International Journal of Music Science, Technology and Music Art
(IJMSTA) 1(1): 24-30, Music Academy "Studio Musica", 2019 ISSN: (Online)

Sound and Music Computing in Higher Education

F. Avanzini, A. Baratè, G. Haus, L.A. Ludovico✉, S. Ntalampiras, G. Presti

Laboratorio di Informatica Musicale (LIM), Dipartimento di Informatica, Università degli Studi di Milano, via Celoria 18, 20133 Milano, Italy
✉ Corresponding author: ludovico@di.unimi.it

Abstract

The context of education of sound and music computing is complex, mainly due to its multidisciplinary nature and the consequent difficulty of fitting it into the traditional, discipline-oriented focus of most university level studies. Sound and music computing does not simply embrace technological issues, rather it requires a deep understanding of artistic, social, cultural, economical, and juridical aspects. In this paper, we compare current higher education initiatives worldwide by administering a suitably-defined on-line survey. By analysing the collected data, we investigate how SMC subjects are perceived and, consequently, propose a revision of the guidelines in SMC education previously identified by the scientific community.

Keywords: sound, music, computing, higher education, academia.

Received on 17.09.2018, accepted on 30.10.2018, published on 07.01.2019

doi: https://doi.org/10.48293/IJMSTA-46

1. Introduction

The discipline known as Sound and Music Computing (SMC) is rapidly gaining interest in the industry, due to its multiple relationships with multimedia production and fruition, entertainment, and advanced technological devices.

About 10 years ago, internationally renowned experts authored a detailed report titled "A Roadmap for Sound and Music Computing", with the aim to identify, characterize and propose strategies for tackling the key research challenges that SMC was expected to be facing in the next ten to fifteen years [1]. The roadmap foresaw that, by 2020, music would have become a commodity as ubiquitous as water or electricity, and its content and the related activities would have promoted new business ventures, which in turn would have bolstered the music and cultural/creative industries. Such a document had the merit of arousing interest within the scientific community, eliciting, on the other side, some critical reactions [2]. Similarly, the 2007–2010 IRCAM research plan [3] was released in order to declare short, medium, and long-term goals, thus identifying the vision and the future directions for research at IRCAM.

An important role was also played by the IEEE Technical Committee on Computer Generated Music (1992-2013), supported by the IEEE Computer Society, which contributed to the definition of IEEE and ACM curricula in the SMC area.

The mentioned reports and initiatives covered heterogeneous research areas, such as sound analysis/synthesis, physical models, sound spatialization, computer-aided composition, and interdisciplinary transversal themes concerning different levels of music representations.

In the meanwhile, new approaches and technologies appeared (e.g., a more pervasive use of augmented and virtual reality and deep learning), which should encourage an update to these 10-years-old guidelines. Nevertheless, the essence of such initiatives remains: the necessity to stimulate a fruitful interaction among culture, science and industry. In this sense, the role played by academia is fundamental.

SMC is considered a promising and constantly evolving field, from a technological, cultural, and occupational point of view. Are we ready to train highly specialized experts, who necessarily should be able to interact with people from other domains? What are the competences and skills that industry and academia are expecting from them? How should an "ideal" university curriculum be conceived to foster these goals?

These research questions can be answered from two different points of view:

(i) Analyzing the differences among current SMC courses and the situation 10 years ago, also pointing out the trends followed by international institutions such as universities and research centers;
(ii) Gathering information from current and former students, experts, and people involved for various reasons, in order to assess the perceived effectiveness of higher education initiatives in the SMC field, as well as their expectations from academia.

The former issue was treated by conducting an investigation at a worldwide level. Concerning the latter, we distributed an on-line survey in Italy, considering this geographical region as representative of the European area due to the common educational structure after implementing the EU directives.

This paper, an extension of the work presented at the 5th International Conference on New Music Concepts (ICNMC 2018) [4], is structured as follows: Section 2 will describe the initial context for our investigation, Section 3 will propose a commonly accepted body of knowledge, Section 4 will review higher education courses in the SMC field, Section 5 will discuss the results emerging from the survey about SMC-related subjects knowledge and expectations among students, experts and enthusiasts, and, finally, Section 6 will draw our conclusions.

2. Context

The roadmaps mentioned in Section 1 emphasized the need for a tight link between SMC education and research, and called for a major effort in developing higher-education programs. Meanwhile, the implementation of the *Bologna process* in European countries has progressed, and the EHEA (EU Higher Education Area) has evolved towards a common structure of degrees [5]. This context and the related trends should be acknowledged in shaping SMC educative initiatives.

This field presents a number of relationships with apparently far domains, ranging from financial issues (e.g., the automatic recognition of playlists from the analysis of audio streams to distribute incomes among right owners) to cultural aspects (e.g., the revivification of traditional archives using technologies). Consequently, SMC education should embrace a number of study subjects that go beyond computer-based techniques and technical approaches.

Employability of graduates should be one of the concerns of any higher-education program. Training should enhance employability of graduates by providing them with complementary and transferable skills aimed at facilitating their flow into the job market. SMC research has wide applicative implications, thus strong links with industry should naturally arise in training programs. Industrial partners should be involved in training programs, with the aim of broadening as much as possible skills related to technology transfer and entrepreneurship, thus widening the career prospects of students.

The SMC research community is a small one. Therefore, the issue of SMC training must be situated in the broader context of neighboring and/or larger and/or more established academic disciplines. The latter question is relevant at all degree levels. Within more basic and general undergraduate degrees, topics related to SMC can still be successfully employed for educational purposes in foundational courses (e.g., insert elements of audio programming on a mobile device in a first-year Java programming course). Within more specialized degrees, such as Master or Ph.D. courses, SMC topics can be relevant to a number of related disciplines (HCI, robotics, etc.).

3. Defining a Body-of-Knowledge

The SMC Roadmap [1] contained preliminary work finalized at defining a set of "content areas", meant to constitute core academic topics on which courses (or course modules) in SMC may be built. This work should now be revised in the light of recent trends, and should be expanded and consolidated by the scientific community in order to define the Body-of-Knowledge (BoK) needed for an undergraduate or graduate SMC curriculum. For instance, sound design has been shifting and enlarging its scope to those contexts and applications where interactivity is of primary importance, thus originating a new discipline known as sonic interaction design [6]. Also the novel field of Unconventional Computing (UC), that aims to develop new types of computers, such as harnessing biological media to implement new kinds of processors, offers new possibilities to SMC [7].

BoK guidelines are available for more established fields. A relevant example is provided by the curricula recommendations by ACM which, starting in the 1960's [8], has been working with leading professional and scientific computing societies in various efforts to establish international curricular guidelines for undergraduate and graduate programs in Computer Science [9], Computer Engineering, Information Systems, Information Technology, and Software Engineering.

Defining such a BoK for SMC curricula is a long-term goal which requires a coordinated effort by the scientific community. The BoK should answer such questions as: What are core skills that an SMC graduate can exploit in the job market? What are the core topics that need to be present in a degree in our discipline? How can these be mapped into degree structures? How may SMC topics be applied to neighboring and more established academic disciplines? What are SMC referential textbooks?

Related to this latter point, it should be noted that almost no foundational textbooks in SMC were available in 2007. A milestone dating back to 1996 and covering all aspects of computer music was the Computer Music Tutorial book [10]. Another notable exception, and a reference example, was the Digital Audio Effects book [11], now in its second edition (the first edition was released as early as 2002): it presents the state of the art in the field, involves leading researchers, includes extensive code examples (in MATLAB), has been and is still widely used for teaching.

Ten years later the situation has changed to some extent. Many excellent textbooks have been published and are in use for teaching. With no claim of being exhaustive, we can cite some examples regarding physically-based sound modeling [12], sound design [13], sonification [14] and sonic interaction design [15], machine learning for audio [16], music processing [17, 18].

4. SMC Higher Education Courses

Appendix A of the SMC Roadmap [1] presented a survey of existing courses and curricula around the EU, with the aim of analyzing trends in SMC education. The document collected relevant data for both single courses and entire curricula centered on SMC, covering 170 courses and 40 curricula across 15 European countries.

It is worth analyzing how the situation has changed in recent times. For this reason, we decided to conduct a new survey in order to provide an updated picture of higher education courses for SMC. Our analysis takes into consideration 22 undergraduate and graduate courses implemented by leading institutions worldwide. Between 2007 and 2017, many subjects not only changed their name, but – more importantly – their scope and goal, too. Thus, the original clustering needs to be slightly adjusted to compare the two *corpora*. Since these differences may lead the reader to biased observations, a 10% confidence bar was added over the plot in Figure 1 to minimize this effect.

The identified clusters, followed by examples of the corresponding subjects, are:

- C1. *Acoustics* – Acoustics of musical instruments, room acoustics, acoustic physics;
- C2. *Audio signal processing and modeling* – Systems, sampling and quantization, spectral and time-spectral representations, digital filters, models for sound synthesis, physics-based modeling, digital audio effects, spatial sound and virtual acoustics;
- C3. *Hardware and software systems* – Sensors and actuators, real-time systems, output devices, software platforms, software engineering;
- C4. *Interaction and design of multimodal interfaces* – Performance analysis, emotion and expression in music performance, computational models and control of music performance, multimodal perception and action, gesture and multisensory analysis and synthesis, representations of multisensory data, control mappings and interaction strategies, evaluation of interaction models, digital and virtual musical instruments, interactive performing arts, interactive installations, education, entertainment, multimedia and new media, therapy and rehabilitation;
- C5. *Music information retrieval and sound analysis* – Including: auditory-based audio signal processing, perceptual coding, content-based audio processing and audio descriptors, content description/transmission languages, content-based transformation, feature extraction/classification, automatic transcription, music information retrieval, computer assisted composition;
- C6. *Systematic musicology* – Music semiotics, score analysis, computational models for music analysis;
- C7. *Music perception and cognition* – Psychoacoustics, music perception, computational approaches and models, sound-based cognition, music cognition, artificial intelligence;
- C8. *Sound design and auditory display* – Auditory warnings, sound in interaction design, sonification, sound design.

Figure 1 shows some surprising effects, such as the significant reduction of topics like music information retrieval and audio signal processing, conversely promoting other fields and making curricula more balanced. A possible explanation is that the in-depth theoretical investigation of the past is now leaving room, in terms of resources, to engineering and implementation aspects. Additional considerations are postponed to the next section. Please note that some theoretical and technological evolutions, envisioned in the Roadmap just as research trends under development, matured in the last decade. These include novel methodologies for systematic musicology (C6), machine learning and deep learning (C5 and C7), interactive sound for virtual and augmented reality (C4). We discuss in the detail these trends in the next section. Other emerging trends, mentioned but not deeply investigated by the Roadmap, concern music-oriented biomolecular automata (C3), and intersections with neurosciences (C7). It is worth underlining that the 2007 survey deliberately ignored some areas supposedly not relevant in SMC, being either too general or too far from a strict vision of the domain. Nevertheless, nowadays they are considered key subjects for the comprehensive education of an SMC expert. Additional subject areas may include:

- C9. *Music and sound technology*, dealing with multimedia-oriented general-purpose technologies, like MIDI, music coding approaches, and mobile app programming;

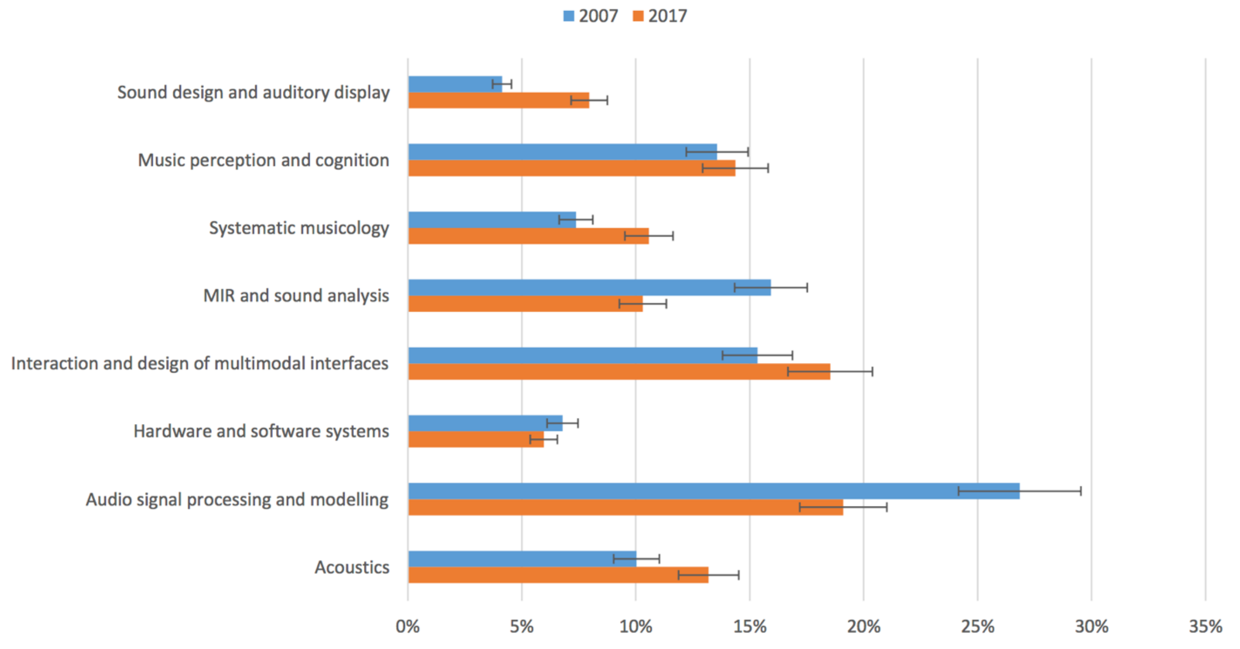

Figure 1. Current balance among core SMC topics and background disciplines.

- C10. *Audio production and post-production*, investigating such processes with the aim of improving available software tools and being able to conduct a more informed analysis of audio signals;
- C11. *Communication, multimedia publishing and law*, providing a market-oriented vision of SMC activities;
- C12. *Sociology of music*, focusing on social aspects of musical behavior and the role of music in society;
- C13. *Music theory, composition and instrument studies*, providing musical training and knowledge;
- C14. *Computer science core subjects*, aiming to improve basic IT skills and knowledge;
- C15. *Math, physics and statistics*, strengthening the foundations of the STEM (Science, Technology, Engineering and Mathematics) area where students often exhibit gaps in their previous knowledge.

From this revised list of skills and competences, the richness of the expected education for an SMC expert clearly emerges. Figure 2 shows the balance of clustered subjects including the areas listed above. Nowadays, mastering only topics closely linked to SMC fields is not enough, rather it is necessary to have multiple skills and fluently speak the languages of music, mathematics, physics, and informatics.

Needless to say, it is very difficult to condense everything into a 5-year university degree, especially if the curriculum must be organized in a coherent 3+2 structure. Such a problem has been tackled in a number of ways by different institutions. For example, the Department of Signal Processing of the Helmut Schmidt University, Hamburg offers an educational program composed by 50% of acoustics and DSP subjects and 50% of scientific topics not directly related to music. Conversely, the University of Ghent focuses its Bachelor and Master degrees on creative disciplines, treating also cognitive music psychology, publishing-related and legal aspects. Finally, it is worth mentioning the case of the University of Milan, which offers one of the few undergraduate programs in Music Informatics.

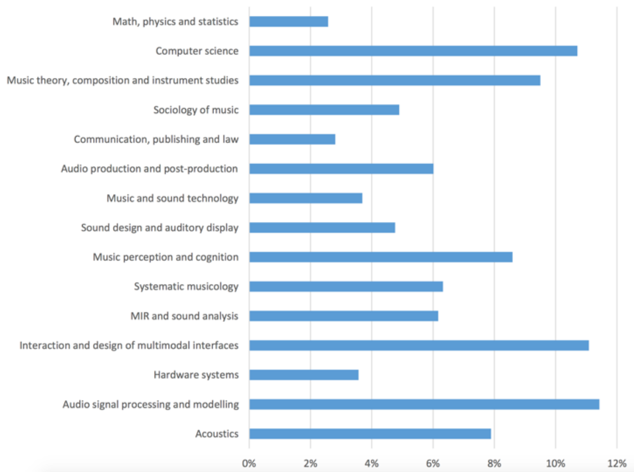

Figure 2. Distribution of SMC core topics and background disciplines (including new content areas C9–C15) in the surveyed university programs.

5. Case Study: How SMC is Perceived in Italy

In order to understand the degree of knowledge and interest of people towards SMC subjects, we administered a survey made of about 40 questions, ranging from user profiling to expectations and suggestions for SMC education. This initiative had the final goal to gather opinions from students, experts, and common people and, consequently, improve the academic curricula in music informatics. Even if the survey mainly focused on Italian users, its results can be easily generalized to other European countries that share a similar structure for SMC academic curricula and experience similar problems such as gender gap in STEM subjects or employability of young people.

The document was disseminated on line, mainly through specialized pages on social networks (e.g., the Facebook group of former music informatics students) and SMC-related communities (*Synth Café*, *Audio Recording Italia*, *Audiofili d'Italia*, the *AIMI* mailing list).

The selected target and the distribution channels could provide biased results for some specific questions, but we took into consideration this phenomenon in evaluating answers. For example, a part of the survey investigated self-evaluated knowledge and competences in using Internet tools and social networks; but the fact that the survey was administered online and advertised through social networks made user answers not relevant.

In total, we collected responses from 284 subjects.

5.1 Characterization of the Sample

Answers have been analyzed not only considering all users as a whole, but also clustering them into a number of significant categories.

For example, we took into account genre distinctions. Answers did not show statistically significant differences between male and female users. Rather, it is worth noting an implicit confirmation of the phenomenon known as *gender gap*, which is afflicting computer science educational and occupational fields: only 15% of interviewed users were female. This percentage is not far from the one registered for student enrollment in the Bachelor degree of Music informatics at the University of Milan: only 10% of females in 2017/18. Experts agree that computer science courses do not have to be completely rethought to be more attractive, but better advertised and "explained" to young women who still wrongly consider this matter as a male domain. The solution is in the cooperation between school and academia, which allows to plan counseling and tutoring activities to be performed in advance to university enrollment. In this sense, a number of initiatives, falling into the so-called *third mission* of academia, are now under way. Narrowing the field to the SMC area, it is worth citing two young apprenticeship programs proposed by the Laboratory of Music Informatics of the University of Milan [19], dealing with the digitization of analog phonic media and the production of multi-layer music contents respectively. These initiatives, attended by about 80 participants per year, attracted 40% of volunteer female students, thus demonstrating their potential interest towards SMC subjects.

In interpreting survey answers, we also aimed to identify people belonging to the target of SMC higher education courses. Specifically, we considered responses in the following areas: personal interests dealing with music and informatics, science and technology; other interests towards SMC-related subjects, such as musicology, sound design, musical cultural heritage, etc.; the declared purpose to find a job in the music field; the interest shown towards the themes of the survey. The two resulting groups, namely people constituting the target vs. others, were balanced to have 50% of users in each cluster. Even if all opinions are considered interesting for our investigation, those expressed by the target group are particularly relevant to reshape academic curricula.

5.2 Results

As mentioned above, not all questions highlighted relevant results. In this section, we will report and discuss only the most significant emerging aspects. Detailed results, including all questions and answers (also clustered by user group), can be retrieved at the following URL: http://www.lim.di.unimi.it/data/smc_survey.php.

Considering the correlation between age and SMC involvement, it emerged that almost 90% of people aged 18-24 and about 55% of subjects aged 25-29 were potentially interested: a promising result for SMC higher education. As the age progresses, involvement in this subject diminishes, hitting a minimum for people over 60: less than 10% were interested.

The question about the way music is mainly experienced by users shows that about 35% of people prefer on-demand streaming services, less than 30% are still anchored to physical media, about 25% listen to downloaded digital files, and about 15% enjoy music on radio or TV; only in a negligible percentage, our sample declares to prefer live music. Answers not only highlight current listening trends, but also the necessity for SMC higher education to tackle this phenomenon from different points of view, teaching technical, legal, economic, and communicative aspects of streaming platforms.

A question in the survey focused on the knowledge of the discipline called SMC. Despite the strongly oriented characterization of the sample, only 40% of interviewed people declared to know its meaning, and this number rises to 53% for subjects potentially interested in SMC education and activities. From the point of view of academia, a poor communication potentially excludes half the user pool from access to higher education in SMC area. Once again, tutoring and dissemination activities, above all engaging young people, may be the key response to the problem, as proven by the success of initiatives such as MeetMeTonight [20, 21].

Another question addressed possible joint applications of music and computer science. People declaring to know the SMC discipline usually provided meaningful responses, listing coherent applications such as: music software development, sound design, sound engineering, signal processing, music information retrieval, multimedia installations, music and sound-based assistive technologies, etc. Only a small part of the sample knowing SMC was not able to see any practical implication. Focusing on a different category, namely people not knowing SMC, most of them thought of the association "music & computer science" as the technological support to music production; but someone also expressed interesting ideas about assisted composition, computational musicology, and musical content broadcasting. Significantly, the category of people not interested in SMC collected all subjects who did not see any practical use of music and computer science. Many of the mentioned applications can be already mapped onto ongoing SMC teaching courses, but gathering users' ideas, as well as common misconceptions, should foster a better definition of academic curricula and counseling activities.

As stated in Section 2, employability is one of the concerns of any higher-education program. From this point of view, through the survey we also investigated the professional outlets expected by interviewed people. Not surprisingly, the group who declared to know the discipline focused on technological development and research, the other group on technology-supported music production and distribution. The comparison between people interested vs. not interested in SMC confirmed this two-faced vision, too. The Italian educational system promotes both paths assigning them to different educational institutions: there are academic curricula in computer science that match the former expectations, and advanced training courses within conservatories to fulfill the latter.

A non-mandatory free-text field of the survey was meant to collect opinions about user's opinions on music informatics. In addition to a number of definitions and some enthusiastic comments ("It's my life", "It's the future"), many subjects highlighted a great potential not fully expressed: "Interesting but complex matter", "Great potential, poorly managed", "It is a field that has yet to affirm itself in Italy", "It does not exist as an autonomous discipline, but it can become", "It has reached excellent levels but we still have to work on its ease of use", "Lack of financing and interest from big actors. This is an area that should be followed and cultivated: it has a very large margin of growth".

6. Conclusions

In this paper, we reviewed the most relevant academic educational initiatives in the field of SMC, comparing them to the situation of 10 years ago. Such an analysis underlined evolutions concerning not only the number of initiatives, but also teaching approaches and technologies, as well as an improved match with occupational expectations.

Current perspectives in the field of SMC are strongly tied to machine learning techniques and new distribution (e.g., streaming services) and communication channels (e.g., augmented and virtual reality) In this sense, academic curricula should include the fundaments of maths, physics, and general-purpose computing, but also shed some light on new technological means and devices.

Our analysis was integrated by a survey conducted on a music-involved target in Italy. Emerging results were not particularly surprising as it regards knowledge and expectations, but they helped to clarify some underlying and, often, underestimated aspects:

- Low female participation, not only to the survey initiative but also to research and job activities in this field. Scientific community is aware of the problem, and initiatives such as Women in Music Information Retrieval (WiMIR) are emerging;
- The importance to better communicate the goals of the discipline and reach a wider audience among young people and professionals in the sector. A side effect of survey distribution was the need to identify the main channels used to exchange information, that are ideal places to conduct out-of-academia awareness campaigns in the future;
- The need for teaching subjects to be constantly reviewed and updated, as requested by students', stakeholders' and employers' expectations.

References

[1] Bernardini, N., Serra, X., Leman, M., and Widmer, G. (2007) *A roadmap for sound and music computing* (The S2S2 Consortium).

[2] Dannenberg, R.B. (2007): Impressions from the SMC roadmap. *Journal of New Music Research* **36**(3): 191–196.

[3] Vinet, H. (2007) Science and technology of music and sound: The IRCAM roadmap. *Journal of New Music Research* **36**(3): 207–226.

[4] Avanzini, F., Baratè, A., Haus, G., Ludovico, L.A., Ntalampiras, S., and Presti, G. (2018) Perspectives in Education for Sound and Music Computing. In: Della Ventura, M. (ed.) *Proceedings of the 5th International Conference on New Music Concepts (ICNMC 2018)*, Treviso, March 17-18, 2018 (Milano: ABEditore), 11–27.

[5] European Commission/EACEA/Eurydice (2015) *The European Higher Education Area in 2015: Bologna Process Implementation Report*. Technical report. (Luxembourg: Publications Office of the European Union).

[6] Rocchesso, D. (2014) Sounding objects in Europe. *The New Soundtrack* **4**(2): 157–164.

[7] Miranda, E.R., Kirke, A., Braund, E., and Antoine, A. (2017) On unconventional computing for sound and music. In: *Guide to Unconventional Computing for Music* (Berlin: Springer), 23–61.

[8] Atchison, W.F., Conte, S.D., Hamblen, J.W., Hull, T.E., Keenan, T.A., Kehl, W.B., McCluskey, E.J., Navarro, S.O., Rheinboldt, W.C., Schweppe, E.J., et al. (1968) Curriculum 68: Recommendations for academic programs

in computer science: a report of the ACM curriculum committee on computer science. *Communications of the ACM* **11**(3): 151–197.

[9] ACM/IEEE-CS Joint Task Force on Computing Curricula (December 2013): *Computer science curricula 2013*. Technical report (ACM Press and IEEE Computer Society Press).

[10] Roads, C. (1996) *The computer music tutorial* (Cambridge, Massachusetts: MIT press).

[11] Zölzer, U. (2011) *DAFX: digital audio effects*, 2nd ed. (Hoboken, New Jersey: John Wiley & Sons).

[12] Bilbao, S. (2009) *Numerical sound synthesis: finite difference schemes and simulation in musical acoustics* (Hoboken, New Jersey: John Wiley & Sons).

[13] Farnell, A. (2010) *Designing sound* (Cambridge, Massachusetts: MIT Press).

[14] Hermann, T., Hunt, A., and Neuhoff, J.G. (2011) *The sonification handbook*. (Berlin: Logos Verlag).

[15] Franinović, K., and Serafin, S. (2013) *Sonic interaction design* (Cambridge, Massachusetts: MIT Press).

[16] Lyon, R.F. (2017) *Human and machine hearing* (Cambridge: Cambridge University Press).

[17] Lerch, A. (2012) *An introduction to audio content analysis: Applications in signal processing and music informatics* (Hoboken, New Jersey: John Wiley & Sons).

[18] Müller, M. (2015) *Fundamentals of Music Processing: Audio, Analysis, Algorithms, Applications* (Berlin: Springer).

[19] Ludovico, L.A., and Presti, G. (2018) Digitization of Analog Phonic Archives in a University Lab: A Report on a Young Apprenticeship Initiative. In: Blazquez, D., de la Poza, E., Domenech, J., and Merello, P. (eds.) *Proceedings of the 4th International Conference on Higher Education Advances (HEAd'18)*, Valencia, June 20–22, 2018 (Valencia: Editorial Universitat Politècnica de València), 81–89.

[20] Ludovico, L.A., Presti, G., and Saija, C. (2017) A Multimodal Sound Installation for Experiential Learning. *Journal of e-Learning and Knowledge Society* **13**(1): 39–49.

[21] Bonafede, D., Ludovico, L.A., and Presti, G. (2018) A Proposal for the Interactive Sonification of the Human Face. In: Constantine, L., da Silva, H.P., Escalona, M.J., Helfert, M., and Jimenez Ramirez, A. (eds.) *Proceedings of the 2nd International Conference on Computer-Human Interaction Research and Applications (CHIRA 2018)*, Seville, September 18–21, 2018 (Setúbal: SCITEPRESS – Science and Technology Publications, Lda.), 163–169.