Audience participation in musical performances can be manifested in many ways, from a receiver sense (sitting in silent contemplation of sounds, for example) to a more active form of participation involving physical actions contributing to the performance (singing along with musicians, for example). We consider the latter to be creative participation. Note that we’re not referring to creative participation in the semiotics sense, implying that the meaning of the artwork is completed by the receiver,¹ which can be considered a cognitive form of participation. Rather, we’re more focused on how creative participation can foster audience-performer collaboration for music making.

As Western art music has evolved from early music forms for the recreation of amateurs, to post-Renaissance music for entertainment by highly skilled professional performers, it has created a divide between audiences and performers. Certain music traditions have developed unwritten rules about audience etiquette, constraining the range of behaviors and interactions judged to be acceptable; in some concert halls, “correct” audiences are expected to sit quietly and applaud only at certain times. The musical communication model that prevails in many cultures and traditions operates in a linear and unidirectional way—from composer to performer to audience-receiver.

What if this were revisited (but not replaced) to create alternative musical experiences, changing the relationships between the composition, composer, performers, and audiences? Reconfiguring the links between the triad of artwork, artists, and audiences is one of the goals of participatory art, and researchers have explored such a reconfiguration within the interactive and performance arts.¹ One remarkable initiative aims to enrich concert experiences using digital multimedia and Internet technology;² however, the work doesn’t address creative participation by audiences during live performances, which is the object of our current and other works.³–⁶

Open Symphony is a new participatory music performance system that explores the creativity and spontaneity of reactive interactions between an ensemble of performers and an audience using mobile technology and data visualization. The system aims to extend the nature of live music performance by enabling audience members to collaborate in the development of a musical piece. Audience members actively influence the music being played in a live environment, creating a mutual experience between multiple audience members and performers.

Audience Participation in the Digital Age
In contrast to a presentational music performance, where performers prepare and provide music for another group, the audience, a participatory music performance can be defined as a special type of music practice in which the performer-audience distinctions are blurred and where all participants actively contribute to the musical outcome.⁷ Participatory music has a long history in many cultures and has taken various forms, but generally, such music shares certain goals, including “heightened social

Yongmeng Wu, Leshao Zhang, Nick Bryan-Kinns, and Mathieu Barthet
Queen Mary University of London

The Open Symphony system explores audience-performer interaction at live music performances. Audiences influence performers by voting for various musical “modes.” Overall, feedback on usability and the user experience was positive, and live interactions demonstrated significant levels of audience engagement.
interactions” and the inclusion of as many participants as possible.7

Motivations for audience participation in modern and contemporary live performing arts include the desire to

- encourage active spectatorship,
- create communities in which participants are equal by developing a sense of closeness between the audience and performers and between audience members themselves,
- undermine the boundaries of traditional expectations and behaviors, and
- reaffirm the “liveness” of a performance (given the ever-increasing number of live acts based on prerecorded media).8

Interesting parallels can be drawn between some of these motivations and the contemporary perception of the audience’s role, which some say has recently changed from a primarily passive role to one of “co-creating values,” with audiences increasingly wanting to “shape” their own experience.9

In our attempt to create a classification framework for participatory live music performance (PLMP) systems, we started by differentiating various participatory art forms based on the level of audience creative participation, from partial (where audiences influence content produced by artists) to full (where there are no artist-audience distinctions). Until recently, participatory art forms with partial participation used low-level technology for audience interventions. For example, in Steve Jackson and Ian Livingstone’s fantasy roleplay gamebooks “in which you are the hero,” readers use dice to determine the progression of the narrative. Another example is verbalizations in improvisational theatre and stand-up comedy, letting the audience give cues to performers.

However, human-computer interaction (HCI) and communication technologies have much to offer when it comes to participatory art forms. These technologies provide a platform for mediating and transforming creative information between agents (whether human or virtual, colocated or remote). Furthermore, they can help overcome the boundaries that low-level technologies impose on creative interactions, with the potential of scaling them up to large audiences. At the intersection of music and HCI, several techniques and interaction models have been proposed to control access points for technology-mediated audience creative participation in the musical context.10

In Open Symphony, the audience acts as a “meta-composer/conductor” by voting for playing modes, communicated to performers through live graphic scores. Our framework for classifying PLMP systems appears in the “Framework for Participatory Live Music Performance” sidebar, along with considerations of how Open Symphony and other works fit into this framework.

The musical form of Open Symphony is directed improvisation, which belongs to the experimental music genre associated with non-traditional compositional and performance practices. Several other nontraditional conducting techniques, not mediated by technology, use playing modes and visual cues. One example is the Conduction system, created by Lawrence “Butch” Morris, which proposes an exchange between a composer/conductor and performers that provides the immediate possibility of altering the musical attributes of a performance based on a system of signs (see www.conduction.us). However, Morris’ Conduction is not concerned with creative participation from the audience.

Design Process and Requirements

We adopted an iterative participatory design methodology because, as described by John M. Carroll and Mary Beth Rosson, “the people whose activity and experiences will ultimately be affected most directly by a design outcome ought to have a substantive say in what that outcome is.”11 Active participation by stakeholders and users (composers, performers, and audiences) took place in four different forms over a year: regular design sessions with Kate Hayes, a musician and Guildhall School of Music and Drama (GSMD) graduate; focus groups during pilot experiments with performers; focus groups during rehearsals with performers; and interactive performances with both audiences and performers, including evaluations. The core design team comprised three of us—Yongmeng Wu, Leshao Zhang, and Mathieu Barthet—plus Hayes.

We initially explored and defined the problem during design sessions with Hayes, who also acted as the project’s music director. From the artistic perspective, Open Symphony aims to challenge the audience and performer roles,
Here, we present our framework for classifying participatory live music performance systems, using the framework to position our work with Open Symphony as well as the works of others:

- **Audience creative participation level**: from partial (Open Symphony) to full (no artist-audience distinctions);
- **Audience creative participation motivation**: imitative, competitive, contributing, or directing/conducting (Open Symphony);
- **Agency distribution**: how creative agency is distributed, from the individual level to the collective level, such as audience subgroups (Jason Freeman’s work\(^1\) and Open Symphony) or the entire audience;
- **Agency mediation**: directness of the agency, from indirect (as in Open Symphony, where performers follow audience instructions and create the sounds) to direct without mediation (where the audience creates sounds themselves\(^2,3\));
- **Agency degree**: whether participants act upon a performance (audience adds content to an existing narrative\(^4\)) or generate the narrative themselves (as in Open Symphony, where the audience co-creates the performance);
- **Agency constraints**: from restrictions (as in Open Symphony, where the audience chooses between certain options) to complete freedom (where the audience has full control);
- **Creative participation modalities**: examples include audition (audience generates sounds\(^2,3\)), vision,\(^5\) multimodal audition and vision (as in Open Symphony, where the audience actions influence projected visuals and sounds mediated by performers, similar to other work\(^6\)) or when audience members produce sounds and visuals with their mobile phones\(^3\);
- **Creative participation media**: for example, sound/music,\(^2,3,6\) lights (where the audience can control light effects\(^7\)), 3D virtual content,\(^8\) or text messages;\(^4\)
- **Creative participation affordances**: based on body and movement (such as dancing\(^5\)), hand/arm gestures,\(^3\) votes (as in Open Symphony and other work\(^6,7\)), or linguistic expressions;\(^4\)
- **User interfaces**: web-based interfaces (such as Open Symphony and other work\(^6,10,11\)), tangible interfaces,\(^12\) wearable interfaces,\(^9\) or a mixed reality display;\(^8\)
- **Situation**: co-located (as in Open Symphony, where the audience and performers physically share the same space), remote, or both\(^4\);
- **Scalability**: from small groups\(^12\) to potentially large audiences (as with Open Symphony and other works\(^6,9–11\)).

**References**

redefining the direction of musical creativity and expertise to create spontaneous and collaborative new music compositions. The core design team thus established the following main design requirements (DRs) for a PLMP system for an audience watching a small ensemble performance:

- facilitate audience creative participation (DR1),
- support performers’ musical expression—performers should not feel controlled by the audience and should be able to express their musical expertise and keep some music credit (DR2),
- allow responsive audience-performer interactions (DR3),
- be intuitive and inclusive to suit musically untrained audience users (DR4),
- foster audience engagement in the performance (DR5),
- support musical co-composition (DR6), and
- be scalable to large audiences (DR7).

We used mockups and prototyping to discuss models, varying creative participation affordances and the musical system and GUI designs (the description of these early models and their evaluation lie beyond the scope of this article).

**Open Symphony System**

To establish a creative balance between the audience and performers, we replaced the traditional musical score and central conductor with deconstructed *music playing modes* and multiple audience conductors.

**Artistic and Interaction Models**

The creative interaction model we developed with Hayes let audience members collectively specify the playing modes—or *typological* music attributes—and let performers control *morphological* music attributes within the constraints established by the modes. Performers’ interpretations of the modes can be based on pre-composed material either provided by a composer or generated during the rehearsal. The interpretations are shaped by the expressive intent—for example, through choices of timing and timbre.

A voting system orchestrates mode selection, where electors are audience members, and “candidates” comprise five playing modes (selected by Hayes):

1. *Drone*: single sustained note,
2. *Two-note*: two notes played alternatively,
3. *Motif*: small set of notes forming a melody,
4. *Improvisation*: free improvisation, and
5. *Silence*: no playing.

The primordial Silence mode was added based on the results of a focus group with performers. We assumed that the modes would be straightforward concepts for the audience to learn and understand, and we assumed that the sufficiently loose constraints would offer performers enough freedom to express their expertise and creativity.

For such interaction to take place dynamically during a performance, we had to present the relevant information in a timely and efficient manner. We developed information visualization techniques to simplify the exchange of creative data. We wanted the visualizations to serve as a cognitive tool to support decision making and to be aesthetically pleasing. We divided the audience into groups, each assigned to a performer automatically once connected to the user client. We used group votes to generate individual symbolic scores for each performer. The voting system relies on the plurality principle, meaning that the winning mode is that with most votes. Mode indications are directive for performers; however, the artistic brief gives performers flexibility in the transitions from one mode to another (namely to avoid abrupt interruption of musical expression).

**Creative Communication System Architecture**

The Open Symphony creative communication system comprises three components.

**Audience user client.** The Open Symphony audience user client is a cross-platform and smartphone-friendly web-based application developed in HTML5. Following visual perception principles, we used different visual channels to display different types of data—shapes were associated with performers and pattern,
color, and motion were associated with playing modes.

The GUI (see Figure 1) displays a shape that identifies the assigned performer, a bar chart representing the number of votes for each playing mode in a given group, and buttons for selecting the playing modes. The vote buttons are located at the bottom of the mobile device for easy single-hand operation. We chose a dark background color for the GUI to avoid any visual disturbance that a brightly lit screen might cause in a concert setting. Users can also access instructions at any time by pressing a “help” button.

Visual client. The visual client generates a graphical score for performers and audience feedback (see Figure 2). The designed score notations build on features of traditional music, where time-based events appear from left to right as well as on contemporary graphic notations. Each performer has a score timeline, starting with his or her assigned shape, where graphical symbols represent the playing modes and the status of the audience votes is shown.

With this one-to-one mapping, the visual client provides direct feedback on the audience’s interaction, encouraging users to actively participate. Audience votes are sampled at a frequency set up to limit network cluttering. When a new mode receives a vote, its symbol appears gradually before reaching its final shape to help users follow time and add dynamism to the interface for increased engagement.

Server. The server component, powered by Node.js, is a cross-platform server-side JavaScript framework. Node.js suits the high-concurrency, low-CPU consumption requirements of Open Symphony. The server caches the instructions from the mobile applications and the visualization client in memory, allowing the system to fetch them with representational state transfer (RESTful) APIs, thus creating a communication channel for mobile applications and the visualization client. We set the frequency of requests such that the graphical score would update every two seconds, avoiding sudden changes.

Evaluation Procedure

We evaluated audience and performer responses in two different performance contexts (in a lab and “in the wild”). Our aim was to gather subjective feedback on the experience through a survey and to explore how the system was used, how it changed performance practice, and how it could be improved.

Sessions and Participants

The first session (denoted SA) was hosted in a black-box performance space at Queen Mary University of London (QMUL). The performers were four professional musicians (three flutists and a clarinetist playing the bass or alto clarinet) who were GSMD graduates. We recruited audience participants through an online call for participations at QMUL and GSMD. In total, we had 13 audience participants (including two experimenters, who interacted occasionally). The survey was completed by the four performers and 11 recruited audience participants (five males and six females) belonging to the following age groups: 20–29 (5), 30–39 (4), 40–49 (1), and 50+ (1). Audience participants included graduate students (MSc and PhD), researchers, a photographer, a teacher, and musicians.

The second session (SB) was held as part of the Conference on Human Factors in Computing Systems’ Interactivity track, in a large open booth located in the conference’s exhibition hall (see Figure 3). The performers were four professional musicians (one violist, two violinists, and a clarinetist playing the bass or alto clarinet) who were University of California, Berkeley music graduates. In total, 102 audience participants took part in interactive performances over two consecutive days (including two experimenters, occasionally). The survey was completed by 20 participants (16 males, two females, and two declined to state) belonging to the following age groups:
Audience participants included researchers, doctoral students, designers, software developers, and lawyers. Two out of the four performers provided feedback in SB.

Because votes from the two experimenters participating as audience members might have influenced other participants’ votes, they were included in the log-based behavioral analyses (discussed later). However, we do not believe these votes had a major impact on the overall audience participation.

**Procedure**

In each session, the procedure included four main stages: performer rehearsal, system presentation, series of interactive performances, and post-performance survey. During the rehearsal, we introduced performers to the system. Then, they practiced with the music director, first without the technology (using paper cards and hand signs for mode indications) and then with the technology (for approximately 2–3 hours).

In SA, all participants took part in four pieces, where the number of active modes gradually
increased (from two to three, four, and five modes for pieces one to four, respectively), so audience members (who were all seated) could progressively learn the concepts of the modes and their influence. The performance and survey lasted approximately two hours.

SB comprised 10 pieces held on consecutive days, mostly with different participants (average of 1.4 performances per participant). Audience members were seated (first rows) or stood at the back. In both sessions, the duration of each piece was fixed to four minutes. During the presentation, we introduced the interaction principle and how to connect to (URL or QR code) and use the app. However, in SB, not all participants followed the presentation, because attendees could join or leave the booth as desired. Instructions cards (A5 flyers) were available on the booth chairs and tables and were distributed to some newcomers. After two iterations with only two and three modes enabled, we decided to keep five modes available for all other performances, because the music was more varied. For both sessions, we made audio/video recordings and stored the interaction data on our server.

Apparatus and Setting
In both sessions, audience and performers faced each other as in a traditional performance setting (see Figure 3a). Two screens connected to the same Apple MacBook displayed the visualization; for the audience, a large 5 \times 3-m rear projection screen (SA) and an 80-inch high definition digital television (SB) was placed behind the performers, and for the performers, an HDTV was located slightly on the side of the stage area (SA) and on the floor in front of the performers at an angle of approximately 45 degrees during SB (see Figure 3b).

In both sessions, audience participants were invited to use their mobile devices with either the venue Wi-Fi or mobile broadband. In SA, we used three video cameras (focused on the performers and the front and back of the audience). In SB, one video camera was used at the back of the audience. In SA, a dimmed lighting was used for projection, letting performers see each other while keeping the intimacy of a concert setting. In SB, normal lighting was used, suiting the open booth configuration in an exhibition hall.

Survey
In both sessions, we conducted a survey using online (SA) and paper (SB) self-completion questionnaires for audience (SA, SB) and performer (SA) participants. We collected reflective feedback for SB performers by email for practical reasons. We chose questionnaires over interviews for scalability reasons, to collect feedback so the performance was still fresh in participants’ minds and to keep the experiment to a reasonable length. In the statistical analyses that follow, we used a type I error rate of \( \alpha = 0.05 \).

Feedback and Observations
We performed subjective evaluations as well as behavior and thematic analyses. We also conducted various modifications and considered suggestions from participants.

Subjective Evaluations
Participants rated their experience and the system (see Figure 4) using a five-point Likert scale, ranging from “strongly disagree” (1) to “strongly agree” (5). Our questionnaires included traditional usability metrics to test ease of use, understanding, and effectiveness. They also included user experience (UX) metrics to enquire about perceived satisfaction, the need for audience creative participation and whether creative collaboration within audience members occurred (DR1), user interface implementation choice (mobile phone), sense of engagement (DR6), and the system’s pedagogical and retention potential. Note that fewer topics were used in SB due to the shorter amount of time for participants.

To test the agreement between participants (raters), we computed inter-rater reliability (IRR) measures adapted to ordinal data.\(^\text{19}\) The intraclass correlation (ICC) was used for SA, which did not present missing data. A strong significant agreement was found, ICC (A, 11) = 0.764 [F-Test, H0: \( r_0 = 0 \); H1: \( r_0 > 0 \); F(10, 60.9) = 5.58, \( p < 0.0001 \)]. Because results for SB included missing data, we assessed IRR using the bootstrapped Krippendorff’s Alpha, which also showed significant agreement (Alpha > 0), Alpha = 0.21, 95 percent confidence interval [0.06, 0.37], although to a lesser extent than in SA. Several limitations are highlighted by the ratings: the score visualizations were not systematically found to be clear at the significant level (SB) and to help the audience participants to follow the music (SA); and the app was not found easy to use at the significant level in the second session (SB only).

The results also highlight several successful aspects of the system: none of the participants significantly disagreed with any of the enabling
topics in either session (upper limit of median notch below 3)—that is, in the worst cases, participants expressed neutral judgements for enabling topics. Participants were satisfied with their overall experience and enjoyed interacting with the performers at the significant level (SA and SB). Participants also found the app easy to use in the first session (SA), thought its interface was clear (SA), and they felt engaged in the performance (SA) at the significant level. The use of mobile devices did not significantly prevent participants from paying attention to the performance (SA), and participants enjoyed collaborating with audience members and were keen to participate again at the significant level (SA and SB; for SA this latter result comes from answers to a polar yes-no question, not reported in Figure 4).

**Behavioral Analyses**

Our behavior analyses looked at interaction data from server logs and video recordings.

**Creative interaction data.** We aimed to analyze how frequently participants voted and whether differences occurred between playing modes. We compared vote interactions for pieces with five available modes (one piece for session A and eight pieces for session B). From the server logs, we computed the following: \( \bar{v}_{ijk} \), which is the mean vote frequency per participant for mode \( i \in \{1; 5\} \), session \( j \in \{1; 2\} \), and session piece \( k_{j-1} = 4 \) (one piece) and \( k_{j-2} \in \{3; 10\} \) (eight pieces). For a given mode and piece, \( \bar{v} \) is obtained by dividing the total number of votes for the mode by the number of participants to the piece and \( \bar{v} \) is expressed as the number of votes per minute.

We conducted a two-way analysis of variance (type II sum of squares analysis of variance) that examined the effects of the session (two levels) and mode (five levels) on the mean vote frequency \( \bar{v} \). Our dependent variable, the mean vote frequency \( \bar{v} \), did not depart from a normal distribution for the groups formed by combining the levels of the session and mode, as assessed by the Anderson-Darling test (A2 always below critical level). There was homogeneity of variance between groups as assessed by Levene’s test for equality of error variances, \( F(9, 35) = 1.30, p = 0.27 \). There was no interaction effect between the session and mode, \( F(4, 35) = 2.24, p = 0.08 \). There also was no significant main effect of the session, \( F(1, 35) = 0.59, p > 0.45 \), indicating that the mean vote frequency between sessions for each mode was similar.

Results show that participants actively interacted with the system and voted on average...
2.21 times per minute (sum of individual mode mean vote frequencies). The main effect of the mode was significant, $F(4, 35) = 7.31, p < 0.0005$, showing that the mean vote frequency between modes for each session differed. A Tukey multiple comparison test (see Figure 5) indicated three significantly different between-mode vote frequencies: TwoNotes versus Drone and Improvisation, and Drone versus Motif. The fact that participants significantly preferred some modes over others suggests that the interaction was not random but guided by creative decisions. TwoNotes and Motif seem to be voted for more frequently—perhaps because they are more discernible and lead to more variations than the Drone mode, for example.

Help interaction data. We found no significant differences in the participant average frequency of using the help button between sessions, denoted $H(k)$, $F(1, 13) = 0.97, p = 0.34$. During the 14 pieces of SA and SB, the help button was used on average $H = 0.21$ times per minute per participant (once every 5 minutes), which is less frequent than for any of the modes (see Figure 5).

In SA, where all participants took part in the four pieces, a linear regression model (ordinary least squares) fits the help frequency data across pieces $k$ almost perfectly, $H^1(k_{j-1}) = 0.52 - 0.13k$ (coefficient of determination $R^2 = 0.995$). The frequency of using the help button decreases linearly between the first and last pieces, with no help button being invoked at all for the last piece ($H^1(4) = 0$). This suggests that after a learning curve (corresponding to three pieces of four minutes), the participants understand how to interact with the system.

**Locus of attention.** As expected, we observed from video recordings that audience members switched their attention between the stage and their mobile devices when they interacted. Video analyses showed that, on average, audience members spent 34 percent of the total duration of the concert looking at their mobile device (an estimation based on the five participants who could be tracked in the video). This might suggest that audience members spend twice as much time directly focusing on the performers (about 2/3 of the total duration) rather than focusing on the mobile app (about 1/3 of the total duration). However, the limited number of participants who could be tracked prevents a generalization, and we rely on other behavioral data, such as the interaction logs presented previously, to discuss creative engagement during the performance.

**Thematic Analyses**

We coupled opinion-scale questions from the survey with open-ended questions, inviting participants to explain the reasons behind their choice. Other open-ended questions addressed what they liked and disliked, how they positioned such interactive performances compared to traditional ones, how they felt about “conducting” performers, which musical attributes they wished to interact with, and how they would improve the system. Inductive (“bottom-up”) thematic analyses$^{20}$ of audience and performer feedback in SA and SB were conducted by two of us (Wu and Barth). Tables 1–4 present the main themes that emerged from the joint analysis. The themes were based on “codes” that identified a feature of the data (semantic content or latent) that the analysts judged to be of interest. Themes were obtained by refocusing the analysis at a broader level, sorting the different codes, and collating all the relevant coded data within the identified themes$^{20}$.

**Modifications**

We made several modifications after SA (and before SB) to improve the system. The results from the SA survey highlighted that equal vote situations hindered the clarity of visual feedback and the sense of agency, because multiple modes for performers to choose from were displayed on the graphical scores (see Figure 2a). To minimize situations of equal votes, we
replaced constant vote weights with dynamic weights $W(t)$ linearly decreasing over time (by favoring the most recent votes, the sum of vote weights is unlikely to be equal across participants, because votes rarely occur at the same time). For each mode $i$, $W_i(t) = \beta(T - t)$, where $\beta$ and $T$ are predefined constants. (We used $\beta = 100$ and $T = 10$ seconds in SB to ensure that when sampling the function every 100 ms for smooth animations in the app user interface, vote weights remained integers, which are easier to deal with in client/server transactions).

Performer feedback during the SB rehearsal led us to increase the size of the mode symbols in graphical scores, because one of the performers was color blind. This illustrates a noteworthy benefit of participatory design, because we had not accounted for this accessibility issue beforehand. Figure 2b shows the modified interface, combining dynamic voting and increased symbol size. To make the interaction model clearer in the mobile client app and to avoid game-like interactions (such as fast tapping), mode buttons were kept disabled for a certain threshold time $T$ after a vote ($T = 10$ s was the minimal interval between two votes in SB, while no threshold was used in SA).

### Suggestions
Several participants provided interesting suggestions that could influence future developments. One suggestion was to replace the voting system by “giving alternate control to audience members, although this wouldn’t scale very well.” Other suggestions were to add playing modes (such as modes based on “mood”$^4$) and to remove the vote numbers from the app user interface (see Figure 1), because they could be a source of distraction. Additional suggestions included using semantic

### Table 1. Thematic analysis of audience feedback for session A.

<table>
<thead>
<tr>
<th>Theme (no. of codes)</th>
<th>Discussion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agency and creative participation (13)</td>
<td>Several audience participants felt a positive sense of agency and enjoyed participating in the musical creation (“It was the direct input I had towards the performance which made me feel like I had considerable influence.”). Some were influenced by other members’ choices (namely the majority), and group interaction raised concerns (“Sometimes I felt a bit peer-pressured”).</td>
</tr>
<tr>
<td>Lack of agency (10)</td>
<td>The feeling of agency could be limited due to the choice of others (“my choice does not always come first”) or of performers (“the performer chose what was ultimately played”) or due to an inability to choose with which performer to interact.</td>
</tr>
<tr>
<td>Musical attributes for creative participation (10)</td>
<td>Audience participants suggested additional musical attributes for creative participation, such as “key,” “tempo,” “rhythm,” “duration,” and “dynamics.” However, we kept a simple five-mode interaction model to avoid cognitive overcharging and to keep the system open to audience participants without musical knowledge.</td>
</tr>
<tr>
<td>Learnability (6)</td>
<td>Some participants felt that the user interface of both the mobile app and visual client were “intuitive and straightforward.” However, ratings showed that visualizations weren’t always found clear. Negative feedback included a misunderstanding of the interaction mechanism with the mobile app (“I initially thought the more you tap on a symbol, the more votes you submit”), which we addressed before SB.</td>
</tr>
<tr>
<td>Responsiveness (6)</td>
<td>Latency issues emerged due to technical reasons or the interaction pathways and intrinsic “time delay” between votes and musicians’ responses.</td>
</tr>
<tr>
<td>Engagement (5)</td>
<td>Several participants reported that the interaction made them feel “engaged” in the performance. For example, they “paid close attention to the musician and how they were reacting to different input” and their “presence was not passive, but instead, very active.” However, others didn’t engage with the music being produced and “missed the interaction between musicians.”</td>
</tr>
<tr>
<td>Distraction (3)</td>
<td>Sources of distractions due to notifications from other mobile phone applications were reported. Possible solutions could be to use a native app (rather than a web app) or a dedicated hardware interface such as a wearable device.</td>
</tr>
<tr>
<td>Identification (3)</td>
<td>Some audience participants reported difficulty in identifying their allocated performer.</td>
</tr>
<tr>
<td>Game (2)</td>
<td>Two participants found the interaction to be game-like, probably due to the social voting and visual elements. This could also be a source of distraction from the music, inviting us to attempt to minimize this effect in future iterations.</td>
</tr>
</tbody>
</table>
descriptions in the visuals to better explain the system, facilitating the identification of performers using garments (“t-shirts with their shapes”), or using scrolling in the graphical score.

Assessing the Design Requirements
The subjective evaluations and behavioral and qualitative analyses provided rich data for assessing our system against the initial design requirements (DRs), giving us insights into how to improve it.

Facilitating Audience Creative Participation
The results demonstrate a significant ability of Open Symphony to support audience creative participation (DR1). In both sessions, audiences enjoyed interacting with performers. A positive sense of agency and creative participation emerged from self-reports, where participants said they valued their influence on the music, the ability to interact spontaneously in a live context, and the collaboration with performers. Compared to traditional performances, the Open Symphony performances were considered more “open,” “engaging,” “empowering,” and “unusual.”

Supporting Performers’ Musical Expression
Regarding support for performers’ musical expression (DR2), the system challenged the creativity of performers, providing a novel framework for musical improvisation, structured by “necessary restrictions.” Performers appreciated sharing creative roles with the audience, which they considered as the “composer” and felt they had enough space for interpretation. This indicates that the system successfully balanced the creative input between audience and performers.

Ensuring Usability and Inclusion
In reviewing the ability to allow responsive interactions (D3) and to offer an intuitive system for musically untrained users (DR4), audience participants (namely in SA) did refer to the design’s “simplicity” and “intuitiveness.” However, prior instructions and a learning curve are required to fully understand how to negotiate the interactions and make creative decisions. Data from SA suggests that participants no longer require help after they have been adequately briefed and have used the system for three performances. Understandability issues emerged in SB when these criteria were not met, principally for non-musicians who skipped instructions and only stayed for one or two performances, without gradual introduction of modes as in SA.

Relatedly, graphical score visualizations were not consistently found clear. In SA, visualizations suffered from cluttered multiple modes due to equal votes, a problem subsequently solved (see Figure 2). In SB, the lack of

<table>
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</thead>
<tbody>
<tr>
<td>Visualisation (9)</td>
<td>The graphical scores proved useful in supporting music-making decisions (“it was pretty clear where we were in the music”), but other performers’ scores and the overview of audience choices were not necessary for some and were a source of distraction for others (“it distracts one from listening to the other players”). For one performer, it induced a disconnection with the audience.</td>
</tr>
<tr>
<td>Creativity (4)</td>
<td>The system gave performers “options to create in a different way” and “freedom to experiment with notes and styles.” Compared to free improvisations, the system provided them with a “structure” and “restrictions” deemed “necessary” by some.</td>
</tr>
<tr>
<td>Musical attributes for creative participation (4)</td>
<td>Performers suggested additional music parameters (“dynamics,” “tempo,” “keys,” “moods”) or styles to play (such as “Baroque and improv”).</td>
</tr>
<tr>
<td>Participatory creation (3)</td>
<td>Performers valued sharing control over music production with the audience (“puts the musician and the composers (audience) on equal ground”). This proved successful because the artistic structure left them some space for interpretation (“It was nice to be able to make the decision based on your ears rather than what was dictated”).</td>
</tr>
<tr>
<td>Lack of compositional structure (2)</td>
<td>Two performers found that the music lacked compositional structure and could become “chaotic” with five modes in play. We partly attributed this impression of chaos for five modes in SA to equal vote situations leading to multiple modes at the same time (see Figure 2a), so we made modifications to prevent this in SB (see Figure 2b).</td>
</tr>
</tbody>
</table>
instructions and short participation time were barriers to understanding graphical information. Although it was not one of our goals to make a fully self-explanatory system, the design could be improved to enable participants without musical expertise to rapidly infer the correct conceptual model about the system. Using semantic information in addition to visual clues, as suggested by one participant, could be a way to bridge the gap between symbols and function.

Although graphical scores helped performers follow directions, they also disconnected them from the audience, forcing their locus of attention toward the screen. Disconnection from the audience was reported in SA, where the visual display for performers was located on one side of the stage. This was improved in SB, where the visual display was placed at the front of the stage on the floor (see Figure 3b). Placing the visual display for performers behind the audience or using augmented reality glasses could further alleviate the sense of disconnection. Another possibility is to convey audience directions using color codes and stage lights on each of the performer.

### Table 3. Thematic analysis of audience feedback for session B

<table>
<thead>
<tr>
<th>Theme (no. of codes)</th>
<th>Discussion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Learnability (26)</td>
<td>Twelve out of 20 participants (11 musicians, one non-musician) did not report understandability issues. However, eight out of 20 participants (six non-musicians, two musicians) expressed difficulty in understanding the meaning of the symbols, the effect of the votes, and the graphical scores. Contrary to session A (SA), not all participants from session B (SB) attended the introduction, because they could join at any point. Participants from SB also took part in only 1.4 performances on average (compared to four for SA). An introduction is thus required, especially for non-musicians, and a minimum number of performances is needed to support the learning curve.</td>
</tr>
<tr>
<td>Pleasure/enjoyment (19)</td>
<td>Many participants communicated their enjoyment of the experience. Reasons were varied, from intellectual pleasure (“This simply rocked and was very fun but also very cerebrally satisfying”), to emotional contagion of seeing skilled performers enjoying interacting together, to the quality of the music (“excellent”).</td>
</tr>
<tr>
<td>Design (18)</td>
<td>Many positive comments were made regarding the interface design (noting its “simplicity,” for example) and feedback provided (“I could easily select what I wanted and see total votes for a certain playing mode”). Other comments contrasted the aesthetics with the clarity (“didn’t know what symbols meant […] but [they were] very pretty”).</td>
</tr>
<tr>
<td>Lack of agency (12)</td>
<td>As in SA, several factors hindering the sense of agency were identified; for example, the voting system caused individual decisions to get “diluted” (“I could not see my personal influence”) and created misunderstandings about the system (“I wasn’t sure if my input reached the performer”).</td>
</tr>
<tr>
<td>Interactivity (8)</td>
<td>System interactivity resulted in a positive emotional experience (“lots of fun”), and the aspect some liked most was the possibility of “interacting with [a] LIVE performance.”</td>
</tr>
<tr>
<td>Interest/curiosity (7)</td>
<td>Several participants found the concept “interesting” and were curious to see future developments.</td>
</tr>
<tr>
<td>Voting strategy (7)</td>
<td>Voting strategies were diverse, such as “personal preference” or multimodal considerations, taking into account the visualization, votes, and music. Other strategies included trial and error and randomness, music dynamics, and votes from others.</td>
</tr>
<tr>
<td>Responsiveness (5)</td>
<td>As in SA, there were issues regarding responsiveness (for example, participants reported that the system was “not responsive enough for effective music” and that there was “a sense of asynchrony between votes and performer execution of vote”).</td>
</tr>
<tr>
<td>Originality/spontaneity (4)</td>
<td>Several participants appreciated how “unconventional” the music was and its “spontaneity.”</td>
</tr>
<tr>
<td>Agency/engagement (4)</td>
<td>As in SA, participants valued the sense of agency toward the music (“you feel like the music is influenced by you”) while respecting the place of the musicians (“I liked that I could influence the music but musicians could choose what to do without my feedback”).</td>
</tr>
<tr>
<td>Identification (3)</td>
<td>Similarly to SA, a few participants were unsure about which performer they were controlling.</td>
</tr>
<tr>
<td>Technical issues (3)</td>
<td>A small number of technical issues occurred, either due to the type of browser/mobile phone or the network, which was at times cluttered.</td>
</tr>
<tr>
<td>Augmented stage (3)</td>
<td>Several participants reported liking the performance setting because of how the stage was presented or because of the “visual display.”</td>
</tr>
</tbody>
</table>
Other drawbacks of the system for audience participants were a felt lack of agency and responsiveness in some cases, indicating that DR3 was only partially met. Reasons included the voting system, which dilutes personal choices; not being able to identify the associated performer; and the limited number of musical attributes to control. The minimal allowed time interval \( T \) between two votes could be reduced in an attempt to increase responsiveness; however, if the interval is too small, it could give the interactions a game-like facet, which would go against the artistic intent. We could investigate voting systems other than plurality, but there are currently no optimal solutions for groups. We could also consider providing audience participants with full control, but over different musical attributes (shared roles in composition), assuming complexity and scalability can be factored in.

**Facilitating Audience Engagement**

Enabling agency and participation fostered audience engagement in the performance (DR5), as participants paid close attention to performers and felt active. Creative voting strategies were diverse, demonstrating system appropriation based on personal preference; some favored certain playing modes, some based their decisions only on the music, and others were influenced by multiple modalities (the visualizations, others’ votes, and the music). In SB, a strong theme of pleasure and enjoyment emerged. Participants had positive affective responses for artistic reasons (such as the quality of the music, the skills, and the performers’ dedication), intellectual reasons (such as the cognitive tasks of voting and evaluating feedback), and also non-musical reasons (the stage setting and visual display with live graphical scores enriching the performance experience), an aspect also observed elsewhere.\(^{21}\)

**Supporting Musical Composition**

In terms of support for musical composition (DR6), some participants thought the music was “excellent” and “unusual.” However, other participants did not engage with it, which might be due to a lack of “overall compositional structure” (as reported in SA), a lack of “modulation” (as reported in SB), or a genuine dislike of experimental music. The musical component should be developed further to ensure that audience compositional directions can form a coherent whole, yet integrating layers of complexity (SB). We could introduce a system of meta-rules to provide a curated, overall direction for Open Symphony interactive pieces, while keeping internal parts responsive and mutable.

**Ensuring Scalability**

Similar levels of interaction (vote frequency) were found between sessions composed of performances with varying number of participants. However, these comparisons were conducted between small-to-medium-scale audiences (with 10–30 interacting participants). Scalability (DR7) tests including larger audiences should be conducted to test the impact of audience size, using both attitudinal and behavioral measures.

The Open Symphony system transforms the traditional unidirectional musical chain by adding creative communication in the reverse direction, from the audience to performers. Our design favored simple affordances (voting for

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**Table 4. Thematic analysis of performer feedback (two) for session B.**

<table>
<thead>
<tr>
<th>Theme (no. of codes)</th>
<th>Discussion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Usability/design (7)</td>
<td>The two performers thought the system was easy to learn and use (“I thought the digital elements were easy to follow and intuitive”) and that the graphic design was clear and aesthetic (“I loved the presentation! The symbols were beautiful and the layout was very very clear.”).</td>
</tr>
<tr>
<td>Musical complexity (4)</td>
<td>They thought the musical complexity could be increased—for example, through modulation (“maybe shift tonalities/and or modes within the piece”) or through harmony/layering (“maybe [add] a few different chords or different layers”).</td>
</tr>
<tr>
<td>Satisfaction (4)</td>
<td>They were very positive about their experience from the rehearsal to the live execution.</td>
</tr>
<tr>
<td>Audience engagement/pedagogical outreach (2)</td>
<td>The potential of the system for audience engagement and music pedagogy was fleshed out by one of the performers (“I think, expanded, this could be a really interesting way to engage non-musicians and help them become familiarized with classical music”).</td>
</tr>
</tbody>
</table>
playing modes) and multimodal interaction mixing musical and visual elements. Both audience and performer participants who trialed the system felt challenged by the novelty—audience members took creative decisions and decoded their effects, and performers followed scores generated while they were playing. Such challenges lead to positive affective responses for some audience participants, who felt engaged in the performance and closely connected to performers, and to frustration for others, who misunderstood the system or wished to have more control.

Open Symphony showed the potential to create performances that are “open,” “engaging,” “empowering,” and “unusual.” Video and photo examples showing live interactions with Open Symphony can be found at http://bit.ly/os_visvideo and http://bit.ly/os_photos. Future analyses will investigate participant creative interactions using time series modeling. We are also interested in exploring applications for music pedagogy and audience engagement agendas.

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References
Yongmeng Wu is a PhD student in the Media and Arts Technology Centre for Doctoral Training, Queen Mary University of London. Her research interests include human-computer interaction, user experience, evaluation of interaction design (aesthetic experience, creativity, and engagement), and support of non-musicians’ creative engagement with novel musical interfaces. Wu has an MA in design (human computer interaction) from Hunan University, China. Contact her at yongmeng.wu@qmul.ac.uk.

Leshao Zhang is a PhD student in the Media and Arts Technology Centre for Doctoral Training, Queen Mary University of London, and a member of the Cognitive Science Research Group. His research interests include human-computer interaction and virtual reality. Zhang has an MSc in media and arts technology from Queen Mary University of London. Contact him at leshao.zhang@qmul.ac.uk.

Nick Bryan-Kinns is a reader in interaction design at Queen Mary University of London, and director of the EPSRC+AHRC Media and Arts Technology Centre for Doctoral Training. His research interests include the evaluation of interaction design, focusing on creativity, mutual engagement, and audio. Bryan-Kinns has a PhD in human-computer interaction. He is a Fellow of the British Computer Society. Contact him at n.bryan-kinns@qmul.ac.uk.

Mathieu Barthet is a lecturer and technical director of the Media and Arts Technology Studios at Queen Mary University of London. His research lies at the intersections of music informatics, human-computer interaction, affective computing, and perception. Barthet has a PhD on musical timbre analysis/synthesis from Aix-Marseille University and Centre National de Recherche Scientifique’s Laboratory of Mechanics and Acoustics. He is a member of IEEE, the Association for Computing Machinery, and the Audio Engineering Society. Contact him at m.barthet@qmul.ac.uk.