless-gaming or digital-game* or digital-gaming or console-game* or console-gaming or handheld-game* or handheld-gaming or internet-game* or internet-gaming or web-game* or mobile-game* or mobile-gaming or online-game* or online-gaming or on-line-game* or on-line-gaming or reality-game* or reality-gaming or serious-game* or serious-gaming or ubiquitous-game* or ubiquitous-gaming or pervasive-game* or pervasive-gaming or virtual-game* or virtual-gaming or electronic-game* or electronic-gaming or arcade-game* or arcade-gaming or massively-multiplayer* or massive-multiplayer* or massively-multi-player* or massivemulti-player* or MMORPG* or multiplayer-game* or multiplayer-gaming or multi-player-game* or multi-player-gaming or first-person-shooter*) not (Nash-equilibria or equilibria).

The search was conducted on February 2, 2007 and it resulted in 2.136 records. The yearly division is presented in Figure 1 (excluding the few hits for year 2007). It should be noted that the results for year 2006 were still incomplete due to a delay in the registering of research in bibliographic databases. It can be seen from Figure 1 that research on digital games has been increasing constantly. Especially after 2003 there has been a major peak in the number of publications.

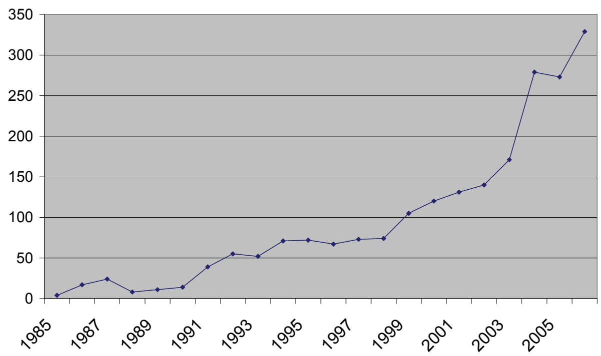

Figure 1. Game publications yearly (in ISI-WoS)

The sample includes records of different document types (see Table 3). Besides articles, we made a decision to include also the other types, as we found that they all appeared in journals (e.g. introductions to special issues). In our sample only the type 'article' has records that are from conference proceedings. Out of the 1733 articles, 258 (15%) are published in conference proceedings (mainly in Springer's series of Lecture Notes in Computer Science). We included also them in the analysis.

Table 3. Document types of the sample.

Document type	#	%
Article (incl. conf. articles)	1733	81.13 %
Meeting Abstract	108	5.06 %
Editorial Material	87	4.07 %
Book Review	73	3.42 %
Review	44	2.06 %
News Item	36	1.69 %
Letter	26	1.22 %
Note	18	0.84 %
Other document types	11	0.51 %
	2136	100 %

Next, to make the analysis possible, we saved the complete records of our ISI-WoS search results (including abstracts, not full-texts), and imported all 2.136 records to a science and technology mining software called the VantagePoint (see details in www.thevantagepoint.com).

The first and most important task after the data import is the cleaning of it field-by-field. Some of the fields are generally unambiguous, like the publication year, others need more pre-work. For instance the keywords provided by the authors have manifold variations. Thus, some of the keywords need to be combined to improve the validity of the analysis results. For example the keyword "MMORPG" should be combined with "MMORPG's" and "Massively Multiplayer On-line Role-Playing Games". Also the author names may have different variations which need to be combined. For example, there where 14 hits for a researcher named "Griffiths, MD" and 10 hits for "Griffiths, M", which proved to be the same person when checking the record details. The VantagePoint software has semi-automated intelligence (based on fuzzy logic or thesauri) to support the researcher in this. Thus, when cleaning e.g. the author affiliation field, the researcher may opt to conduct the process with the pre-built affiliation thesaurus, which automatically suggests combining e.g. "MIT" and "Massachusetts Institute of Technology" and other variations of it. The researcher, however, has the final authority before accepting the combinations suggested by the system.

As soon as the cleaning is completed, the data analysis may be started. The analyses (lists, matrices, charts and maps) can be produced extremely easily and fast, with a few button-clicks using fully-automated scripts. Besides illustrative results that can be used in reports, the science mining software offers to the researcher also very powerful interactive features to zoom-in and drill-down to the data.

Phases B & C: Analysis and Design & Choice

The analysis that follows contains basic statistics (lists of prolific terms), but also many elaborate profiles and visualizations, which we think are important and of interest to digital game researchers. Our analyses and the choices we have made for representing the data are meant to answer to the research questions phrased in the intelligence phase.

Subject categories and areas of science

The sample contains research from a respectable amount of disciplines, classified into altogether 182 different ISI subject categories. One article may belong to several subject categories. Due to the large spread, we wanted to group the research into larger wholes. At first we tried combining categories that had the same prefix (e.g. *Psychology, Applied* and *Psychology, Social*). After this merge, there were still 129 categories left. Yet, two disciplines came up that were significantly more represented in the sample: Computer Science (26% of the sample) and Psychology (25%). The third was Engineering (6%). To get a "birds-eye view" of the digital game research we wanted to group the disciplines further.

With the advice from Moya-Anegon et al. [12] we were able to find one classification that groups ISI categories in superior classes. This classification (http://www.uv.es/=serinves/v/anun/TablaAnep.pdf) is prepared by the Spanish ANEP agency (Agencia Nacional de Evaluación y Prospectiva de España, http://www.mec.es/ciencia/anep), and it suited well to our purpose. After grouping all subject categories into larger wholes, three major areas of science conducting digital game studies emerged (Figure 2). These areas are the Social Sciences, Law and Economics (30%), Health Sciences (29%) and ICT and Mathematics (25%). Also Arts and Humanities (6%) as well as Engineering (6%) were prominent. The rest (4%) were classified under "Others".

As digital game research spans also over the areas of science (one record may be classified e.g. both under

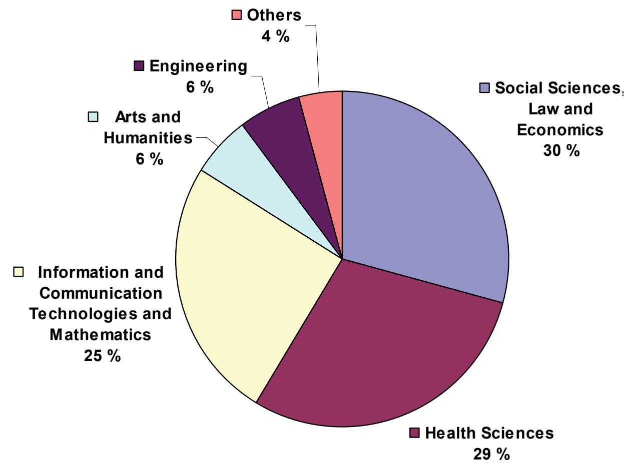

Figure 2. Digital game research by areas of science

social sciences and health sciences), we wanted to see how much of these areas of science overlap in the sample. A Venn-diagram helps to get a snapshot view of this [16]. The diagram (see Figure 3 below) shows that there is a considerable overlap between the Social sciences and Health sciences (190 records), as well as between ICT & Math and Engineering (92 records). However, ICT & Math and Engineering do not have many common records with the other two main areas – and none with Arts & Humanities.

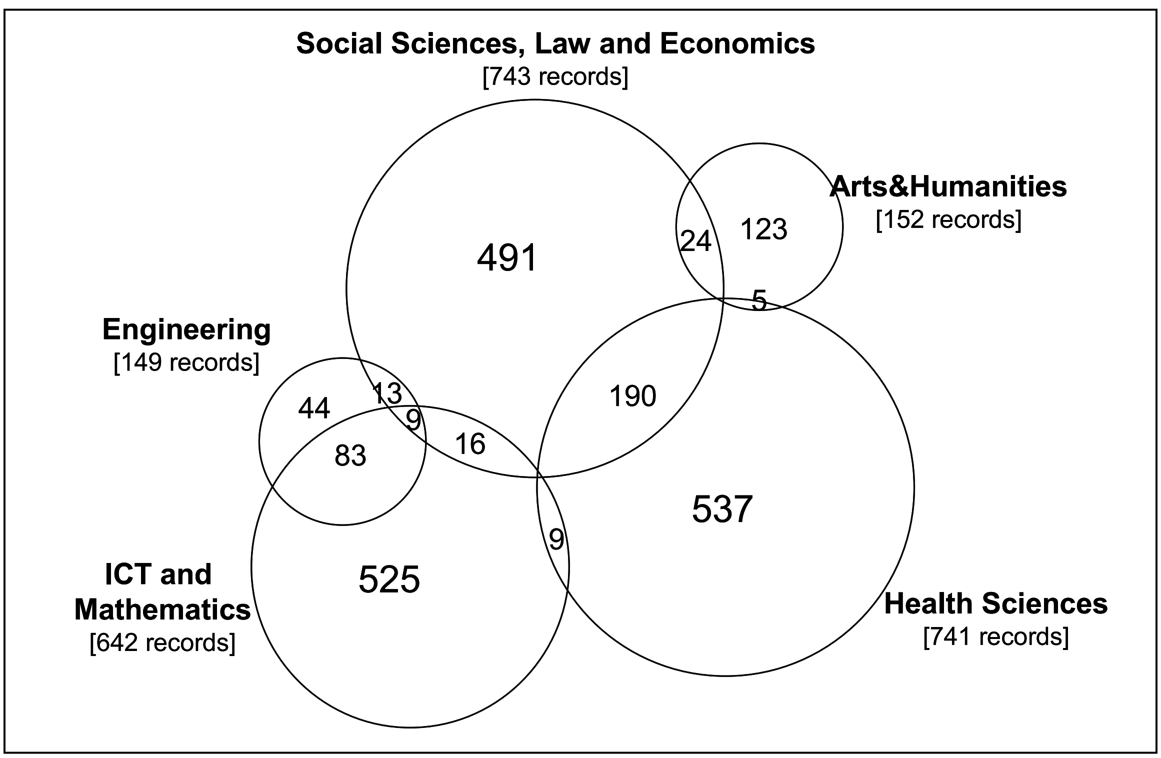

Figure 3: Venn-diagram on main areas of science conducting digital game research.

In Table 4 we have listed the largest single disciplinary categories of the sample. Studying only these top-10 categories represent 48% (1017) of the records of the sample. The total sum in the table is larger as one article may belong to several categories. Computer Science and Psychology dominate the list.

Table 4: Top-10 ISI Subject Categories

Subject category	#	% **
CS*, Theory & Methods	268	22 %
CS, Software Engineering	154	12 %
Psychology, Multidisciplinary	141	11 %
Psychology, Experimental	125	10 %
Communication	99	8 %
Psychology	98	8 %
CS, Artificial Intelligence	92	7 %
Psychiatry	90	7 %
Engineering, Electrical & Electronic	88	7 %
CS, Information Systems	83	7 %
	1238	100 %

* CS = Computer Science

** Note that the percentages in all tables refer to the *selection's total*, not the sample's total.

One way of characterizing the digital game research community is by studying how many times each article has been cited (see Figure 4). In this sample, 7 % (152 records) of the publications have 20 or more citations (of which 9 articles have more than 100 citations). In contrast, 76% (1.631 publications) of the sample have less than 5 citations. More than half (52%) of the publications have been never cited. On average, each publication is citing 23 references.

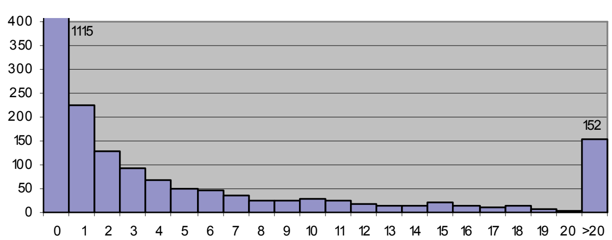

Figure 4: Publications presented by times cited.

Who are conducting digital games research?

In the sample almost one third (31%, 653) of the articles have one or more authors from the United States (see Table 5). The second place goes to United Kingdom with 206 publications. When inspecting those studies that the top-ten countries are responsible for, it amounts to 60% of the articles of the sample (or 83% if not counting those that do not have a definition for country in the database). When grouping the European countries together, it can be found that the Europeans have contributed in 562 articles (in 26%). USA is clearly in the first place in most categories. Besides its large population and strong research traditions, also the high volume of the domestic game industry may explain this interest. Also the UK and some Asian countries in the top-list have been very active in developing digital games, and this has had a great economic impact on their exports, too.

Table 5: Top-10 countries

Country of authors	#	% *
USA	653	48 %
UK	206	15 %
Germany	88	6 %
Canada	85	6 %
South Korea	73	5 %
Australia	65	5 %
Japan	56	4 %
Netherlands	53	4 %
China	44	3 %
France	43	3 %
	1366	100 %

The top-ten organizations conducting digital game studies are predominantly US universities. There is only one outside the US, which is the Nottingham Trent University from UK (See Table 6). However, the research is widely scattered as studying the articles of these top affiliations amounts only to 9.6 % (207) of the whole sample.

Table 6: Top-11 affiliations

Affiliation	#	%
Medical College of Georgia	26	12 %
Univ. of Texas	26	12 %
Harvard Univ.	24	11 %
Univ. of North Carolina	23	11 %
Univ. of Michigan	21	10 %
Nottingham Trent Univ.	18	8 %
Stanford Univ.	18	8 %
Univ. of Pittsburgh	16	7 %
MIT	14	7 %
Univ. of Illinois	14	7 %
Univ. of Washington	14	7 %
	214	100 %

Table 7 lists the most prolific authors. Again, when studying these authors' publications, it amounts only to 92 articles, representing 4.3% of the sample. This is due to the fact that many of the authors on this top-list are co-authors. Two clear groups, marked A and B, appear on the auto-correlation map of authors (see partial MDS-map in Figure 5). In group A, almost all authors are from the Medical College of Georgia, USA, and they study e.g. peripheral vascular diseases, and represent mostly the Health Sciences. Group B has both UK and US authors, and their major discipline is Psychology (social, applied and multidisciplinary).

Table 7: Top-10 authors

Author	#	%
Griffiths, M D	24	17 %
Treiber, F A	24	17 %
Davis, H	19	14 %
Anderson, C A	14	10 %
Funk, J B	13	9 %
Strong, W B	10	7 %
Kapuku, G K	9	7 %
Miller, S B	9	7 %
Harshfield, G A	8	6 %
Trenite, DGAKN	8	6 %
	138	100 %

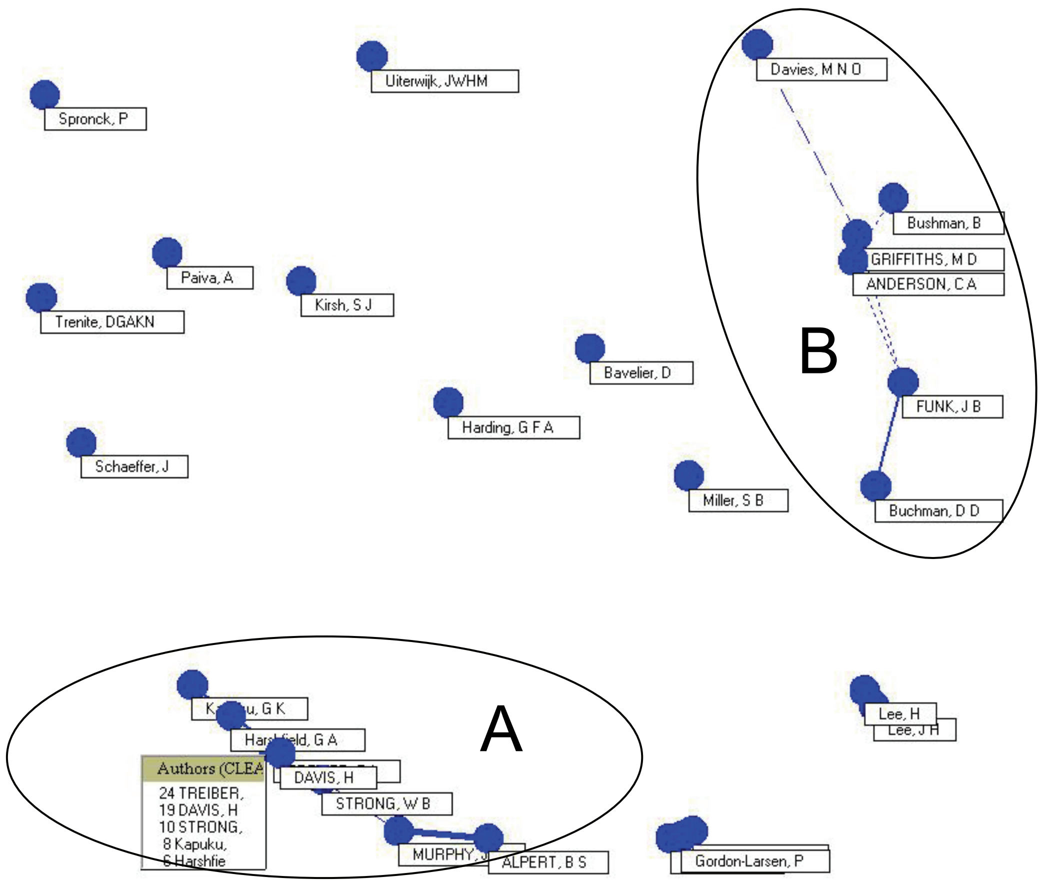

Figure 5: Auto-correlation map (partial selection) of prolific authors, based on multi-dimensional scaling.

The research of digital games is published in a large variety of journals. Table 8 lists the top-ten journals based on frequency. These journals represent 217 articles (10.2%) of the sample, which is indicative of the large variety of the journal titles.

Table 8: Top-10 journals

Journal	#	%
Cyberpsychology & Behavior	32	15 %
Forbes	26	12 %
Epilepsia	24	11 %
Psychophysiology	23	11 %
Electronic Library	21	10 %
Psychosomatic Medicine	21	10 %
Perceptual and Motor Skills	20	9 %
Pediatrics	19	9 %
Computer Graphics World	16	7 %
Journal of Adolescence	15	7 %
	217	100 %

What is being studied in digital games research?

Besides the game-related search terms, the most used keywords defined by the authors are "adolescents", "children" and "television" and various terms related to medical issues such as "blood pressure", "stress" and "cardiovascular reactivity" (see Table 9).

Table 9: Top-15 keywords (defined by authors)

Keywords (authors')	#	%
Video games	110	19 %
Computer games	84	14 %
Adolescents	47	8 %
Children	44	8 %
Television	43	7 %
Blood pressure	34	6 %
Internet	30	5 %
Stress	29	5 %
Computer	27	5 %
Game	24	4 %
Cardiovascular reactivity	23	4 %
Physical activity	23	4 %
Virtual reality	22	4 %
Aggression	20	3 %
Heart rate	20	3 %
	580	100 %

It is notable that such recent terms as the" Internet" and "Virtual reality" have climbed to the top-15 list of the whole sample. When selecting these top-15 keywords, altogether 385 (18%) articles are represented. Again, this echoes the large spread in the research topics. We will analyze later in Table 15 and Figure 8 the trends over time in these top keywords.

The ISI-WoS derives so-called Keywords Plus terms from the titles of *cited* papers, and processes these algorithmically to identify the most-commonly recurring words and phrases (see more details in http://scientific.thomson.com/free/essays/citationindexing/concept/). The most prolific Keywords Plus are listed in Table 10. Many of them are represented in Table 9, but also new terms such as "obesity" and behavior-related terms appear. These Keywords Plus represent 416 (19.5%) of the articles of the whole sample.

Table 10: Top-11 keywords (Plus)

Keywords (Plus)	#	%
Children	137	19 %
Behavior	96	13 %
Video games	94	13 %
Adolescents	91	13 %
Responses / reactivity	60	8 %
Performance	52	7 %
Television	46	6 %
Physical-activity	41	6 %
Obesity	39	5 %
Aggressive-behavior	37	5 %
Personality	35	5 %
	728	100 %

Profiling research on main areas of science

Due to the multidisciplinarity of digital games research, the top-ten lists just presented do not well reveal the prolific terms *inside* each area of science or main discipline. Consequently, we studied the sample in groups. Table 11 illustrates the sample separately under the Social Sciences, the Health Sciences and ICT & Math and Engineering. Engineering was combined to ICT due to the large overlap of these areas, see the Venn-diagram earlier). The analysis in Table 11 is based on 91% of the sample's articles. In Table 12, we have done the same sector-specific analyses with studying the two largest (consolidated) disciplines separately: Computer Science and Psychology. These two disciplines represent 50% of the sample's articles.

Table 11: Profiles of main scientific areas conducting games research

	Social Sciences, Law and Economics [743]	Health Sciences [741]	ICT, Mathematics and Engineering [699]
Key disciplines	Psychol., Multidisc. [141] Communication [99] Psychology [98] Psychol., Experim'l [79] Psychol., Develop'l [72]	Psychol., Experim'l [125] Psychiatry [90] Psychology [82] Pediatrics [81] Clinical Neurology [80]	Comp Sci, Theory & Methods [268] Comp Sci, SE [154] Comp Sci, AI [92] Engineering, Electrical & Electronic [88] Comp Sci, IS [83]
Key countries	USA [256] UK [76] Canada [33] Germany [26] Australia [24]	USA [285] UK [64] Canada [43] Australia [29] France [23]	USA [169] UK [73] South Korea [59] Germany [43] China [35]
Key affiliations	Univ Texas [15] Nottingham Trent U [14] Iowa State Univ [12] Med Coll Georgia [9] Univ Illinois [9] Univ Missouri [9]	Med Coll Georgia [24] Harvard Univ [22] Univ N Carolina [15] Univ Pittsburgh [15] Stanford Univ [10]	MIT [11] Univ Alberta [10] Univ Maastricht [10] Georgia Inst Technol [9] Kyungpook Natl Univ [9] Univ Texas [9]
Key authors	Griffiths, M D [18] Anderson, C A [14] Funk, J B [9] Treiber, F A [9] Davis, H [8]	Treiber, F A [22] Davis, H [18] Strong, W B [10] Miller, S B [9} Harshfield, G A [8] Kapuku, G K [8] Trenite, DGAKN [8]	Mauve, M [6] Moltenbrey, K [6] Nussbaum, M [6] Paiva, A [6] Schaeffer, J [6]
Key journals	CyberPsychol. Behav [32] Forbes [26] Psychophysiology [23] Psychosom. Med [21] J. Adolesc [15]	Epilepsia [24] Psychophysiology [23] Psychosom. Med [21] Percept. Mot. Skills [20] Pediatrics [19]	Electron. Libr [21] Comp. Graph. World [16] Commun. ACM [13] Computer [13] Comput. Graph.-UK [10] IBM Syst. J [10]
Top keywords (authors') (search words not included)	Aggression [18] Adolescents [17] Stress [15] Sex-differences [14] Exposure [13]	Adolescents [38] Television [37] Children[36] Blood pressure [34] Stress [29]	Internet [9] Virtual environment [8] Animating [7] Virtual reality [7] Education [6] Human comp interact. [6] User interface [6]
Top keywords (Plus) (search words not included**)**	Children [70] Behavior [68] Adolescents [44] Performance [30] Aggression [26] Personality [26] Responses / reactivity [26]	Children [85] Adolescents [56] Responses / reactivity [47] Physical-activity [36] Behavior [34] Obesity [34]	Model [16] System [9] Performance [8] Internet [7] Behavior [5] Design [5]

Table 12: Profiles of two main (consolidated) disciplines conducting games research

	Computer Science [555]	**Psychology [528]**
Key disciplines	Comp Sci, Theory & Methods [268] Comp Sci, Software Engineering [154] Comp Sci, Artificial Intelligence [92] Comp Sci, Information Systems [83] Comp Sci, Hardware & Architecture [51] Engineering, Electrical & Electronic [38] Comp Sci, Interdisc Applications [26] Telecommunications [26] Comp Sci, Cybernetics [24]	Psychology, Multidisciplinary [141] Psychology, Experimental [125] Psychology [98] Psychology, Developmental [72] Psychology, Social [69] Psychology, Applied [66] Psychology, Biological [58] Psychology, Clinical [53] Communication [42]
Key countries	USA [129] UK [56] South Korea [53] Germany [38] China [28]	USA [195] UK [42] Canada [28] Germany [22] Australia [21]
Key affiliations	MIT [11] Univ Alberta [10] Univ Maastricht [10] Kyungpook Natl Univ [9] Univ Michigan [8]	Nottingham Trent Univ [13] Iowa State Univ [11] Med Coll Georgia [10] Univ Texas [10] Univ Missouri [9]
Key authors	Mauve, M [6] Moltenbrey, K [6] Nussbaum, M [6] Paiva, A [6] Schaeffer, J [6]	Griffiths, M D [19] Anderson, C A [14] Treiber, F A [19] Davis, H [9] Funk, J B [7] Miller, S B [7]
Key journals	Comput. Graph. World [16] Commun. ACM [13] Computer [13] Comput. Graph.-UK [10] IBM Syst. J [10]	CyberPsychol. Behav [32] Psychophysiology [23] Psychosom. Med [21] Percept. Mot. Skills [20] J. Adolesc [15]
Top keywords (authors') (search words not included)	Animating [7] Virtual environment [7] Neural network [6] Human computer interaction [5] Virtual reality [5]	Adolescents [18] Aggression [16] Cardiovascular reactivity [16] Stress [15] Blood pressure [13] Heart rate [13]
Top keywords (Plus) (search words not included**)**	Model [13] Internet [7] Performance [5], System [5] Behavior [4], Design [4], Environment [4], Index [4], Information-technology [4], Validity [4], Workplace [4]	Children [60] Behavior [59] Adolescents [36] Performance [33] Responses / reactivity [29]

When? Trends in time

In order to find out the trends over time in research we grouped the sample in 5-year periods. First, we study how the main areas of science have developed since 1987 in 5-year periods (this analysis includes 98.6% of the sample). Figure 6 below shows that all areas represent considerable linear growth, but the area of ICT & Mathematics seems to show even an exponential growth: the number of articles has surged up to 482 in the latest period as compared to 107 in the period before that.

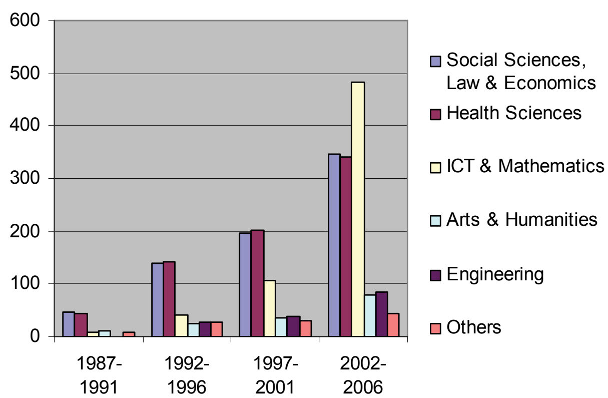

Figure 6: Trends in research publications of science areas (including conference articles)

To examine the reasons behind this trend we drilled down to the subject categories belonging to ICT & Math, and found the most growing ones (see Table 13, which lists all categories with more than 5 hits). Several categories, mainly in Computer Science, show a radical increase in publications between the last two 5-year periods, even a 1614% growth.

Table 13: Trends in ICT & Math's largest disciplines

Subject Category	1997-2001	2002-2006	Growth
CS, Theory & Methods	14	240	1614 %
CS, Software Engineering	36	106	194 %
CS, Artificial Intelligence	16	68	325 %
CS, Information Systems	18	53	194 %
Telecommunications	13	35	169 %
CS, Hardware& Architec.	13	32	146 %
Information Science & Library Science	9	33	267 %
CS, Interdisc. Applicat.	8	14	75 %
CS, Cybernetics	5	17	240 %
OR & MS	5	7	40 %

When studying these categories in more detail, we found that much of the rise is due to conference proceedings (Springer's Lecture Notes e.g. in Computer Science). In the whole sample, ICT & Math was the only area which had more than 2 conference articles in the sample, altogether 256. We are not aware what the factors are behind this disparity. However, in order to make the trends more comparable, we present the comparison chart anew *without* the conference articles (Figure 7). It still appears that ICT & Math has grown at a larger pace than any other area.

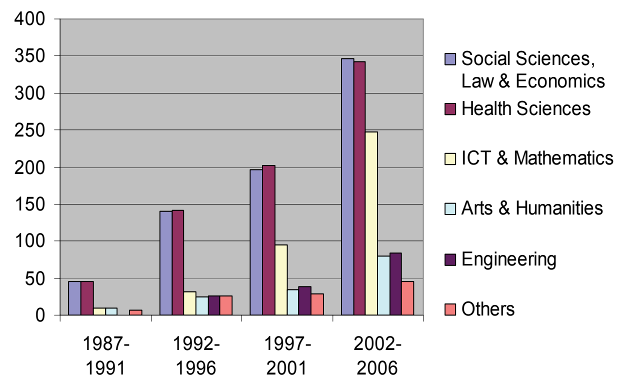

Figure 7: Trends in research publications of science areas (only journal articles)

We calculated the growth-% between the last two 5-year periods of each area. The statistics in Table 14 below confirm that ICT & Math has indeed grown fastest, with 160%. The second fastest growing area is Arts & Humanities, with 129%.

Table 14: Growth of main areas of science between two 5-year periods of 1997-2001 and 2002-2006.

Area of science	Growth
ICT & Mathematics	160 %
Arts & Humanities	129 %
Engineering	115 %
Social Sciences, Law & Economics	77 %
Health Sciences	69 %
Others	55 %

Next, we study the trends in authors' keywords. It can be seen from Table 15 that the issues related to 1) adolescents and children, 2) media (television, computers and the internet) and 3) health have been important throughout the last 15 years of digital game research. The years before 1992 are not included in the table as the ISI-WoS sample reports only few keywords before that time. When presenting these numbers in stacked bars summing up to 100%, one finds that the health related keywords, i.e. heart rate, cardiovascular reactivity, stress and blood pressure, have relatively diminished in importance, and given up space for other ones, like the Internet (see Figure 8). This is an indicator of a shift in the research focus.

Besides author-defined keywords, it is possible to study also the titles of the research papers by utilizing Natural Language Processing (NLP) to parse words and noun phrases from the titles. We conducted a title analysis separately in each area of science, and in two "time slices" in the last 10 years. The results are presented in Tables 16-18.

Table 15: Trends in Top-15 keywords (authors').

Keywords (authors')	1992-1996	1997-2001	2002-2006	Whole sample
Video games	11	25	73	110
Computer games	8	24	50	84
Adolescents	2	15	29	47
Children	6	18	17	44
Television	1	15	26	43
Blood pressure	14	8	9	34
Internet	1	8	21	30
Stress	11	7	9	29
Computer	1	4	22	27
Game	0	4	19	24
Cardiovascular reactivity	13	5	3	23
Physical activity	2	7	14	23
Virtual reality	1	8	13	22
Aggression	1	6	13	20
Heart rate	10	1	6	20

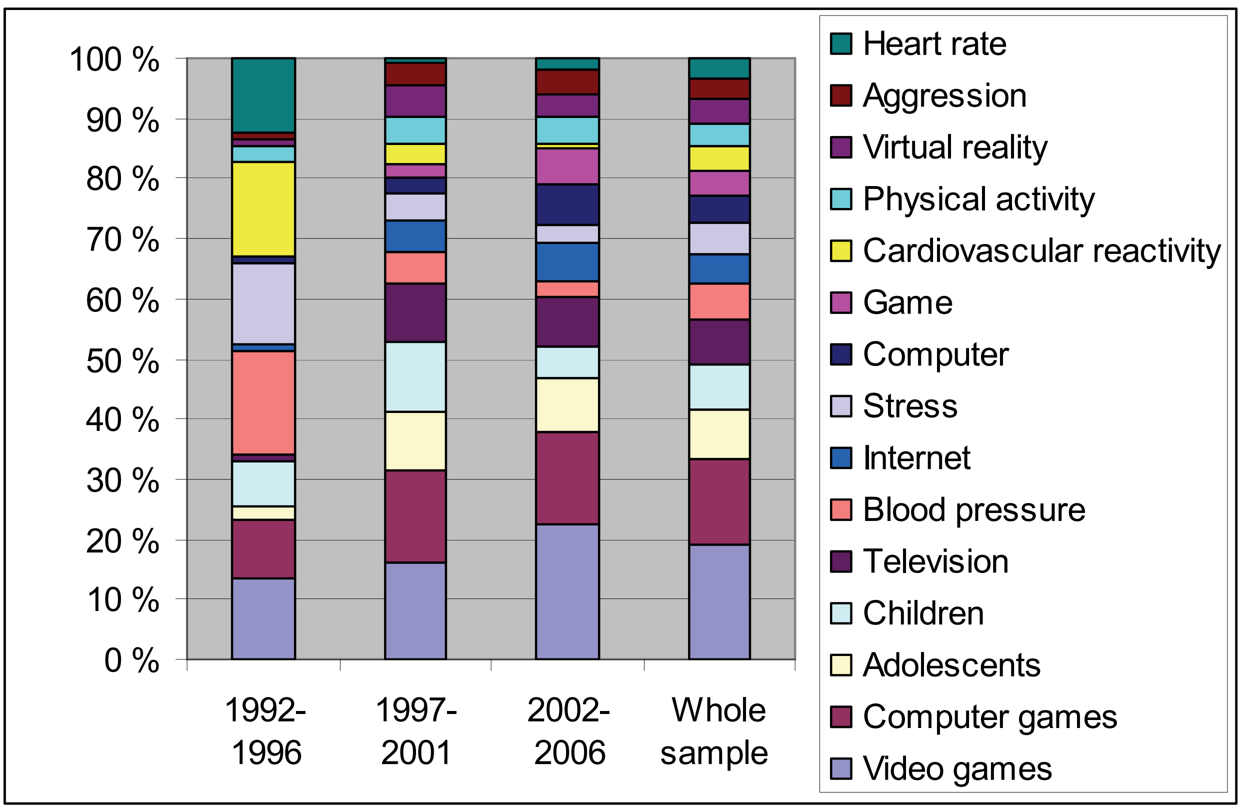

Figure 8: Trends of authors' keywords (the top-15 keywords of the whole sample are presented in this graph)

Table 16: Most used title words and phrases (NLP) of ICT & Math in two latest time periods

ICT & Mathematics

1997-2001 [107]	2002-2006 [482]
Computer games [8]	Computer games [33]
Online / Internet games [5]	Online / Internet games [18]
Game [4]	Game [16]
Video games [4]	Video games [11]
Development [2]	Mobile games [10]
Distributed interactive media [2]	Application [8]
Engagement [2]	Interactive computer / video games [7]
Multiplayer games [2]	Virtual environment [7]
New approach [2]	Effects / impact /influence [6]
Sound [2]	Multiplayer games [6]
Video / Computer game playing [2]	Multiplayer online games [6]
Virtual environment[2]	

Table 17: Most used title words and phrases (NLP) of Social Sciences in two latest time periods

Social Sciences, Law & Economics

1997-2001 [196]	2002-2006 [347]
Video games [25]	Effects / impact / influence [34]
Effects / impact / influence [22]	Video games [26]
Computer games [19]	Computer games [22]
Children [13]	Violent video / computer games [19]
Aggression [9]	Video / Computer game playing [17]
Adolescents [7]	Aggression [12]
Gender [6]	Children [11]
Violent video / computer games [6]	Online / Internet games [11]
Relationship [5]	Adolescents [8]
Video [5]	Relationship [8]
Video / Computer game playing [5]	Violence [7]
Youth [5]	Aggressive behavior [6]
Aggressive behavior [4]	Learning [6]
Young children [4]	

Table 18: Most used title words and phrases (NLP) of Health Sciences in two latest time periods

Health Sciences

1997-2001 [203]	2002-2006 [342]
Children [22]	Effects / impact / influence [28]
Effects / impact / influence [20]	Children [26]
Video games [13]	Video games [25]
Adolescents [10]	Adolescents [24]
Computer games [10]	Computer games [22]
Video / Computer game playing [9]	Physical activity [15]
Use [8]	Video / Computer game playing [13]
Youth [8]	Development [10]
Physical activity [7]	Relationship [10]
Appraisals [4]	Use [8]
Cardiovascular response / reactivity [4]	Youth [8]
Epilepsy [4]	Adults [7]
Interactive computer / video games [4]	Patients [7]
Relationship [4]	Association [6]
Rest [4]	Computer [6]
Results [4]	Violent video / computer games [6]
School [4]	Gambling [5]
Video-game epilepsy [4]	Results [5]
Violence [4]	Role [5]
Virtual reality [4]	Television [5]
	Television viewing [5]

Finally, in Figure 9 we present the yearly trends of all key terms (number of publications, subject categories, authors, affiliations, countries, journals, outlets, keywords). For example, the trend Authors shows how many *different* authors have published digital game research in each year. In Outlets, both journals and conference sources are depicted. These trends have been condensed in 5-year sequences, showing the averages of each five year period (Figure 10).

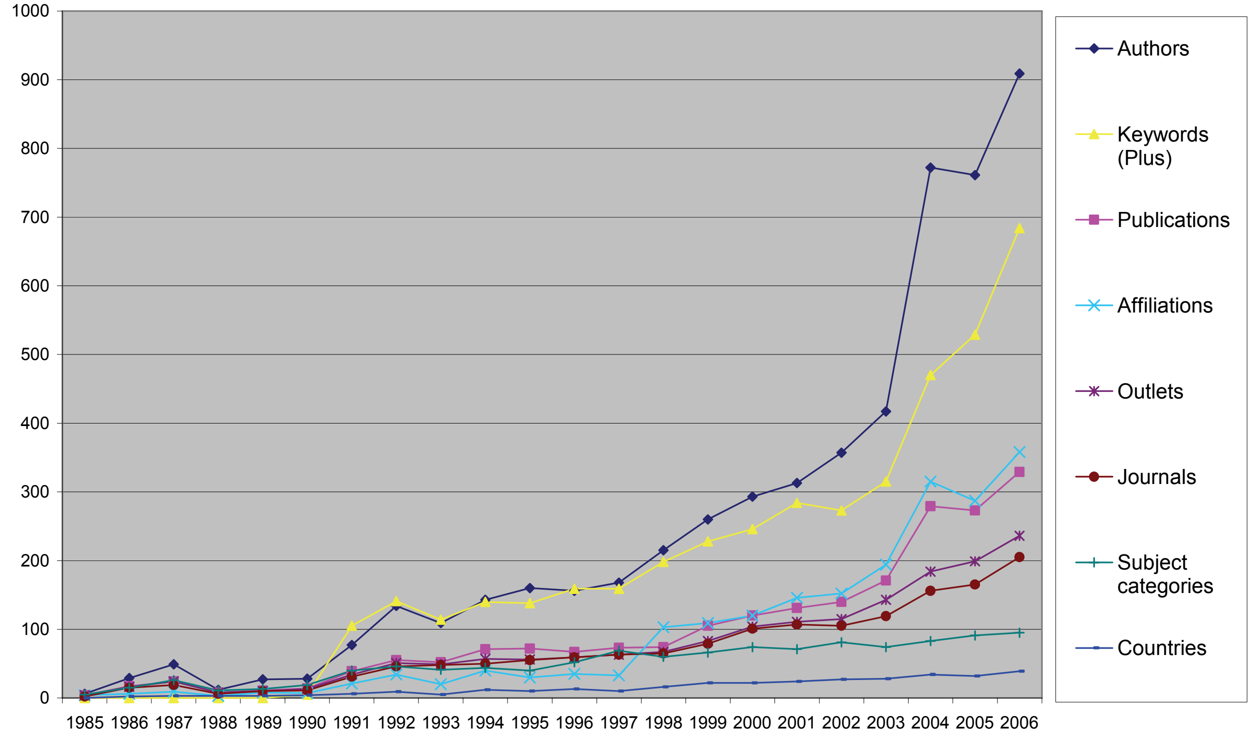

Figure 9: Trends of key games research indicators between 1985-2006 (the lines depict the number of *different* indicators in each year)

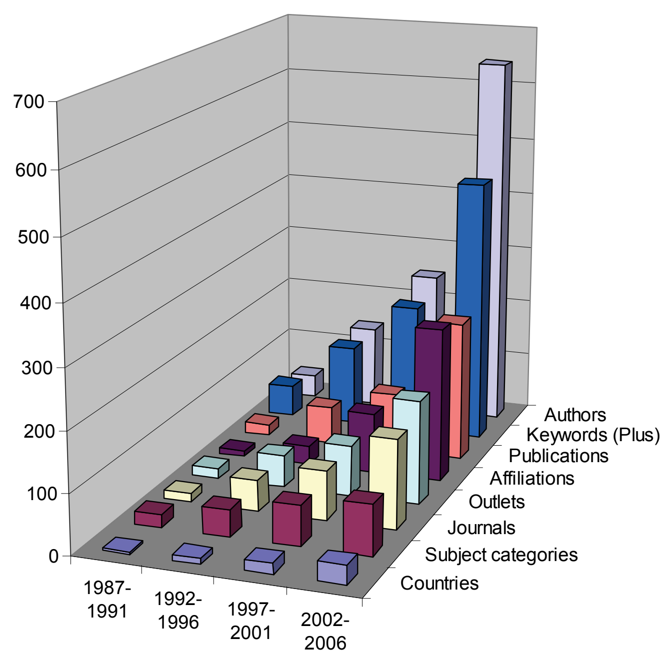

Figure 10: Trends of key indicators (the bars depict the yearly statistics averaged over a 5-year period)

DISCUSSION

The combination of the great market value and increasingly powerful technologies is a frequent starting point in a substantial amount of writings on digital games [5]. During the mid 1980's the computer game business was suffering from economical crisis, there was an overproduction of low-quality games and the games were dumped with very low prices which lead many companies to severe problems and to a consolidation of the industry [17].

Regarding the research on digital games, this study shows that there has been three points in time when the research has started to grow, each time at a larger pace than before (see Figures 9 and 1). Firstly, in the beginning of the 1990's, and secondly, around year 1998. The third peak is after 2003 when the research has really surged up: many indicators in Figure 9 show really considerable increases. The first rise happened at the time when the new wave of handheld gaming started with devices such as Nintendo GameBoy. The second peak may partially be explained by technological innovation which influenced to the interest in conducting research on digital games. Towards the end of the 1990's the gaming experience improved rapidly due to the development of better 3D graphics and thus, better games. The sales of PC's and cartridge video games systems grew exponentially [17]. There were also new technological platforms such as the mobile phones made available. Last but not least, the Internet was commercialized in mid 1990's, which gradually started to show in online game development. These same reasons could probably explain the rise in research after 2003, when second generation consoles such as the Sony Playstation2, Microsoft Xbox and Nintendo GameCube were launched to the market. Moreover, the original hype over the internet had turned into it being a serious platform for the game industry. All these technological improvements probably contributed to the growth of research in digital games.

Naturally, there are many more reasons to the increase in the research interest than enhanced technology and growing business figures. Digital games are used also for other purposes than entertainment. Besides being helpful in the treatment of various health disorders, games are also increasingly used in learning and education. Children and adolescents will presumably still remain to be a subject of active research in future. The youth's new modes of socialization via the online multi-player games and virtual worlds are certainly inspiring new streams of research. Also the recent advancements in the combination of various sporting activities and digital games are certainly reflected e.g. in health studies.

Digital games have attracted researchers from new disciplines constantly throughout the whole period of digital game research we studied. This is also reflected in the growth of the other indicators (different journal titles, keywords etc.). The field has also become more and more international. By 2006, research was conducted already in 53 different countries all over the world, and a way more than in 1.000 different affiliations. The multidisciplinarity of the research is really showing off in these figures.

CONCLUSIONS AND FUTURE RESEARCH

The aim of this paper was to profile the literature found from the ISI Web of Science on digital games. We used sophisticated text mining tools to conduct the analysis. Our main results show that 1) the amount of research on digital games is increasing rapidly, 2) digital game research is spreading steadily to new scientific disciplines and to new countries, 3) the main areas of science conducting digital game research are the Social Sciences, Law and Economics, the Health Sciences and the ICT and Mathematics, and 4) the fastest growing areas are the ICT and Mathematics as well as Arts & Humanities.

We hope that the results of this study would be of interest to the digital game researchers. It is our attempt to portray the research domain in "hierarchies" as called for by Bryce and Rutter [4]. Consequently, we think that this study could be a quick way to get a "big picture" of the digital game research, and thus serve as a complement to the books consisting of selected multidisciplinary papers [e.g. 15, 16].

As in any other research, there are limitations to this study. First of all, we analyzed only the records from the ISI-WoS database. Even though ISI-WoS is the "gold standard" by which some governments (e.g. in USA, UK, Australia) evaluate their national R&D performance [15], the database is not comprehensive. It probably depicts an under-represented picture of the research in education and humanities, and concurrently, has an excellent coverage among others on health related studies. Ideally, we could have fused the search results from several databases, but for the sake of clarity and data integrity (as science database contents are not standardized), we chose to conduct this study using only ISI-WoS. Secondly, we were not able to drill-down very deep in the present analysis (partially due to space restrictions). Thirdly, the nature of the iterative search and learning process leaves room for possible errors in the profiling process.

We have recently continued this profiling research by drilling down deeper into the data [4]. Specifically, we looked for the studies that have been made from a business or management related perspective. In the future, we plan to expand the search to other databases, such as the INSPEC or ProQuest.

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