NIME Prototyping in Teams: A Participatory Approach to Teaching Physical Computing

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ABSTRACT

In this paper, we present a workshop of physical computing applied to NIME design based on science, technology, engineering, arts, and mathematics (STEAM) education. The workshop is designed for master students with multidisciplinary backgrounds. They are encouraged to work in teams from two university campuses remotely connected through a portal space. The components of the workshop are prototyping, music improvisation and reflective practice. We report the results of this course, which show a positive impact on the students' confidence in prototyping and intention to continue in STEM fields. We also present the challenges and lessons learned on how to improve the teaching of hybrid technologies and programming skills in an interdisciplinary context across two locations, with the aim of satisfying both beginners and experts. We conclude with a broader discussion on how these new pedagogical perspectives can improve NIME-related courses.

Author Keywords

STEAM education, physical computing, music improvisation, reflective practice, distance education, courses, NIME design

CCS Concepts

•**Applied computing** → **Sound and music computing;** Performing arts; •**Social and professional topics** → *Computing education;* •**Human-centered computing** → *Collaborative interaction;*

1. INTRODUCTION

STEAM is a techno-artistic approach to education that brings the arts to science, technology, engineering and mathematics (STEM) fields [23]. STEAM education has been reported as a successful approach to capture the interest of a broader audience and bring more diversity to STEM fields [8, 13, 14]. Teaching computational thinking and programming to mixed groups of students with different backgrounds and music knowledge is a common and challenging use case scenario [14]. This is not an exception for NIME design, where a range of teaching methods has been explored targeting different ages, from primary and secondary school level [16], to undergraduate [10, 22] and master [20, 27] levels, either using hybrid technologies [10, 16, 22, 27] or focusing on a single or a constrained set of technologies and platforms [20, 31].

The future university is changing due to an increase of the global population that is much faster than the increase of campuses [7]. The design of new university courses should be modular and scalable so that distance education is possible.

This paper aims to address the following research question: *To what extent teaching NIME prototyping to cross-campus teams using hybrid technologies is a useful strategy to improve prototyping and programming skills and the intention to continue in STEM fields among technological humanist students with multidisciplinary backgrounds?*

To answer this research question, we gathered and analyzed teaching observations, students' feedback and reflective notes from a 4-day intense workshop of physical computing applied to NIME design. Our results point to a positive impact on the students' confidence in prototyping and intention to continue in STEM fields, however the use of hybrid technologies and programming languages should be revised to suit better an interdisciplinary context e.g. avoid early-on frustration among beginner programmers.

2. BACKGROUND

There exist a number of courses and workshops that relate to NIME topics [10, 16, 20, 22, 27, 31], of which some promote instrument building in teams [16, 20, 22, 31]. It is notable the design of particular technological platforms to teach NIME courses, such as Satellite CCRMA [3] or Bela [24]. Other courses promote the use of hybrid technologies [10, 16, 22, 27]. Some of the courses focus on the mappings between gestures and sounds by providing constrained technological

NIME'19, June 3-6, 2019, Federal University of Rio Grande do Sul, Porto Alegre, Brazil.

environments [20, 27]. Laptop and mobile music-making has been an important theme that promotes participatory music using everyday technologies [12, 30].

The hands-on interdisciplinary NIME courses seem to be preferred by students among the different courses they are enrolled [20, 22]. Sometimes using the self-built prototypes for music improvisation [16] or public concerts [10, 20] is part of the curriculum. Also, an evaluation mechanism can be included, e.g. students' feedback [20] or teacher's analysis of videoed outcomes [10], to improve the next iteration of the course. It is in the spirit of the above NIME courses that we have designed the Physical Computing Workshop (PCW), a hands-on interdisciplinary NIME course that is held in two university campuses connected through a portal space, with an emphasis on cross-campus participatory prototyping with the use of hybrid technologies, in combination with music improvisation and reflective practice.

3. THE WORKSHOP

In this section, we present the context, curriculum, and outcomes of the workshop.

3.1 Context

The PCW is part of the new international master Music, Communication, and Technology (MCT),[1] a master's program in collaboration between the Norwegian University of Science and Technology (NTNU) in Trondheim, Norway, and the University of Oslo (UiO) in Oslo, Norway. The program has as a distinctive dedicated physical space in both sites, *the Portal*, with real-time low-latency audiovisual and networking technologies [29]. This master's program, led by the second and third authors, started in August 2018. The program is designed for those interested in music who would like to learn more about cutting-edge technologies, in a cross-campus setting. The pedagogical design of the different courses of the master is based on a range of novel pedagogical methods, including: team-based learning (TBL) [25], active learning [2], and flipping classroom [4].

The students have a multidisciplinary background ranging from digital humanities, to music technology to engineering. For that reason, the purpose of this workshop (together with other workshops of the first semester of the master) is to bring the students to a common baseline knowledge. At the time of doing this workshop, the number of total students was 14 forming three cross-campus teams, with seven students in each site, and two women. The group is international with students from Europe and Asia.

The size of the group is small, therefore the teaching style varies compared to larger groups, the latter being a standard in most universities [5]. Teaching to small groups demands a more individualized teaching style [26]. With the two remotely connected portals, it becomes a more online and virtual experience for both students and teachers than in a traditional class. Having half of the students in a remote room demands the frequent use of communication strategies (e.g. rich media, interactive teaching styles, keeping eye contact with local and remote students) to be successful in distance learning [32]. In the master's program, this is supported with the use of suitable technologies (e.g. using a video conferencing system to connect and share the teacher's or a student's computer screen, using a document camera to showcase small prototypes, using a microphone to communicate with a clear voice, and so on). Therefore, in order to deliver a satisfactory class, the teacher should be proficient with the technologies in the Portal and develop good communication skills applied to both co-located and remote spaces [32].

[1] `https://www.ntnu.edu/studies/mmct`

3.2 Curriculum

Within this context, we have designed entirely the content of the PCW, of which slides and code are available online.[2] This has been the first edition of the workshop (as it is also the first edition of the MCT master's program). The workshop design criteria are to:

1. Facilitate a hands-on workshop with affordable and DIY technologies (e.g. mobile phones, contact microphones, Arduino boards, littleBits, Web Audio API).
2. Explore individually and in group the fundamental concepts behind physical computing (e.g. tinkering, programming, making).
3. Promote a sharing culture of code and discoveries (e.g. writing reflective blog posts, sharing code repositories).
4. Contextualize the workshop to the broader context of interactive systems for music performance at both theoretical and practical levels (e.g. readings, practices).

This 4-day workshop is an intense series of practical sessions (7 hours per day, 28 hours in total), where the students are invited to explore physical computing and interactive systems applied to music performance. The workshop is designed so that students are intuitively exposed to current professional software and hardware (e.g. Arduino board, littleBits, mobile apps) and modern programming languages (e.g. C/C++ for Arduino, JavaScript).

The approach of the workshop is inspired by the hands-on tutorials from Collins's book [9] and Igor's book [17]. We borrow from Collins [9] the notion of prototyping musical circuits based on intuition, and from Igor [17] the concept of creating projects with applications in the real world by using pedagogically-friendly creative computing environments, such as Arduino. Due to the nature of the master's program and hands-on workshop, the emphasis is on (1) TBL [25] linked to communities of practice [21], (2) the production of knowledge in artistic research in terms of "thinking in, through and with art" [6, p.44], and (3) a critical attitude based on reflective practice [28] through blogging [11]. This workshop should be seen as a starting point to get interest with physical computing applied to music performance. For this reason, it has been designed to be low cost using consumer affordable gadgets and open source materials.

Each of the first three days of the workshop had a theme: (1) intuitive circuits and hacking, (2) sensors and actuators in our pockets, and (3) microcontrollers, tangible bits and chiptunes. At the beginning of each session there was a warm-up discussion based on a relevant related reading, which was followed up with paced hands-on exercises. At the end of each session there was one hour allocated for network music performance using the Portal facilities, where the cross-campus teams improvised music using their daily self-built prototypes. The improvisations were audio recorded and shared with the students immediately. Each team was required to write a daily blog post about the challenges and opportunities of their self-built prototypes. On the last day, there was a mini-hackathon. The teams developed and presented a prototype of an interactive system for music performance by mixing technologies and techniques learned throughout the workshop (Figure 1).

[2] `https://github.com/axambo/physical-computing-workshop`

Figure 1: Team B performing with the Percampler (view from Oslo). (Photo by Alexander Refsum Jensenius.)

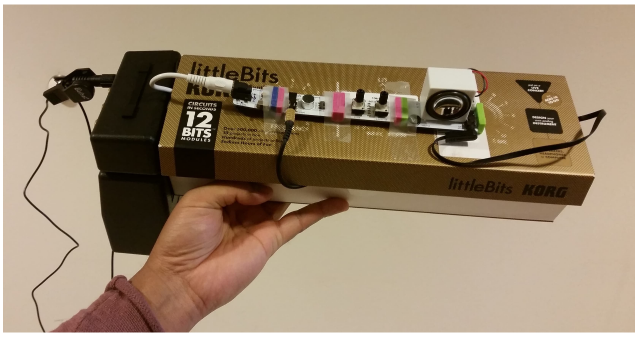


Figure 2: Closeup of the analog system of the Percampler. (Photo by Eigil Aandahl.)

3.3 Outcomes

A total number of 12 blog posts were written, distributed into one blog post per day and team, which can be found online in the student-led MCT blog.[3] It is out of the scope of this paper to analyze systematically the content of the blog posts. Here we summarize the students' work from the last day of the workshop, where a mini-hackathon took place that was open to public. The students were asked to (1) express a concept from ideation to prototyping by combining and building on the prototypes developed previously that week, (2) be able to demonstrate a custom-made musical instrument in a performance setting, and (3) reflect on their design and performance by writing a blog post about it. The teams were given three hours to develop their idea and rehearse. At the end of the session, each team was asked to present their work during 15 minutes, where they should pitch their idea and perform with the instrument. For the mini-hackathon, we asked three external jury members to assess each music hack: Tone Åse (associate professor at NTNU and singer working with voice, improvisation and electronics), Charles Martin (postdoctoral fellow specialising in music technology and machine learning at UiO), and Gerard Roma (postdoctoral fellow specializing in real-time computer music systems and sound analysis and retrieval at University of Huddersfield). One of the three jury members was present in the oral presentations, and the other two read the blog posts and listened to the audio recordings of the performance afterwards. The criteria of evaluation was inspired by the criteria of the Georgia Tech Moog Hackathon,[4] where the first author was a jury member: originality/creativity, design/engineering, and performance/musicality. The team of the best music hack was awarded with a BBC micro:bit Go![5] for each team member. Next, a brief description of the three prototypes is provided:

- *Art is Anything You Can Get Away With* (Team A) – A network-based instrument with a signal chain loop that sends a sound source from one place to another in real time over a mobile phone, which can in turn modify the sound with mobile phone gestures. The setup sends back the signal to its original source creating feedback elements. The technologies used include mobile phones, littleBits, a JavaScript web sampler, Google Hangout, VB-Audio Voicemeeter Banana and Ableton Live.

- *Percampler* (Team B) – A prototype that combines digital and analog systems for musical collaboration and improvisation within a space and over distances. The prototype is designed in two segments based on each of the two locations: the Trondheim site includes the analog system while the Oslo site covers the digital system (Figure 1). The analog system (Figure 2) allows for recording and modifying sounds samples in real time. The technologies used in the analog system include littleBits, a mini-amplifier, and a contact microphone, whilst the technologies used in the digital system include a JavaScript web sampler, littleBits, and sound samples recorded during the workshop.

- *The Koolboard* (Team C) – A music controller based on sensing the human body and environment. With this prototype, it is possible to map input data from light and temperature sensors to control parameters in Ableton Live, such as frequency, tone, and volume. The technologies used include Arduino Uno, light and temperature sensors, Max4Live, and Ableton Live. For the performance, the team used three Arduino boards with different sensors setups in each and mapped to different palettes of sounds.

[3]https://mct-master.github.io/physical-computing
[4]https://guthman.gatech.edu/moog-hackathon
[5]https://microbit.org

The three prototypes are original ideas, yet there are three commonalities. They (1) are hybrid prototypes that combine a range of varied technologies as encouraged throughout the workshop, (2) support multi-user interaction, and (3) explore the nature of the Portal and possibilities of network music, taking into consideration both co-located and remote communication. The three jury members agreed on the quality of the prototypes and performances, and encouraged the students to continue with their prototypes. After this hands-on experience, the students were able to continue in two follow-up courses: a hands-on workshop of DSP led by the fifth author which promoted a practical exploration of digital processing techniques by also building prototypes and performing with them, and a series of lectures on human-computer interaction led by the first author, where the students were asked to reflect on the prototypes built in the PCW, contextualize them within the HCI and NIME communities, and discuss potential future work.

4. TEACHING OBSERVATIONS

For the teaching observations, we asked two academics from the Department of Music to come over, observe, and fill in a teaching observation sheet, which was provided by the course "Learning and Teaching in Higher Education" from Queen Mary University of London. The form includes questions about: (1) clarity of the aims and learning outcomes, (2) clarity and organisation of the session including timekeeping and structure, (3) teaching and learning methods – are they appropriate and innovative?, (4) the form and extent of active learning and student participation, (5) delivery and pace of the session, (6) use of learning technologies, and (7) suggestions to build on strengths and/or improve teaching.

4.1 First Observation

The first observer, O1, is professor in music technology at NTNU. O1 came on the first day and observed the initial three hours. The content of this part of the class included a preamble with an introduction to the course, learning outcomes of the day, a discussion of the suggested reading on soundwalking [1], and sound hunter activities around soundwalking and circuit sniffing. The lead teacher of the course (first author) asked O1 to focus on the co-located and remote communication, given the cross-campus situation.

From the observations, positive aspects included that the communication of the learning outcomes was clear and the activities were well-paced. The use of a digital mind map in a shared screen to reflect on the reading before class was reported as inclusive and connects with eliciting prior knowledge [15], active learning [2], and student participation. In the next three exercises, the cross-campus teams were asked to do field trips to collect sounds using different devices and report back to the group their discoveries, one team per activity. O1 described this approach as efficient in combining participation with time-efficiency.

Negative aspects included technical issues with the communication technology of the Portal, which were quickly sorted. Other technical issues highlighted by O1 were related to the lack of *"checking the technology for compatibility with student devices"* for some of the activities. It would be important to check the compatibility of technologies between students days before the class starts to keep the exercises as inclusive as possible. Misunderstandings of the material delivered were also identified, which would require a slower pace in explaining the basic concepts for clarity and more mechanisms to check that students are following them when presenting each exercise.

4.2 Second Observation

The second observer, O2, is a PhD student in music technology who has teaching duties with undergraduate and master courses of music technology at NTNU. O2 was also asked to focus on the communication side. O2 came on the second day and observed 1.5 hour of the day, when the first activity based on a home reading [12] was ending, and the new activity was about to start, which was around testing the sensors available in the students' mobile phones. Each team was asked to install two mobile apps that measure sensor data, compare them, and present their favorite to the class using the corresponding classroom document camera, connected to a screen that was visible to the group.

From the observations, positive aspects included that the overall class environment was seen as open and cooperative. The novel teaching and learning methods of *"practice-based learning and team-based learning across two different campuses at the same time"* were highlighted as effective, were the role of the teacher becomes a *"moderator"* of a *"student-led session"*. As a teacher of a more traditional model, O2 mentioned that the students in traditional settings are less active and can foresee how the MCT program can be a positive change and influence new practices in teaching:

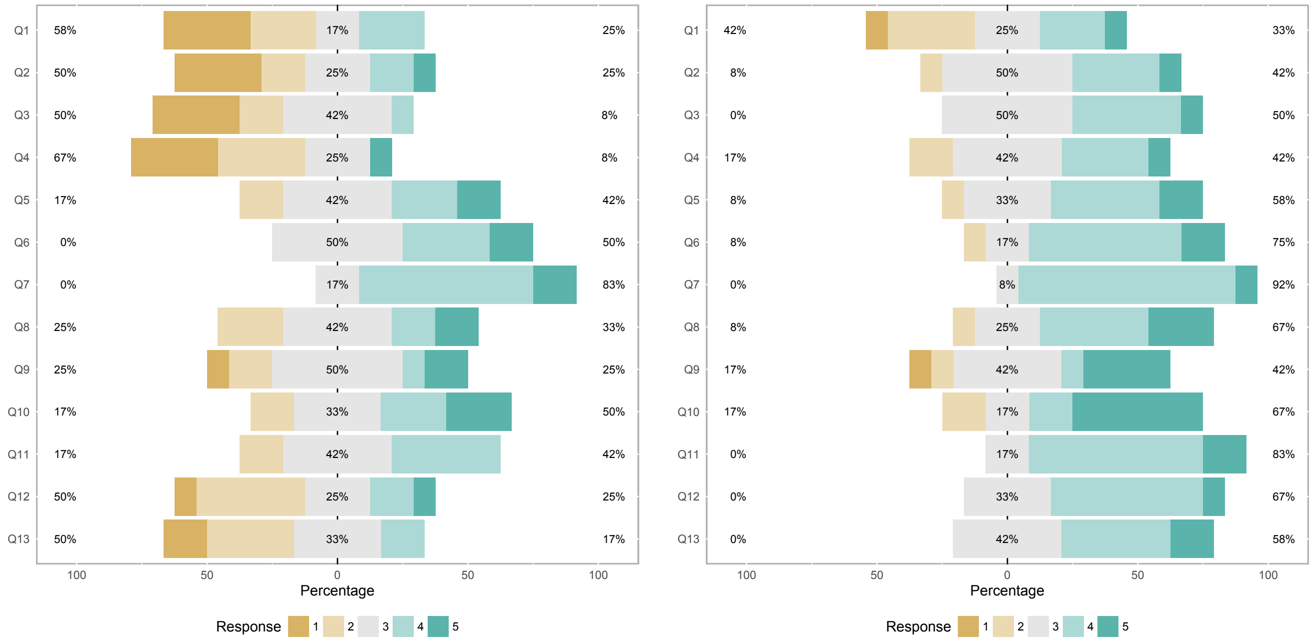
> *"This is innovative and radically different than most university environments which assume that the lecturer is the lone vessel of knowledge for the students. In this environment, the flow of knowledge went both ways, effectively being innovative, more creative and strengthening bonds between students and lecturer(s)."* (Quote from O2's teaching observations, 2018)

In terms of negative aspects, it is unclear how the class was experienced in the remote site where the teacher was seen through a screen (an observer at the other side would have been useful). O2 reported that this makes difficult to assess the overall result as the information is partial. Regarding how the technical issues were faced, and probably from the experience of the first day of the workshop, *"the students and instructors worked together to make everything work properly"*, which *"forced the students to engage with the technology"*, in alignment with TBL [25] and distance-learning principles [32]. O2 acknowledged the technical challenge that the Portal demands to the teachers and stressed the importance of knowing exactly how is the experience delivered at the remote location, or at least have a great control on it. Although the technical setup could have worked more smoothly sometimes, this observed class was an example of students finding workarounds quickly and solving real-world problems, which is close to problem-based learning in teams [19] and the notion of keeping the activity more as a highly communicative exercise than a technological exercise.

5. STUDENTS' FEEDBACK

Students were invited to fill in a pre-questionnaire and post-questionnaire to assess their expectations and impact of the workshop, respectively. The questionnaire had the same 5-point Likert-item questions. There were questions that asked the level of confidence (1 = not at all confident; 2 = a little confident; 3 = somewhat confident; 4 = highly confident; 5 = extremely confident) about their ability for programming (Q1), computational thinking (Q2), prototyping (Q3), instrument building (Q4), performing (Q5), reflective practice (Q6), and teamworking (Q7). There were also questions that asked the level of agreement (1 = strongly disagree; 2 = disagree; 3 = neutral; 4 = agree; 5 = strongly agree) about a set of statements on their intention to continue courses related to STEM fields (Q8), to continue their education in STEM fields (Q9), and to use their STEM knowledge in their future careers (Q10). They were also asked their level of agreement of the extent to which they can understand the purpose of physical computing (Q11), describe the process of prototyping (Q12), and apply the technique of designing a prototype for music performance to their work (Q13).

We obtained the pair of responses from 12 students ($n = 12$). As shown in Figure 3, the percentages of the level of confidence and agreement tended to be more positive in the post-questionnaire (Mdn=4, M=3.66) than in the pre-questionnaire (Mdn=3, M=2.98). The level of confidence of prototyping (Q3), together with the level of understanding of physical computing (Q11) and prototyping (Q12) applied to music performance (Q13) improved considerably, as well as the intention to continue courses related to STEM fields (Q8). However, the level of confidence of programming only improved slightly (Q1), which reveals a group with mostly beginners in programming, and the need of reinforcing their programming skills early on in the master. As part of the students' feedback, it was reported the need of an instructor in the remote site to help the students with the programming exercises. This request aligns with findings in distance-based learning about the need of providing an adequate technical support staff to improve students' perceptions of the richness of the medium [32]. The level of confidence of teamworking (Q7) and reflective practice (Q6) increased from an already high score, two aspects that are explicitly promoted across the different master's courses.



(a) Bar plot of the pre-questionnaire responses.

(b) Bar plot of the post-questionnaire responses.

Figure 3: Bar plot for the results of thirteen (Q1–Q13) 5-point Likert-item questions ($n = 12$).
Questions: Q1 programming; Q2 computational thinking; Q3 prototyping; Q4 instrument building; Q5 performing; Q6 reflective practice; Q7 teamworking; Q8 continue STEM courses; Q9 continue STEM education; Q10 future use of STEM knowledge; Q11 understanding of physical computing; Q12 understanding of prototyping; and Q13 designing a prototype for music performance.

6. REFLECTIONS

Reflecting on the teaching observations and students' feedback can help to improve the forthcoming workshop editions. Four aspects are worth discussing: (1) prototyping NIMEs, (2) using hybrid technologies, (3) delivering cross-campus experiences, and (4) developing new pedagogical methods.

Prototyping NIMEs. Revising the research question, the results from the students' feedback indicate that teaching NIME prototyping to cross-campus teams using hybrid technologies seems to be a useful strategy to improve the confidence in prototyping and the intention to continue in STEM fields among students with multidisciplinary backgrounds. However, the confidence in programming is more difficult to improve in a workshop of these characteristics.

Using hybrid technologies. The use of hybrid technologies combined with interdisciplinary teams who have complementary skills promoted variety in the final prototypes. The results from the students' feedback point to a positive impact on the students on their intention to continue in STEM fields, however the use of hybrid technologies should be revised to suit better an interdisciplinary context e.g. avoid early-on frustration among beginner programmers. A potential area of improvement is the content of the workshop. For some students it was fun, but others expressed the lack of more time to cover all the content. This is inherent in the interdisciplinary design of the leveling workshops of the master, and therefore this feedback is expected by design.

Delivering cross-campus learning experiences. It is remarkable that cross-campus learning is a future expected scenario in education. Although this workshop could have been held in one campus only, it is timely to design hands-on NIME courses suitable for distance education. In this workshop, the two locations influenced not only in the teamworking and music performance activities, but also in the themes of the final prototypes, which incorporated concepts related to the physical and digital connectivity between the two locations. However, there are some challenges about the portal space, which include making sure to have the same ecosystem of technologies and setup in both sites, and delivering the same learning experience in both sites.

Developing new pedagogical methods. As shown, TBL and active learning promote student-led learning based on the interests of the students. TBL also promotes diversity in groups, which is in alignment with the solutions in front of ability grouping issues reported in [18]. Ability grouping or differentiation is reported to be not necessarily beneficial in the class, the main recommendation is to keep flexibility and to reduce the negative effects of ability grouping strategies [18]. However, there are a number of factors that can weaken these strategies from the students' perspective and should be adapted to suit their needs. The positive results of the workshop can inspire other in-house courses currently taught using more traditional learning mechanisms. We also hope to inform more broadly at the national and international levels. NIME-related courses should be kept at the forefront of promoting innovating ways of STEAM teaching and learning.

7. CONCLUSIONS

In this paper, we presented a team-based workshop on physical computing applied to NIME design that includes prototyping, music improvisation and reflective practice. The workshop was delivered to 14 students of a cross-campus master's program. We reported the results of the workshop in terms of teacher observations, students' feedback and authors' reflections. The two teacher observers agreed on the potential of the workshop from a pedagogical perspective. The students' feedback showed a positive impact on the students' confidence in prototyping and intention to continue STEM fields. We concluded with reflections on how this workshop can improve and influence other similar courses. As future work, we plan to include systematic content analysis of the students' blog posts, further observed iterations of this workshop and a study about the long-term experience.

The workshop and master's program presented here are taking risks in exploring new ways of education. We need to keep exploring and refining these new methods (e.g. TBL, active learning, distance learning), a progress that can be made with the help of both teachers and students. Delivering a STEAM workshop focusing on NIME design seemed to be successful among students who have a music background or interest, but not necessarily a computer science background. From the teacher's perspective, after seeing the benefit of being observed, it would be important to advocate for regular teaching observations as part of the future workshop editions, which can be a pilot for similar local, national and international curriculums to come.

8. ACKNOWLEDGMENTS

The authors wish to thank the students and jury members who participated in the workshop. This work was partially supported by the NTNU SALTO project (80340480).

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