STEAM for non-novice STEM students with Digital Musical Instruments

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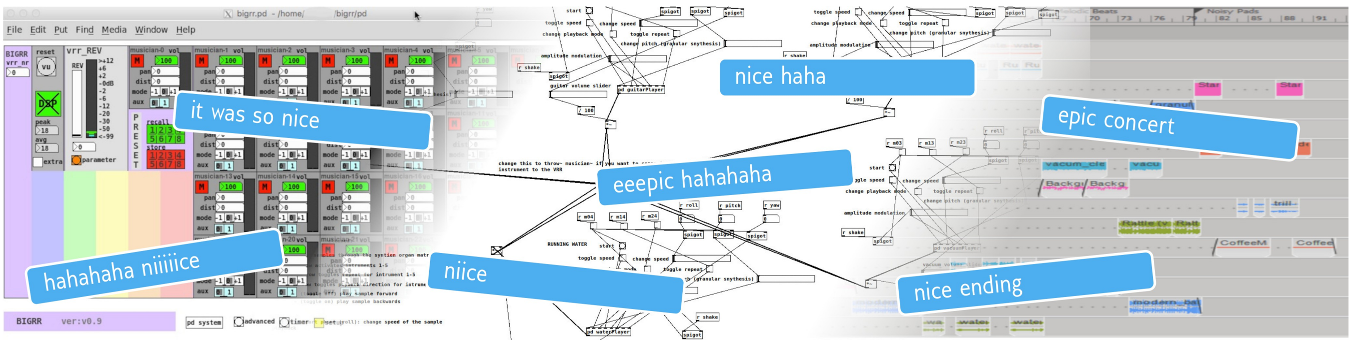

Figure 1: Extracts from left to right: Virtual Rehearsal Room mixing console for 20 remote players; student-built Digital Music Instrument with Pure Data; and the (informal) score of the final performance. Overlain: Students' online chat reactions after playing the score together for the first time.

ABSTRACT

STEAM education extends STEM (Science, Technology, Engineering, and Mathematics) with Arts, often with the aim to attract newcomers to technical disciplines. We present and report on a university STEAM course implemented for non-novice STEM students: advanced Computer Science students with little or no musical background designed, built, and performed with Digital Musical Instruments. We examine the collected quantitative and qualitative data (attendance, dropouts, feedback, homework submissions, participation metrics) in the light of qualities and deficits of STEAM discussed in the literature. Our results coincide with purported beneficial outcomes of STEAM such as a growth in skills, evidenced for instance by our students' success acquiring and applying both new technologies and musical insights. Furthermore, we avoid common pitfalls such as an unclear extent and role of artistic content and issues in the practical course implementation through thorough planning. This is corroborated by the students' sustained participation and positive feedback.

CCS CONCEPTS

• **Social and professional topics → CS1**; **Student assessment**; • **General and reference → Empirical studies**; • **Applied computing → Collaborative learning**; *Sound and music computing*.

KEYWORDS

STEAM education, digital musical instruments, interactive music systems, electronic music programming, university education

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1 INTRODUCTION

The stereotypical computer scientist is often perceived as lacking interpersonal skills and being exclusively interested in technology and computers [6]. Likewise, Computer Science (CS) as a field is generally viewed as a STEM (Science, Technology, Engineering, and Mathematics) subject rather than an artistic one. From a pedagogical and educational perspective, scholars have argued that interdisciplinary intersections of science or technology subjects with arts subjects can create rich synergies for students from both disciplinary areas. This is especially true in the realm of STEAM (Science, Technology, Arts, Engineering, and Mathematics), an emerging transdisciplinary pedagogical approach that focuses on incorporating the liberal arts and humanities into traditional STEM subjects [16].

Comprehensive research on Science, Technology, Arts, Engineering, and Mathematics (STEAM) education is still scarce as we

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review in Section 2 next. Particularly with respect to possible learning effects and outcomes, the potential of STEAM education has not yet been fully scoped. Given the highly situated and contextual nature of STEAM-based approaches, scholars have furthermore emphasized the importance of explicitly stating research methods and educational settings applied to increase the likelihood and credibility of future meta-studies [8].

In this paper, we present a novel STEAM inspired course concept for non-introductory computer science students involving designing, building, and performing with Digital Musical Instruments (DMIs) remotely over the Internet. The course curriculum as described in Section 3 was designed for CS students in higher education with no musical background. Introducing an artistic perspective on CS topics traditionally approached in a purely technical manner allowed us to explore the impact of STEAM-based approaches on students already pursuing a Science, Technology, Engineering, and Mathematics (STEM) discipline. We contextualize our observations presented in Section 4 with respect to recent findings in STEAM education as we discuss finally in Section 5. We do not claim our results to be generalizable. Instead, we use our case study to discuss effects and purported outcomes of STEAM education such as a growth in different skills of students and how to avoid common pitfalls in the practical course implementation through thorough planning. Overall, we want to contribute to this still emerging transdisciplinary pedagogical approach and hope to encourage and facilitate implementation of further STEAM-based practices.

2 STATE OF THE ART

2.1 STEAM Education

STEAM is based on STEM, an educational approach centered around disciplines related to Science, Technology, Engineering and Mathematics. Over the past 20 years, the STEM movement has attracted considerable attention from educational policymakers worldwide, not least due to its impact on workforce development and economic competitiveness. Simultaneously, the paradigm has been repeatedly criticized for lacking diversity, interdisciplinarity, and creativity [3, 4, 9, 17, 18, 36].

Lack of diversity is known to be a key problem in most STEM fields. Recent statistics have shown that the number of female students enrolled in STEM disciplines has been declining over the last twenty years [4]. Addressing this issue, a number of researchers have pointed to the potential of STEAM-based curricula to broaden participation in STEM courses by adding a creative component such as arts or design [2, 25, 31].

The need for interdisciplinarity in STEM subjects is another issue frequently addressed in research [17, 36]. Creating interdisciplinary settings has been found to increase student engagement and enthusiasm, for such learning environments allow students to integrate knowledge from two or more disciplines to create a more applicable understanding of reality. In contrast to the STEM paradigm, STEAM education is consistently inter- or transdisciplinary in nature as it builds on the premise of integrating the arts with one or more STEM discipline in a defined learning context [27]. Such an integrative approach is considered to be overall more effective in integrating context knowledge and supporting learners in producing new perspective and innovative problem-solving skills [15]. The interdisciplinary aspect is further intensified in practise as STEAM-based learning contexts regularly involve multidisciplinary team settings [37].

2.2 Evidenced Impact and Outcomes

The literature on STEAM education reports a wide range of positive outcomes, with many scholars arguing STEAM-based curricula to be more suitable in fostering creative and higher-order thinking abilities necessary for dealing with (global) challenges in the context of the 21st century [14, 33]. Similarly, multiple empirical studies have demonstrated STEAM practices to have beneficial effects on student motivation and engagement, perceived confidence and competence levels towards the respective subject area(s), and overall improved attitudes towards careers in STEM disciplines [10, 28, 29, 32, 37]. Following the taxonomy of learning outcomes in STEM education proposed by Martín-Páez et al. [17], we have pooled and assigned the learning and teaching outcomes reported in the literature around STEAM education into three categories.

Cognitive outcomes. These refer to any measurable growth in knowledge and cognitive capabilities in one or more STEM fields. Scholars have demonstrated STEAM-based creative teaching approaches (including music) to be effective for increasing content acquisition and improving conceptual understanding of scientific topics in STEM fields [1, 21, 28, 34].

Procedural outcomes. This category includes any increase in task- or skill-related proficiency and competence levels as well as mental habits, e.g., creative, critical, innovative thinking, problem solving. Studies have reported increased creativity levels after having implemented STEAM practices involving either design or music remixing tasks [19, 22]. With respect to skill-based competence and proficiency levels, literature provides empirical evidence of performance improvements: introducing students of various multidisciplinary backgrounds to a STEAM-based physical computing class featuring prototyping, music improvisation and reflective practise, Xambó et al. have found improved prototyping skill levels [37]. Similarly, increased coding abilities in a math and computer science class were reported for a creative learning environment that integrates animation, dance and music [28].

Attitudinal outcomes. These refer to any observed changes in perception and attitude from the student's perspective. Several studies have demonstrated the effectiveness of STEAM-based teaching methods in improving students' attitudes towards STEM subjects, increasing student engagement and motivation, and improving overall intentions to persist in or pursue a career in a STEM discipline [1, 10, 11].

2.3 Criticism of STEAM

Despite the positive response to STEAM education, researchers have identified a number of issues related to the conceptual understanding of the STEAM paradigm, the role of the arts, and practical implementation challenges [8, 13, 27].

Lack of conceptual clarity. Similar to the STEM paradigm, there is no shared understanding on the definition of STEAM education.

This is particularly true for the nature and extent of disciplinary integration in the context of STEAM-based curricula. Definitions and descriptions in the literature include interpretations of (1) STEAM as an interdisciplinary or transdisciplinary paradigm [15, 23], (2) STEAM as a multi- or cross-disciplinary approach [12, 24], and (3) STEAM as a merely arts-infused or arts-integrated approach [26, 35]. While this lack of conceptual clarity does not hinder the conduct of individual case studies, it does considerably limit the possibilities and credentials of meta-studies [8].

Role of the arts. Regarding the nature and extent of arts integration, a number of different approaches can be observed: while some scholars emphasize the inclusion of visual or performing art forms and/or design and creative processes to foster imagination, innovation, and self-expression [15], others use the arts merely as a synonym for project-based learning or to refer simply to tinkering or building techniques that do not explicitly target artistic knowledge [7]. Furthermore, there has also been criticism with respect to the direction of transfer effects from arts learning to learning in other subjects [5], with some studies suggesting creative transfer to be taking place in multiple directions [30].

Implementation challenges. Lastly, studies have pointed out major practical challenges during STEAM concept implementation. These include issues related to adequate curriculum timing and pacing, content and discipline alignment along with teacher collaboration, and inflexible school policies that hamper effective STEAM implementation [13].

2.4 Research Questions

In conclusion of the reviewed literature, we pose the following research question: Given a higher education STEAM course that introduces an artistic perspective on CS topics traditionally approached in a purely technical manner to non-introductory computer science students, *(a)* which effects can be observed with respect to purported outcomes in STEAM education, and *(b)* how can the critical viewpoints on STEAM be addressed in the course implementation?

3 COURSE DESCRIPTION

3.1 Background

The Network-based Computer Ecosystems (NCE) course is part of the Computer Science (CS) bachelor and master program at University of Vienna, Austria. It is a compulsory elective course that builds upon certain mandatory courses as prerequisites, and is open for enrollment for both advanced bachelor's as well as master's students.

The course is designed to be hands-on and interdisciplinary using Pure Data[1]: students first implement Digital Musical Instruments (DMIs), then connect them remotely via the Internet and finally play them in a joint performance. Thereby students are gaining practical experience in a variety of topics ranging from interaction design and music computing to network and protocol design. The course addresses non-beginner Computer Science students with interest in music, though no background or prerequisite knowledge in music is required. The teaching team are two post-doctoral lecturers with research expertise in Human-Computer Interaction (HCI) and computer networks, respectively, and a master's student as teaching assistant. All three have had musical education and training (to varying degrees).

Originally, the course was designed to take place on-campus, but as a result of the COVID-19 outbreak, several adjustments had to be made. We shifted to a purely distance-based format, which included live online lectures, homework assignments, written feedback on each submission, and an online course forum for interaction outside the lectures. For live lecture we used an online meeting platform[2], which enables live audio and video streaming, chats and screen casting.

3.2 Curriculum

The course aim and schedule were designed and set well before the start of the semester already. The workload distribution and topic direction was adapted from the previous iteration of the course, including student feedback we received on that iteration. Effort was devoted to have clear instructions, grading criteria, and aims to communicate for every lecture and assignment.

In Figure 2 we give an overview of the whole course curriculum along the timeline of the semester. The course consisted of five 'topic' parts, each corresponding to one step in the Stanford Design Thinking process [20], and the submission of a final report as the main columns of Figure 2 illustrate.

Each *Part* was introduced and discussed in a theoretical *Lecture*. Students were subsequently asked to work on the topic in a hands-on manner through various homework *Assignments* (A1 to A5) with firm deadlines, either individually or in pre-assigned groups. For each assignment, students had to hand in some form of *Artefacts*: a written concept on a design task, a DMI prototype version, a video demonstration of an implemented DMI, or audio samples generated by the DMI. The dashed lines in Figure 2 mark the approximate time frames for each topic on a *Week*-based timeline at the bottom showing additional events throughout the course.

Assignments and Artefacts. With respect to difficulty and effort of the assignments, it should be noted that three assignments (A2, A3, and A4) required particular effort on behalf of the students, as they were expected to acquire programming skills in Pure Data, understand and practically implemented different methods of sound synthesis, or use integrate additional tools (mobile interfaces, networking technology) to augment their DMIs and create a sound mapping. For A1-A4 students had to record themselves playing their DMI in a demonstration video, which was subsequently reviewed by the lecturers or in the case of A3 by two peer students. Additionally, students had to integrate an audio networking technology called Virtual Rehearsal Room (VRR)[3], an auditory virtual environment enabling joint performance in a distributed fashion, to be able to participate in the final performance. This performance was the result of the last assignment A5 involving all students playing their DMIs. The musical piece to be performed was composed by the first author specifically for the purpose of this final performance, based on sound samples students had previously recorded on their DMIs. In the final course lecture, students then interconnected their DMIs

[1]https://puredata.info/ (last accessed 14 April 2022)

[2]https://bigbluebutton.org/ (last accessed 14 April 2022)

[3]https://vrr.iem.at/ (last accessed 14 April 2022)

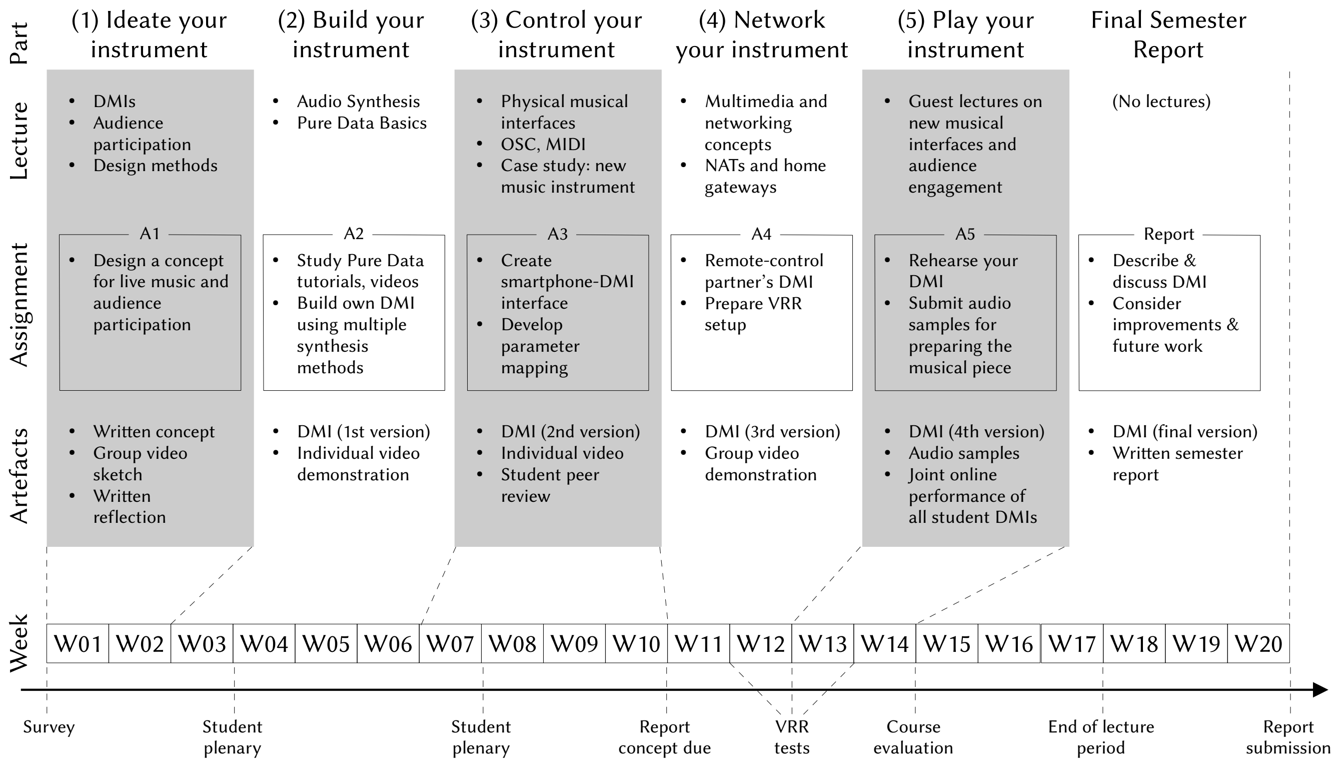

Figure 2: Course progression over the semester, time spans shown in weeks: each topic area with details on lecture content, homework assignments, and artifacts produced is shown in one column. Additional events are marked below the timeline.

using the Virtual Rehearsal Room (VRR) to rehearse and perform together over the Internet (see Fig. 1 left).

Additional events. At the beginning of the course, students participated in an informal *Survey* in which they were asked about their extent of musical knowledge and/or training, and proficiency in Pure Data. To answer practical questions or solving specific implementation challenges, two *Student Plenaries* were held by the teaching assistant. Additionally, three slots for *VRR tests* were scheduled for students to test their network setup for the joint performance. Towards the *End of lecture period*, students were asked to participate (voluntarily) in the university-internal *Course Evaluation* survey. The standardised questionnaire[4] includes rating-based and open questions related to the quality of teaching, relevance of topics covered in the course and appropriateness of the workload.

Final Semester Report. Students were required to reflect on and describe the process of implementing their DMI, from the first prototype to its iterative refinements, in a final report. They were briefed to describe and discuss different aspects such as synthesis methods, the interface and sound mapping, technical and an aesthetic perspective, possible improvements, etc. Formal requirements were to meet certain scientific standards (i.e., proper citation of external references, proper formatting using a paper template). The submission was split into two stages. The first draft submission was a *Report concept due* in the middle of the course on which students received feedback. The second and final *Report submission* was due at the end of the semester.

Assessment and workload. Students were awarded percentage points for active participation (max. 20%), practical work on assignments (max. 60%) and the seminar report (max. 20%). Therefore the maximum overall score achievable was 100%. We graded along pre-defined criteria either quantitatively (e.g., forum and lecture activity, number of submitted required samples and sound synthesis methods implemented) or qualitatively (e.g. evaluating assignment submissions). We did not grade aesthetics and artistic qualities of the students' submissions, but provided informative feedback to support their music-related learning effects. In all cases the first check using the pre-defined grading criteria was done by the student assistant and then reviewed and finalised by one of the lecturers. The course was designed for 6 ECTS credits[5], which equals 150 hours workload in Austria's higher education scheme.

[4]See https://www.qs.univie.ac.at/fileadmin/user_upload/d_qualitaetssicherung/LV_Evaluation/LV_Frageboegen/Fragebogen_HTML/005-1-V6-en.html for the full questionnaire (last accessed 21 July 2022)

[5]https://education.ec.europa.eu/levels/higher-education/inclusion-connectivity/european-credit-transfer-accumulation-system (last accessed 14 April 2022)

4 DATA ANALYSIS AND RESULTS

4.1 Data Collection

The online format and the subsequent changes in interaction and feedback, which all happened online, meant that it was comparably simple to collect data of different qualities on the progression of the course:

Quantitative data: Attendance and dropouts (§ 4.2), participation metrics for the online lecture (§ 4.3) and Moodle[6] course forum (§ 4.4), percentage points for the different submissions graded by lecturers and students' final grades (§ 4.5).

Qualitative data: Recorded expressions of the students' participation in the online sessions mostly as chat messages (§ 4.3) and in the forum (§ 4.4), the students' submissions of multiple exercises throughout the semester including iterations of the DMI and a seminar report (§ 4.5), the University-internal course evaluation (§ 4.6) and the joint performance (§ 4.7). The lecturers' written feedback on the submissions (assignments and final report) was not considered for this paper.

4.2 Registration, Participation and Dropouts

The seminar's 25 seats were fully booked before the semester started. Students came from three different programmes: Master Computer Science (M) 11 students, Bachelor Computer Science (B) 13 students, and Master Computational Science as optional subject in Physics (M Ph.) 1 student. 4 students deregistered before the semester started. Table 1 gives an overview of the 16 students who participated and finished the course. 5 other students dropped out during the course (mostly after the first assignment A1) and did not pass. When we asked the students about their experience with musical instruments, 10 out of 21 students stated to play or have played at least one instrument, but none had experience with Pure Data.

4.3 Lecture Participation of Students

There were 9 lectures with mandatory attendance held online. 14 of 16 students that passed the course attended all of the lectures or missed at most one. We counted as active participation during a lecture when someone asked a question, provided a comment, or answered a question to the audience at least once. Overall, we recorded 904 chat messages in the public chat of the virtual seminar room. Most students used the written chat to communicate questions or comments throughout the lectures. Their chat messages addressed course topics such as administrative questions (e.g., grading, group work organisation), questions addressing the learning content (e.g., acoustics, Pure Data basics) or unsolicited feedback on the lecture.

In some lectures, a sudden "burst" of chat messages occurred when students expressed their excitement. The first occurred after demoing the wireless remote control of a Pure Data patch and modulating the sound with a smartphone. Students immediately commented with messages such as *"this is cool, haha this is amazing [..] fun!"* (S04) or *"epic! [..] really excited, but real life hands on with the interfaces would have been extremely cool :D"* (S11). When showing the students the remote control of Pure Data patches over the Internet using our custom-made UPD forwarder, one commented *"You guys both seem genuinely motivated and happy to teach this class. One can really notice this as a student and it makes the course much more enjoyable"* (S11), and most of the others agreed. Lastly, the joint performance caused many outbursts of approval and enjoyment (see overlay messages in Fig. 1).

[6]https://moodle.org (last accessed 14 April 2022)

4.4 Lecture Forum Activity of Students

The lecture's Moodle forum had 28 predominately short threads on three main topics: organisational issues (e.g., group finding, problem with Moodle), teaching modalities (e.g., questions about homework assignments or report guidelines) and learning content (e.g., technical question on software or tutorials used and provided in the course). See Table 1 where we counted whenever a student contributed at least once to a thread. This analysis shows that the forum was mostly used for issues around learning content.

4.5 Homework Assignments, Seminar Report and Final Grades

14 of 16 students handed in all required submissions. Two missed one assignment each, causing one (S14) to be not included in the composition for the joint performance. Regarding the quantitative grading of the homework assignments, points were deducted for missing tasks, poor quality, missed deadlines or a combination of these, for instance in most cases of A2, because the student did not create all three required sound synthesis methods.

For the seminar report, most students scored 17% or more of 20% maximum. Three students submitted reports with major problems. Their reports were either to too short, missing important and required parts, had formal problems, or a combination of these. Two students submitted high-quality reports but missed the deadline, resulting in zero points for the draft (S11) and the final report (S06), respectively.

The rightmost column of Table 1 lists the final grades. The positive students achieved a 1.7 on average (dev. 0.8) on the 5-point academic grading scale. 5 students failed the course due to achieving less than 50 percent of the maximum credit. Including these, the average course grade was 2.5 (dev. 1.6).

4.6 University-internal Course Evaluation

11 students filled out the anonymous course evaluation questionnaire. In the first part of the questionnaire, students rated 19 statements using 5-point Likert scales different course aspects such as quality of learning material, examination modalities or presentation aspects of the lecturers. According to the statistical analysis, our course received high and above-average ratings compared to all other lectures of the Faculty of Computer Science at the University of Vienna.

When asked about beneficial partial achievements in the course, students predominately picked the following (multiple choices allowed): exercises, active participation and peer feedback. Many students added free-text feedback such as *"It was nice to create a 'musical instrument' out of nothing as part of the exercise. We also got to give feedback to others, so we could see how others did it. And we got to try out these instrument in the end, orchestrated together."*

Student		Lecture participation			Forum act. and topic			Homework assign.		Report	Grade
nr.	study	attend.	active	points	org.	teach.	learn.	subm.	points	points	
S01	M	9	6	17 %	-	-	-	5	59 %	17 %	1
S02	M	9	6	17 %	-	1	-	5	58 %	17 %	1
S03	B	8	6	16 %	1	3	3	5	51 %	19 %	2
S04	B	9	9	20 %	2	-	3	5	58 %	19 %	1
S05	B	9	5	16 %	-	-	1	5	50 %	15 %	2
S06	M	7	4	13 %	1	-	-	5	49 %	5 %	3
S07	M	9	6	17 %	-	-	2	5	59 %	19 %	1
S08	B	9	7	18 %	-	4	4	5	58 %	19 %	1
S09	B	6	4	12 %	-	-	1	4 (not A3)	47 %	17 %	3
S10	B	9	7	18 %	-	-	-	5	56 %	17 %	1
S11	M	9	5	15 %	-	-	1	5	58 %	13 %	2
S12	M	8	8	19 %	-	-	3	5	60 %	19 %	1
S13	M	9	5	16 %	1	1	2	5	56 %	19 %	1
S14	M	6	4	12 %	-	2	-	4 (not A5)	41 %	13 %	3
S15	M	8	3	13 %	-	-	1	5	58 %	9 %	2
S16	M	8	5	15 %	-	-	-	5	56 %	18 %	2

Table 1: Overview of passing students and their numerous activities in certain parts of the course

For the question what they liked about the course they mentioned the good communication, to learn a new programming language (Pure Data) in one semester, the learning content, the highly motivated teachers, to be creative, to have an artistic experience, the high fun factor, good balance between demanding exercises and fun. Quoting one student: *"This is the best course I have taken at University of Vienna so far. It's content is very original and interesting and opens new horizons to computer science students. The lecturer is super motivated and inspiring and motivated me to steer my further studies in this direction."*As improvement suggestions the students mentioned presence teaching, more preparation time for the VRR setup and for solving technical problems, more detailed explanation of Pure Data, and asking for less group work.

4.7 Final Instruments, Musical Piece and Joint Performance

At the end, all 16 remaining students had working and playable instruments written in Pure Data and controlled by a mobile device to perform a piece together. The piece was composed by using 15 samples the students submitted as part of the last homework assignment A5. (One student missed to submit the last homework assignment and was thus not included in the score.)

14 students performed the composition together playing their own instruments. One (S08) had technical problems which could not be solved during the session. For the performance, an image showing the samples on a timeline how they should be played by each player was displayed for everyone as shared screen (see Fig. 1 right). The first "premiere" had a duration of 3'15" and the second performance took 3'22". An annotated screencast video of the final performance is available online[7].

[7]https://youtu.be/sNNtggwXwzc (last accessed 14 April 2022)

5 DISCUSSION

5.1 Observed Outcomes and Impacts

We revisit the first part of our research question that asks which effects we can observe with respect to purported outcomes in STEAM education. The literature shows positive cognitive outcomes through the application of STEAM in teaching [21, 28, 34]. The self-developed and constantly improved DMIs that our students enhanced their programming skills by learning and using Pure Data, which was previously unknown to them. Also, the development of remote-control user interfaces and the requirement to network their instruments taught and strengthened skills in these areas. This is of particular relevance since problems were resolved with techniques that are applied in practical, non-DMI applications the very same.

Procedural impact of increased creativity [19, 22] is difficult for us to gauge. We do note, however, that our course provided ample ground for the students to express themselves throughout the semester in the ideation, design, building, enhancing, and playing of their instruments, including all of the programming and aesthetic choices. At the end of the course, all but one student succeeded to play together in the joint performance.

Many of our results can be seen as attitudinal impact, similar in spirit (though not in method) to findings of [1, 10]. This starts with the number of enrolled students: the course description which mentioned ideation, design thinking, DMIs, and networking attracted students to this elective course. Student engagement and motivation are expressed on the one hand by the overall and regular active participation. On the other hand, the many positive messages that students posted in the chat during lectures showed their enjoyment, especially during the joint performance. The same is true for the university-internal course evaluation where students expressed their content with the setup and implementation of our course.

5.2 Addressing Criticism of STEAM Education

We now look at our results in the light of the criticism of STEAM. The first sentiment criticizes the lack of a shared understanding of what STEAM actually comprises, limiting the comparability [8]. In comparison to STEAM school projects that try to attract pupils to STEM fields, our course occupies a peculiar place in the STEAM landscape in that it targets advanced university students of computer science – that is, non-novices in tertiary education that have already subscribed to STEM. Our course advances our students' STEM skills while introducing them to artistic knowledge.

Concerning the arts integration [15], we settled for DMIs and networking them, which aligns well with our specific sub-fields of expertise in Computer Science. The students' instruments play a central role throughout the course, from design to implementation and playing in the final session. We clearly go beyond exploiting arts as a mere source of project ideas for tinkering, and do provide room for our students to innovate and express themselves. In terms of emphasizing the creative thinking process or the final creative outcome, our course does not tend to one side or the other: both the constant evolvement of instruments and their joint performance are of importance to the motivation and engagement of our students.

The third major point of critique regarding STEAM education concerns problems in concrete implementations in teaching [13]. Student reactions and course evaluation results indicate that our course successfully steered clear of these problems. We attribute this to the goals we had for the course, the detailed plan (dates, times, deadlines, see Fig. 2) we prepared accordingly, the structured assignments with feedback loops, and the concise assessment and grading criteria. Self-directed learning, while demanding for the students, was supported by our teaching assistant. Also, non-novice students are generally more experienced and likely familiar with studying topics on their own, so the probability was lower that this would pose an insurmountable problem.

5.3 Reflection on Teaching Experience

Reflecting on the overall teaching experience can facilitate future implementation of STEAM-based curricula. With respect to our contextual factors, the following aspects might provide insights:

Pacing and timing. The course design worked as planned, requiring no major deadline extensions or assignment adaptations. Given the short amount of time allocated on presenting and discussing (the theory of) new topics – including music computing, sound synthesis methods, and various network topics –, and the different knowledge and competence levels of the students, they were strongly challenged to explore novel concepts independently. We note that while this type of self-directed and motivated learning can be presumed in the context of higher education, this might not be true for less experienced or novice audiences.

Stimulating student collaboration. We ensured during group assignments that students could work with students with whom they had not previously worked on other homework assignments to encourage collaboration among all participants. Our observations in the first and second plenary sessions of the students suggested that this group formation approach was indeed effective in supporting students to get to know and join efforts to solve complex assignment topics. The students also noted this positively in the university-internal course evaluation.

Distance learning format. The forced transition to a distance learning format not only led to a number of adjustments with regards to course implementation (i.e., online live sessions, stronger reliance on the online course forum), but also introduced some technical challenges, particularly related to the joint performance. To perform, students were required to set up connections from their home networks. As some students were not able to access their local routers (i.e., in dormitory networks), a special UDP forwarder had to be developed for this purpose. Furthermore, the setup of the VRR library was difficult on computers running on macOS due to software security measures. Overall, these obstacles had positive implications. First, students were able to learn an additional network technology and to participate in a new type of performance experience. Second, in order to solve issues accounted with the VRR software, students were strongly encouraged to work closely with the teaching team to resolve these issues.

5.4 Limitations

While our findings align well with the positive purported impacts of the STEAM education approach, and its known critical issues did not arise as far as we could see, we must emphasize their limited generalizability. Our work only contributes to a specific form and context of STEAM education: university students that are already subscribed to Computer Science, a typical STEM topic. Therefore, our course contributed little to attracting outsiders or newcomers to STEM fields. In particular, we cannot draw conclusions on improving the inclusion of minorities through STEAM education due to our small sample size. Also, Digital Musical Instruments provided a peculiar vehicle to integrate arts in our STEM course. Other choices of art forms and processes are possible and interesting in their own right. In terms of gauging improvements and learning outcomes, we neither tested for these specifically, nor have base values – e.g. from a non-STEAM version of the same course – to compare with. The course was implemented in distance learning mode due to the ongoing COVID-19 pandemic. This severely limited our pedagogical options, especially for the joint performance at the end. On the other hand, using online platforms for teaching provided a straightforward and reliable method to record student participation and interactions as the data corpus for this study.

6 CONCLUSION

We present the implementation and evaluation of a new university STEAM course for non-novice CS students using DMIs and contribute to the ongoing discussion on STEAM education as follows. With respect to known benefits of STEAM education, we have observed the following concrete outcomes: acquisition of programming skills in Pure Data, DMI prototyping and refinement, and continuous student engagement and motivation through active participation. Addressing critical views on STEAM education, we hope to facilitate comprehensive comparative studies in the future by having described our approach and various contributing contextual factors.

Our results suggest that sound and music computing and in particular DMIs are suitable concepts for advancing both technical skills and artistic/musical knowledge of non-novice STEM students. The implementation of a STEAM course for non-novice STEM students worked well for our student sample. Future studies should go beyond the 25 students and a single iteration of this course.

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