

# Holistic Framework for Quality Assessment of Mediated Social Communication

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The authors have no conflicts of interest to declare that are relevant to the content of this article.

### ***Availability of data and material***

The Holistic Mediated Social Communication Questionnaire (H-MS-C-Q) is publicly available (both in Microsoft Word and interactive PDF format) from the Open Science Framework (OSF) repository at [osf.io/9qkhr](https://osf.io/9qkhr) with doi: 10.17605/OSF.IO/9QKHR under the CC-By Attribution 4.0 International license. Use is only allowed after complying with the following two conditions: (1) a credit line in publications and presentations reading: “The Holistic Mediated Social Communication Questionnaire (H-MS-C-Q) is available from the OSF repository at [osf.io/9qkhr](https://osf.io/9qkhr),” and (2) a citation to the current article in any publication in which the H-MS-C-Q is used.

### ***Code availability***

Not applicable

### ***Authors' contributions***

Jan van Erp had the idea for the article. Alexander Toet performed the literature search and review and wrote the first draft of the manuscript. All authors critically reviewed previous versions of the manuscript. All authors read and approved the final manuscript.

1 **Abstract**

2

3 Modern immersive multisensory communication systems can provide compelling mediated  
4 social communication experiences that approach face-to-face (F2F) communication. Existing  
5 frameworks to assess the quality of mediated social communication experiences are typically  
6 targeted at specific communication technologies and do not address all relevant aspects of  
7 social presence (i.e., the feeling of being in the presence of, and having an affective and  
8 intellectual connection with, other persons). Also, they are typically unsuitable for application  
9 to social communication in virtual (VR), augmented (AR) or mixed (MR) reality. Here we  
10 present a comprehensive and general holistic mediated social communication (H-MSC)  
11 framework and associated questionnaire (the H-MSC-Q) for measuring the quality of  
12 mediated social communication. The H-MSC framework comprises both the experience of  
13 Spatial Presence (i.e., the perceived fidelity, internal and external plausibility, and cognitive,  
14 reasoning and behavioral affordances of an environment) and the experience of Social  
15 Presence (i.e., perceived mutual proximity, intimacy, credibility, reasoning and behavior of  
16 the communication partners). Since social presence is inherently bidirectional (involving a  
17 sense of mutual awareness) the H-MSC-Q distinguishes between the internal ('*own*') and  
18 external ('*the other*') assessment perspectives. The H-MSC-Q is efficient and parsimonious,  
19 using only a single item to tap into each of the relevant processing levels in the human  
20 brain: sensory, emotional, cognitive, reasoning, and behavioral. It is also sufficiently general  
21 to measure social presence experienced with any (including VR, AR, and MR) type of multi-  
22 sensory (visual, auditory, haptic, and olfactory) mediated communication system.

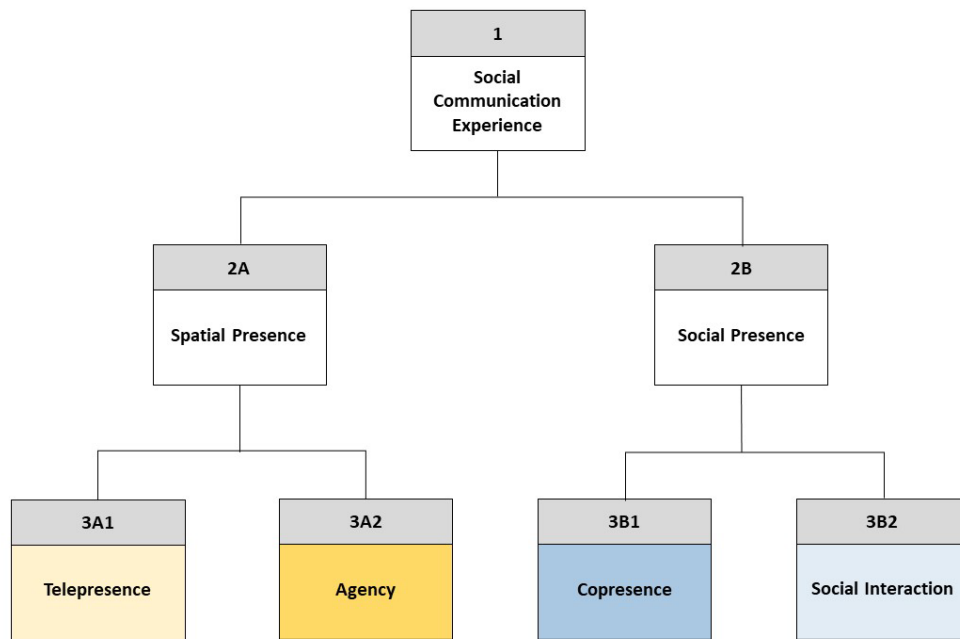
## 23 **1 Introduction**

24

### 25 *1.1 Mediated social communication*

26 Humans have an inherent social and personal need for communication to maintain their  
27 interpersonal relationships and mental wellbeing [1]. In our digital age, human social  
28 communication is often mediated. Technologies like videoconferencing software (e.g., Zoom,  
29 Microsoft Teams, Skype, etc.) are becoming increasingly popular as they afford a new form  
30 of virtual togetherness by facilitating shared and synchronous social activities, thereby  
31 substituting face-to-face (F2F) interactions [2,3]. New immersive (VR, AR or MR-based)  
32 communication systems extend regular video- or audio-conferencing tools by affording social  
33 experiences that more closely approximate the experience of F2F meetings. Sophisticated  
34 capturing, modeling, and rendering techniques afford high-fidelity shared mediated  
35 experiences of remote communication partners and their physical environment [4-9]. For  
36 instance, VR-based collaborative communication systems can represent their users either as  
37 computer generated avatars or as photorealistic point clouds and place them in shared virtual  
38 spaces in which they can interact and communicate [10]. The same holds for systems that  
39 take in other positions on Milgram's reality-virtuality continuum [11], like AR, MR and  
40 augmented virtuality (AV) platforms that afford the blending of high-fidelity representations  
41 of remote users into shared collaboration spaces in which they can interact with the local  
42 users. Extended reality (XR, i.e. AR, VR or MR) based communication systems attempt to  
43 merge the physical world with digital information (e.g., the mediated representation of the  
44 communication partners, elements from their own environment or computer generated  
45 objects) while preserving the (multisensory) coherence and plausibility of the overall  
46 representation. These systems can give local hosts the impression that their remote  
47 communication partners are actually present in their immediate (shared) environment [12,13].  
48 Systems stimulating multiple sensory channels (mulsemedia systems: [14]) can be  
49 particularly effective in eliciting a strong feeling of a shared space.

50 To develop and optimize social communication systems, there is a need for metrics  
51 that allow an efficient and full evaluation of the Quality of Experience (QoE; [13,15]) of  
52 mediated social communication.



53

54

Figure 1. The relation between the different constructs involved in a mediated social communication experience.

### 55 1.2 Quality assessment of mediated social communication

56 Effective mediated shared social communication experiences involve a sense of social  
 57 presence (the sense of being together with someone in a F2F meeting) together with a sense  
 58 of spatial presence (Figure 1). The sense of *social presence* consists of two components:  
 59 *copresence* [16]: the sense of being physically together with one's communication partner in  
 60 the same environment (physical proximity), and *social interaction*: the sense of having an  
 61 affective and/or intellectual interaction with one's communication partner [17-19]. The sense  
 62 of *spatial presence* [20] also consists of two components: *telepresence* [21]: the feeling of  
 63 being located in the mediated (shared) environment, and *agency* [22]: the feeling of being  
 64 able to act within that environment. The difference between these two concepts is that social  
 65 presence primarily deals with human-human relations, whereas spatial presence only pertains  
 66 to human-object relations. A valid QoE metric for mediated social communication should  
 67 quantify both social and spatial presence and their subcomponents.

68 Social interaction is inherently bidirectional, involving a sense of mutual awareness.  
 69 A valid QoE assessment tool should therefore also be able to distinguish between the internal  
 70 ('one's own') and external ('the other's') assessment perspectives.

71 The interaction with our environment and the people therein activates different  
 72 (sensory, emotional, cognitive, reasoning, and behavioral) processing levels in our brain, that  
 73 all contribute to the subjective quality of the experience [23,24]. A valid QoE metric should  
 74 therefore describe how a mediated social communication experience affects our brain at each  
 75 of these different processing levels, and should link these levels to relevant perceptual,  
 76 affective, cognitive, reasoning, and behavioral outcomes.

77 Next to the fidelity of the representation of a mediated environment and the persons  
 78 therein, the experienced quality of a mediated social communication experience may also  
 79 depend on highly subjective secondary factors like its personal relevance [25] and the user's  
 80 context (e.g., task, available information: [26,27]), current (mental and physical) state,

81 personality [28-30], engagement and involvement (e.g., enjoyment, flow, and mental  
82 absorption or attention, [31]). A universal QoE metric for social communication should  
83 primarily address the fidelity of subjective experiences or the experiential fidelity [32] to  
84 ensure that its outcomes are relatively independent of such secondary factors. In other words,  
85 a QoE metric should quantify the intrinsic capability of a communication system to provide a  
86 compelling social communication experience that feels realistic or natural at all psychological  
87 processing levels. In agreement with the media richness theory [33,34], this requirement is  
88 based on the hypothesis that the fidelity of the experience increases with the quality and the  
89 capability of the communication medium.

90 Summarizing, a universal QoE metric for mediated social communication should satisfy the  
91 following four requirements:

- 92 1. The metric should measure both social and spatial presence and their subcomponents  
93 (copresence + social interaction and telepresence + agency),
- 94 2. The metric should distinguish between the internal (*'one's own'*) and external (*'the*  
95 *other's'*) assessment perspectives,
- 96 3. The metric should address each of the relevant psychological processing levels  
97 (sensory, emotional, cognitive, reasoning, and behavioral), and
- 98 4. The metric should measure a communication system's experiential fidelity (its  
99 intrinsic capability to provide a realistic or natural mediated social communication  
100 experience).

101

102 In the next section we discuss the most widely used and related measures for mediated social  
103 and spatial presence, and we identify their limitations for measuring the quality of mediated  
104 social communication experiences. Then we propose a new general quality assessment  
105 framework, together with an associated measurement tool (questionnaire), that meets our  
106 requirements. Finally, we draw some conclusions and discuss the limitations of the new  
107 framework in its current form.

## 108 **2 Related work**

### 109 *2.1 Spatial presence questionnaires*

110 A wide range of methods have been developed to measure the sense of telepresence in a  
111 mediated (possibly virtual) environment (for reviews see [18,35,36]). The most widely  
112 applied telepresence questionnaire is the Presence Questionnaire (PQ: [37,38]). Other  
113 frequently used methods are the Slater-Usuh-Steed Questionnaire (SUS: [39]) the  
114 Measurement, Effects, and Conditions Spatial Presence Questionnaire (MEC-SPQ: [40]), and  
115 the Igroup Presence Questionnaire (IPQ: [22]). While most questionnaires aim to quantify the  
116 same underlying construct (typically spatial presence), they differ widely in their scope (since  
117 they are based on different definitions of presence) and details (their items and subscales  
118 differ largely; for a review see [35]). The SUS and PQ tap into different aspects of presence.  
119 The SUS addresses the user's sense of being in the represented environment, the extent to  
120 which the represented environment replaces the user's physical environment, and the extent  
121 to which the represented environment is remembered as an actual place. The PQ, IPQ, MEC-  
122 SPQ and Place Probe [41] also measure the user's involvement. The PQ is more sensitive for  
123 factors related to technology and interaction while the SUS is more sensitive to personal  
124 factors [42]. However, both questionnaires are insensitive to variations in the internal

125 consistency or plausibility of a represented environment [43], which is an essential factor  
126 contributing to the sense of spatial presence [44]. The IPQ also measures the experienced  
127 realism of the environment. The MEC-SPQ and the Place Probe also measure the amount of  
128 attention users devote to the represented environment and the quality of their mental spatial  
129 model of that environment.

130 The sense of agency in the mediated environment is typically measured through  
131 questionnaire items asking users to rate the extent to which their actions in the mediated  
132 space appear natural. Only few existing presence questionnaires address the sense of agency:  
133 the PQ [38] includes six items related to agency, the MEC-SPQ [40] three items, and the  
134 Igroup Presence Questionnaire (IPQ: [22]) only one item.

## 135 *2.2 Social presence questionnaires*

136 Next to making strong assumptions about the technology that is used [17], most  
137 existing social presence questionnaires only implicitly and incompletely address the different  
138 processing levels in the human brain that are involved in mediated social communication  
139 experiences [13,45-47]. An exception is the Virtual Experience Test (VET, [48]) that  
140 provides a more holistic measure of a mediated social presence experience by including  
141 affective, cognitive, active and relational dimensions in addition to its sensory dimension.  
142 However, the instrument is designed for the development of virtual environments and games  
143 and is not sufficiently general for the evaluation of multisensory communication systems.  
144 Also, the VET only measures the quality of social interaction at the behavioral and reasoning  
145 levels, but not on the sensory, emotional, and cognitive levels. The Multimodal Presence  
146 Scale (MPS, [49]) measures three components of presence in a mediated environment:  
147 physical presence (the experience of the environment), social presence (the experience of the  
148 social actors in the environment), and self-presence (the extent to which the virtual  
149 representation of oneself is experienced as the actual self). Like the VET, this instrument was  
150 designed for the assessment of virtual environments and games, and not for MSC systems.  
151 Also, the MPS does not address the quality of social interaction at the emotional and  
152 reasoning processing levels. The Networked Minds Social Presence Inventory (NM-SPI,  
153 [47]) was specifically designed to measure social presence in mediated communication. It  
154 measures social interaction at the sensory, emotional, and behavioral processing levels from  
155 both the internal and external assessment perspectives, but contains no items related to the  
156 cognitive and reasoning levels. Also, its items measuring copresence do not relate to the  
157 sense of physical proximity (being in the same environment). The Social Presence Survey  
158 (SP Survey, [45]) measures social interaction from the 'own' perspective, explicitly at the  
159 sensory level and only implicitly at the emotional and cognitive levels. The Sense of Being  
160 Together questionnaire (SBT, [46]) measures social interaction only from the 'own'  
161 perspective, explicitly at the sensory level and only implicitly at the emotional and behavioral  
162 levels. The Social VR Questionnaire (SocialVR-Q, [13]) was designed to investigate photo  
163 sharing experiences in immersive environments. It addresses social presence only from the  
164 'own' perspective. Also, it contains no items that tap into the cognitive processing level of  
165 social interaction.

## 166 *2.3 Limitations of existing questionnaires*

167 In this section we systematically discuss the extent to which existing social and spatial  
168 presence questionnaires meet the four requirements for a mediated social communication

169 QoE metric formulated in Section 1.2 (see Table 3). Table 3 shows how ten of the most  
170 widely used presence questionnaires tap into each of the five relevant (sensory, emotional,  
171 cognitive, behavioral and decision making) processing levels for multisensory environmental  
172 stimuli [24], for both Spatial Presence and Social Presence and for both ('one's own' or 'the  
173 other's') assessment perspectives. This table also shows whether the items in these  
174 questionnaires explicitly (filled circles in Table 3) or implicitly (open circles) address each of  
175 these constructs.

### 176 *2.3.1 Requirement 1: Measure both social and spatial presence*

177 The MPS is the only questionnaire that measures both social and spatial presence and their  
178 subcomponents (copresence + social interaction and telepresence + agency). All other  
179 questionnaires measure either only spatial presence (SUS, PQ, IPQ, MEC-SPQ, Place Probe)  
180 or social presence (SP Survey, SBT, NM-SPI, SocialVR-Q).

### 181 *2.3.2 Requirement 2: Measure both internal and external assessment perspectives*

182 The NM-SPI measures both copresence and social interaction from both assessment  
183 perspectives. Social interaction is measured explicitly at the emotional level, and only  
184 implicitly at the behavioral level.

185 The MPS explicitly measures copresence from both assessment perspectives. It  
186 measures social interaction implicitly and only from the 'own' perspective at the cognitive  
187 and behavioral psychological processing levels.

188 The SocialVR-Q measures copresence explicitly from the 'own' perspective and  
189 implicitly from the 'the other's' perspective. It measures social interaction explicitly at the  
190 emotional level from both perspectives, and only from the 'own' perspective at the reasoning  
191 and behavioral levels.

### 192 *2.3.3 Requirement 3: Measure all relevant psychological processing levels*

193 For Spatial Presence, only the PQ-v.3 and the MEC-SPQ address all five processing levels.  
194 However, the PQ-v.3 only explicitly addresses agency and telepresence at the emotional  
195 processing level, while the MEC-SPQ only implicitly addresses telepresence at the reasoning  
196 level.

197 For Social Presence, none of the questionnaires measures all relevant psychological  
198 processing levels. All social presence questionnaires (SP Survey, SBT, NM-SPI, MPS and  
199 SocialVR-Q) measure copresence (typically explicitly, except the NM-SPI). Most social  
200 presence questionnaires also measure social interaction at the emotional (except the MPS)  
201 and behavioral (except the SP Survey) processing levels.

202 The SocialVR-Q measures social interaction at three processing levels (all except the  
203 cognitive level) from the 'own' perspective. The SP Survey, SBT, NM-SPI, and MPS each  
204 measure social interaction at two processing levels from the 'own' perspective.

### 205 *2.3.4 Requirement 4: Measure a communication system's experiential fidelity*

206 All questionnaires listed in Table 3 that tap into the cognitive processing level, measure the  
207 fidelity of the (telepresence or social interaction) experience at this level. The PQ also  
208 measures the fidelity of spatial presence at the behavioral level (i.e., the fidelity of agency),



209 while the SocialVR-Q measures the fidelity of social interaction at the behavioral level. None  
210 of the existing questionnaires measures the fidelity of a social communication experience at  
211 the sensory or reasoning levels.

### 212 **3 Towards a holistic quality framework for mediated social communication**

213 We adopt the feeling that one actually experiences a natural social interaction in a realistic  
214 shared environment (i.e., the experiential fidelity) as the overarching (holistic) quality factor  
215 for a mediated social communication experience. A high quality mediated social presence  
216 experience then implies that the communication system provides both a natural sense of  
217 spatial presence (with subcomponents telepresence and agency) and a natural sense of social  
218 presence (with subcomponents copresence and social interaction), without introducing any  
219 idiosyncrasies (sensory distortions) due to system limitations or abnormalities in the mediated  
220 representations of the environment and the persons therein.

221 In the next section we will first discuss an existing conceptual holistic framework that  
222 describes how multisensory stimulation affects our brain at five different processing levels  
223 (sensory, emotional, cognitive, decision making, and behavioral), and we will link these  
224 levels to relevant perceptual, affective, and cognitive outcomes. Then, in the following two  
225 sections, we will show how this holistic framework can be used to characterize the overall  
226 quality of mediated social communication based on social and spatial presence (the Holistic  
227 Mediated Social Communication or H-MSC framework). We also propose an associated tool  
228 (the Holistic Mediated Social Communication Questionnaire or H-MSC-Q) that measures the  
229 quality of mediated social communication by tapping into each of the five relevant processing  
230 levels as defined in the conceptual framework. The H-MSC-Q measures the quality of social  
231 communication through (1) the sense of spatial presence (telepresence and agency) in the  
232 mediated environment and (2) social presence (copresence and social interaction) with the  
233 other person(s) therein. In practice, the items in the H-MSC-Q should be scored on a 7-point  
234 Likert scale.

235 The H-MSC framework and an initial draft of the H-MSC-Q were presented as a  
236 poster at the EuroVR 2020 conference [50]. The final version of the H-MSC-Q presented  
237 here evolved from this initial version after an iterative refinement process that involved  
238 several rounds of expert evaluations and discussions that served to improve the relevance and  
239 clarity of its questions.

#### 240 *3.1 A holistic framework for multisensory perception*

241 The new framework for the quality assessment of mediated social communication proposed  
242 in this paper is based on a holistic model that describes how multisensory stimulation affects  
243 our brain at the sensory or perceptual, emotional, cognitive, behavioral, and decision-making  
244 levels [24]. This holistic model distinguishes two assessment perspectives, related to the  
245 object of focus that is assessed and responded to: an *external perspective* in which individuals  
246 only assess and respond to information in their environment, and an *internal perspective* in  
247 which the internal reaction of the individual to the environmental information is assessed and  
248 responded to. For instance, if a person is asked to describe an experience, an internally  
249 focused assessment and response follows, e.g.: “*I felt excited/stressed*”. If a person is  
250 explicitly asked to provide an affective evaluation of an object or environment, an externally  
251 focused assessment and response follows, e.g.: “*This conversation or environment is*

252 *stimulating/boring*". Both assessment perspectives tap into different processes as we will  
253 discuss next.

254 The first processing steps of environmental stimuli are mediated automatically and  
255 unconsciously through our senses and the primary sensory areas in our brain. In both  
256 assessment perspectives this processing level results in the sensation of environmental  
257 stimuli. In these early processing stages, one can, however, already distinguish different  
258 processing routes, which are later linked to the different assessment perspectives [51,52]. One  
259 route (that goes through the sensory cortices where feature extraction and sensory integration  
260 take place) serves to guide the external focus and performs an assessment of environmental  
261 stimuli (*'external assessment perspective'*). This processing level involves a subtle interplay  
262 of lower-order and top down processes, steering attention and resource allocation [53,54].  
263 This internal perspective is mediated by a secondary route via the limbic structures,  
264 prominently including the amygdala that affects the arousal level (*'internal assessment  
265 perspective'*).

266 The second processing level involves both conscious and unconscious processing.  
267 From the external assessment perspective, the integration and interpretation of the sensory  
268 information results in a holistic percept (Gestalt) of an object or environment, while it results  
269 in an emotional experience from the internal assessment perspective. In this paper we define  
270 an emotional experience or emotion as a short-term state that is directly related to the  
271 environmental stimuli.

272 The third processing level involves higher order processes for cognitive processing.  
273 From the external assessment perspective, the primary outcome is an evaluation or appraisal  
274 of the percept. Depending on the task, this appraisal can be affective (like or dislike of a  
275 percept) or functional (evaluation of the characteristics of a percept such as strength, size).  
276 From the internal assessment perspective, the cognitive processing may result in an emotional  
277 response (e.g., conscious feelings or behavioral intentions).

278 The fourth processing level involves both conscious and unconscious behavioral  
279 responses. From the external perspective, environmental appraisals may trigger both highly  
280 trained (automated) reflexive behavior or more deliberate (externally motivated) behavioral  
281 responses. From the internal assessment perspective, emotions and appraisals may elicit  
282 (unconscious or deliberate) approach and avoidance behaviors.

283 The fifth processing level involves decision making processes. From the external  
284 assessment perspective, appraisals trigger cognitive functions such as working memory,  
285 reasoning, and planning. From the internal assessment perspective, emotions and feelings  
286 drive our judgements and choices.

287 In the next two sections, we will identify the characteristics of a mediated social  
288 communication experience that determine its perceived quality, by decomposing the  
289 experience into quality features at each of the five relevant processing levels in the human  
290 brain [24]. Here we distinguish between quality factors and quality features [15]. A *quality  
291 factor* can be defined as *'Any characteristic of a system, whose actual state or setting may  
292 influence the QoE for the user'* (free after [55]). A *quality feature* can then be defined as *"A  
293 perceivable, recognized and nameable characteristic of the individual's experience of a  
294 service which contributes to its quality"* [56]. Thus, features can be seen as a dimension of a

295 multidimensional perceptual event. A feature becomes a quality feature when it is relevant for  
296 the experienced quality of the event. For the experience of social presence, we will identify  
297 associated quality factors and features at each of the five processing levels and formulate  
298 questionnaire items that can be used to rate the quality features. Since the new framework for  
299 the quality assessment of mediated social communication proposed in the next two sections is  
300 based on experiential fidelity, its associated quality factors are in between objective factors  
301 related to a system's quality of service (QoS: system characteristics) and highly subjective  
302 context, task and mood dependent secondary qualities like enjoyment, engagement, flow, and  
303 mental absorption or attention. This allows the formulation of an associated QoE  
304 questionnaire with items that are relatively insensitive for variations across conditions and  
305 personalities.

### 306 *3.2 Quality of spatial presence*

307 In this section, QoE will refer to the quality of the spatial presence component (i.e., the  
308 environment in which the social communication experience takes place) of a mediated social  
309 communication experience.

#### 310 *3.2.1 Sensory level*

311 At the sensory level, the relevant quality factor for telepresence is the perceptual or *sensory*  
312 *fidelity* of the experience, i.e. the extent to which users fail to perceive or acknowledge the  
313 fact that (part of) their sensory input is mediated. Users should preferably experience the  
314 feeling that their sensory input originates directly from the represented environment (the  
315 illusion of non-mediation: [57,58]). In other words, they should experience a natural and  
316 acute awareness of the (partially) mediated environment. At this level, QoE is therefore  
317 directly related to the QoS or fidelity of the system mediating the remote or simulated  
318 environment [59]. ITU-T [60] section 6.212 defines QoS as “[The] Totality of characteristics  
319 of a telecommunications service that bear on its ability to satisfy stated and implied needs of  
320 the user of the service.” Note that QoS is defined from a system's perspective, in contrast to  
321 the QoE, which is defined entirely from the user's perspective. QoS evaluations therefore  
322 typically rely exclusively on system performance parameters and metrics, such as PSNR  
323 (peak signal-to-noise ratio) and SSIM (structural similarity) measures [61]. However,  
324 attempts to link QoS parameters to QoE have only had very limited success because QoE is  
325 inherently a subjective, multidimensional and multisensorial construct [59]. Hence, it is still  
326 not clear how QoS parameters relate to the affective, behavioral, and cognitive aspects of a  
327 mediated communication experience. Note that the fidelity of an experience can differ largely  
328 between the different sensory modalities. Such inconsistencies can lead to a strong sense of  
329 presence in one modality but not in another [62]. At this level, quality features are related to  
330 individual sensory channels, such as visual features, auditory features or tactile features, and  
331 may also be linked to the perception via multiple senses in parallel (e.g., audio-visual  
332 features; [56]). Example quality features for the visual channel include color naturalness,  
333 sharpness, darkness (of black areas), brightness, contrast, flicker, blur, geometrical distortion,  
334 and coding and packet-loss induced degradations such as blocking, freezing, and slicing.  
335 Examples for the auditory channel include audio-streaming quality parameters like  
336 localization and timbre, and speech-transmission quality features like coloration, noisiness,  
337 loudness, or continuity. For services that address multiple sensory channels simultaneously,  
338 relevant features are e.g. balance and synchrony, and a QoE assessment should address the

339 extent to which one feels like being in direct contact with the environment (one's impression  
340 that one directly sees, hears, feels, or smells the environment). At this level, the overall QoE  
341 can be assessed by rating the following statement: "*I feel in direct contact with the*  
342 *environment*" (item 1 in Table 1).

### 343 3.2.2 Affective / emotional level

344 At the affective or emotional level, the relevant quality factor for telepresence is the *internal*  
345 *plausibility* or sensory congruity [63] of the experience, i.e. the extent to which users have the  
346 feeling that their multisensory input is coherent [43] and agrees (is congruent and consistent)  
347 with their mental model (expectations or memories) of the represented environment  
348 [44,63,64]. Hence, the relevant quality feature at this level is the semantic consistency and  
349 congruency between all sensory signals, and the QoE can be quantified by rating the  
350 following statement: "*My sensations are consistent and agree with the represented*  
351 *environment*" (item 2 in Table 1).

### 352 3.2.3 Cognitive level

353 At the cognitive level, the relevant quality factor for telepresence is the *external plausibility*  
354 or environmental and thematic congruity [63] of the experience, i.e. the perceived fidelity  
355 [65], realness [66,67] or illusion that the represented environment is authentic [68] and a  
356 place that can actually be visited [62,69]. At this level, the QoE can be quantified by rating  
357 the following statement: "*The represented environment appears real*" (item 3 in Table 1).

### 358 3.2.4 Reasoning level

359 At the reasoning level, the relevant quality factor for telepresence is the degree of realism of  
360 the multisensory representation of the mediated environment [70]. A multisensory  
361 representation of the mediated environment with a high degree of fidelity and realism is  
362 expected to influence one's reasoning in a similar way as its unmediated counterpart. At this  
363 level, the QoE can be quantified by rating the following statement: "*The environment affects*  
364 *my thoughts as its real counterpart would*" (item 4 in Table 1).

365 People typically find it difficult to assess and verbalize the exact origin and nature of  
366 their feelings and emotions. For the Spatial Presence subscale of the H-MSQ-Q, a distinction  
367 between the internal and external assessment perspectives on the environment would result in  
368 items with only slight nuances in their formulation (asking people to assess either the  
369 *capability* of the environment to evoke their response or to assess their *actual* response to the  
370 environment on different processing levels). This would make these items hard to distinguish  
371 and would therefore most likely yield similar responses (not understanding the difference  
372 between the items, people would probably give the same answer to both items). We therefore  
373 collapsed both environmental assessment perspectives into a single item for each processing  
374 level in the Spatial Presence subscale of the H-MSQ-Q. Since the different perspectives are  
375 so closely linked, we believe this reduction in the number of items will not result in a  
376 significant loss of information on the experience of mediated social communication.

### 377 3.2.5 Behavioral level

378 At the behavioral level, the relevant quality factor for agency is the degree to which the  
379 mediated environment affords natural behavior without any limitations or restrictions, i.e. the

380 feeling that one can interact with objects and persons in the represented environment as in  
381 reality. At this level, the QoE can be quantified by rating the following statement: “*My*  
382 *interaction with the represented environment feels realistic*” (item 5 in Table 1).

### 383 3.3 *Quality of social presence*

384 In this section, QoE will refer to the quality of the social presence component of a mediated  
385 social communication experience. Social presence inherently involves a bidirectional  
386 exchange of physical and emotional signals. Since the difference between the internal (‘*own*’)  
387 and external (‘*the other*’) assessment perspectives can be clearly formulated for social  
388 interaction, the distinction in both perspectives is maintained for the social presence subscale  
389 of the H-MSQ-Q (see Table 1). However, by emphasizing the bidirectionality in the  
390 formulation of the items of this subscale, both assessment perspectives can also be collapsed  
391 into a single one to obtain a more concise version of this subscale (see Table 2).

#### 392 3.3.1 *Sensory level*

393 At the sensory level, system factors should not affect the sensory impression that people have  
394 of one another, i.e. users should have the impression that they are in direct contact with each  
395 other (physical immediacy or the illusion of non-mediation [71]). At this level, the relevant  
396 quality factor for copresence is the feeling that the represented individuals are in one’s  
397 physical proximity or direct influence sphere (the feeling that one can make direct physical  
398 contact). The QoE can then be quantified from one’s own perspective by rating the following  
399 statement: “*I feel the presence of the other person(s)*” (item 6 in Table 1), and from the  
400 other’s viewpoint by rating the following statement: “*The other person(s) appear to feel my*  
401 *presence*” (item 7 in Table 1). Both perspectives can be assessed simultaneously by rating the  
402 following statement: “*We feel each other’s presence*” (first item in Table 2).

#### 403 3.3.2 *Affective / emotional level*

404 At the affective or emotional level, the mediation process should not degrade the feeling of  
405 intimacy [71], i.e. the mediated representation of an individual should evoke similar emotions  
406 as its unmediated counterpart. At this level, the relevant quality factor for social interaction is  
407 the feeling that one has an emotional and intellectual connection with the represented  
408 individuals [72-74]. The QoE can then be quantified from one’s own perspective by rating  
409 the following statement: “*I feel an emotional and intellectual connection with the other*  
410 *person(s)*” (item 8 in Table 1), and from the other’s viewpoint by rating the following  
411 statement: “*The other person(s) appear to feel an emotional and intellectual connection with*  
412 *me*” (item 9 in Table 1). Both perspectives can be assessed simultaneously by rating the  
413 following statement: “*We feel a mutual emotional and intellectual connection*” (second item  
414 in Table 2).

#### 415 3.3.3 *Cognitive level*

416 At the cognitive level, the mediation process should not affect the natural appearance of the  
417 represented individuals (the fidelity or credibility of their representation). At this level, the  
418 relevant quality factor for social interaction is the feeling that the represented individuals  
419 should look as in normal life. The QoE can then be quantified from one’s own perspective by  
420 rating the following statement: “*The appearance of the other person(s) feels normal*” (item  
421 10 in Table 1), and from the other’s viewpoint by rating the following statement: “*My*

422 *appearance seems normal to the other person(s)*” (item 11 in Table 1). Both perspectives can  
423 be assessed simultaneously by rating the following statement: “*Our appearance feels*  
424 *normal*” (third item in Table 2).

#### 425 3.3.4 Reasoning level

426 At the reasoning level, the mediation process should not affect the reasoning processes of the  
427 communication partners. At this level, the relevant quality factor for social interaction is  
428 feeling that the communication system represents individuals in such a way that they affect  
429 one’s thinking as they would in normal life. The QoE can then be quantified from one’s own  
430 perspective by rating the following statement: “*While communicating, my reasoning feels*  
431 *normal*” (item 12 in Table 1), and from the other’s viewpoint by rating the following  
432 statement: “*While communicating, the reasoning of the other person(s) feels normal*” (item  
433 13 in Table 1). Both perspectives can be assessed simultaneously by rating the following  
434 statement: “*While communicating, our mutual reasoning feels normal*” (fourth item in Table  
435 2).

#### 436 3.3.5 Behavioral level

437 At the behavioral level, the mediation process should not restrict the natural interaction  
438 between individuals. At this level, the relevant quality factor for social interaction is the  
439 feeling that one’s interaction with represented individuals is the same as in normal life. The  
440 QoE can then be quantified from one’s own perspective by rating the following statement:  
441 “*While communicating, my behavior feels normal*” (item 10 in Table 1), and from the other’s  
442 viewpoint by rating the following statement: “*While communicating, the behavior of the*  
443 *other person(s) feels normal*” (item 15 in Table 1). Both perspectives can be assessed  
444 simultaneously by rating the following statement: “*While communicating, our mutual*  
445 *behavior feels normal*” (fifth item in Table 2).

### 446 4 Conclusions

447 There is a need for efficient, validated, and standardized measures that fully characterize the  
448 QoE of mediated social communication experiences. To this aim we propose a new holistic  
449 mediated social communication (H-MS-C) framework and an associated measurement tool  
450 (the H-MS-C-Q). The framework is based on a recently developed conceptual framework for  
451 multisensory perception. The H-MS-C framework is based on experiential fidelity, to ensure  
452 that the associated measurements are largely independent of context, media content and  
453 personal factors. It is also technology independent and can therefore be applied to a wide  
454 range of multisensory (visual, auditory, haptic, and olfactory) communication systems along  
455 the reality-virtuality continuum. The framework agrees with the latest theoretical insights that  
456 perceived realism, plausibility and coherence are the central outcomes of the sensory,  
457 perceptual and cognitive processing layers in the human brain that determine the quality of a  
458 mediated experience [67,70,75]. In contrast to existing questionnaires, the H-MS-C-Q does  
459 not rely on ambiguously formulated presence items that have no clear relation to AR/MR/XR  
460 experiences [70,76,77]. The H-MS-C-Q is complete and parsimonious, using only a single  
461 item to tap into each of the relevant processing levels in the human brain: sensory, emotional,  
462 and cognitive, reasoning, and behavioral. It measures the quality of Spatial Presence (i.e., the  
463 perceived fidelity, internal and external plausibility, and cognitive, reasoning and behavioral  
464 affordances of an environment) and the experience of Social Presence (i.e., perceived mutual

465 proximity, intimacy, credibility, reasoning and behavior of the communication partners).  
466 Initial validation studies (not reported here) confirm the content and face validity of the H-  
467 MSC-Q.

#### 468 *4.1 Limitations*

469 In its current form the H-MSC framework and the associated H-MSC-Q only apply to social  
470 communication in (simulated) real world settings. For certain thematic environments, such as  
471 those associated with science fiction or fantasy, several items in the questionnaire (e.g.,  
472 plausibility and agency) may need to be adapted.

473 To keep the questionnaire concise, high-level formulations were adopted for each of  
474 its items. For each of the individual constructs of the H-MSC-Q, additional subscales can be  
475 formulated with items that for instance zoom-in on each of the individual sensory modalities  
476 (visual, auditory, haptics, olfactory) of a system.

#### 477 *4.2 Availability of the questionnaire*

478 The Holistic Mediated Social Communication Questionnaire (H-MSC-Q) is publicly  
479 available (both in Microsoft Word and interactive PDF format) from the Open Science  
480 Framework (OSF) repository at [osf.io/9qkhr](https://osf.io/9qkhr) with doi: 10.17605/OSF.IO/9QKHR under the  
481 CC-By Attribution 4.0 International license. Use is only allowed after complying with the  
482 following two conditions: (1) a credit line in publications and presentations reading: “The  
483 Holistic Mediated Social Communication Questionnaire (H-MSC-Q) is available from the  
484 OSF repository at <https://osf.io/9qkhr>,” and (2) a citation to the current article in any  
485 publication in which the H-MSC-Q is used.

486

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## Tables

Table 1. The Holistic Mediated Social Communication Questionnaire (H-MS-C-Q) for measuring the quality of mediated social experiences. The item numbers and their identifiers are enclosed in square brackets. C = construct describing the experience that is to be assessed, Q = questionnaire item used to assess the associated construct.

		Processing level				
		Sensory	Emotional	Cognitive	Reasoning	Behavioral
2A. Spatial Presence		3A1. Telepresence				3A2. Agency
		[ 1: fidelity]	[2: int. plausibility]	[3: ext. plausibility]	[4: reasoning]	[5: agency]
		C: The feeling that one's sensory input is directly linked to the represented environment.  Q: I felt in direct contact with the environment.	C: The feeling that one's sensory input is consistent and congruent with the represented environment.  Q: My sensations were consistent and agreed with the environment.	C: The feeling that the represented environment really exists.  Q: The environment appeared real.	C: The feeling that the represented environment affects one's thoughts and reasoning as its real counterpart would.  Q: The environment affected my thoughts just as its real counterpart would.	C: The feeling that one's interaction with the represented environment is just like it would be with its real counterpart.  Q: My interaction with the environment felt realistic.
2B. Social Presence	Internal ("own") Perspective	3B1. Copresence	3B2. Social interaction			
		[6: immediacy]	[8: intimacy]	[10: credibility]	[12: reasoning]	[14: behavior]
		C: The feeling that one's communication partners are physically present in one's influence sphere.  Q: I felt the presence of the other person(s).	C: The feeling that one has an emotional and intellectual connection with one's communication partners.  Q: I felt an emotional and intellectual connection with the other person(s).	C: The feeling that the communication partners appear like they would in normal life.  Q: The appearance of the other person(s) felt normal.	C: The feeling that one's communication partners affect one's reasoning just as in normal life.  Q: While communicating, my reasoning felt normal.	C: The feeling that one can behave (speak with, look at, touch) towards the communication partners as in normal life.  Q: While communicating, my behavior felt normal.
	External ("other") Perspective	[7: immediacy]	[9: intimacy]	[11: credibility]	[13: reasoning]	[15: behavior]
		C: The feeling that the communication partners experience one's physical proximity.  Q: The other person(s) appeared to feel my presence.	C: The feeling that the communication partners experience an emotional and intellectual connection with oneself.  Q: The other person(s) appeared to feel an emotional and intellectual connection with me.	C: The feeling that the communication partners experience one's appearance like they would in normal life.  Q: My appearance seemed normal to the other person(s).	C: The feeling that one affects the reasoning of the communication partners like one would in normal life.  Q: While communicating, the reasoning of the other person(s) felt normal.	C: The feeling that the communication partners behave (speak with, look at, touch) towards oneself like they would in normal life.  Q: While communicating, the behavior of the other person(s) felt normal.

Table 2. Concise version of the Social Presence part of the Holistic Mediated Social Communication Questionnaire (H-MSQ-Q) C = construct describing the experience that is to be assessed, Q = questionnaire item used to assess the associated construct.

	3B1. Copresence	3B2. Social interaction			
	[immediacy]	[intimacy]	[credibility]	[reasoning]	[behavior]
2B. Social Presence (Combined perspectives)	<p><b>C:</b> The feeling that the represented individuals experience each other's physical proximity.</p> <p><b>Q:</b> <i>We felt each other's presence.</i></p>	<p><b>C:</b> The feeling that the represented individuals experience an emotional and intellectual connection.</p> <p><b>Q:</b> <i>We felt a mutual emotional and intellectual connection.</i></p>	<p><b>C:</b> The feeling that the represented individuals experience each other's appearance as in normal life.</p> <p><b>Q:</b> <i>Our appearance felt normal.</i></p>	<p><b>C:</b> The feeling that the represented individuals behave (speak with, look at, touch) towards each other as in normal life.</p> <p><b>Q:</b> <i>While communicating, our mutual behavior felt normal.</i></p>	<p><b>C:</b> The feeling that the representation of all individuals affects their thoughts as in normal life.</p> <p><b>Q:</b> <i>While communicating, our mutual reasoning felt normal.</i></p>

Table 3. The relation between some of the most influential presence questionnaires and each of the five relevant (sensory, emotional, cognitive, behavioral and decision making) processing levels for Spatial Presence and for Social Presence. Filled circles represent questionnaire items that are explicitly formulated according the requirements formulated in Section 1.2. Open circles represent questionnaire items that are only implicitly related to these requirements.

		Spatial Presence					Social presence											
		Telepresence				Agency	Co-presence	Internal perspective					Co-presence	External perspective				
		Sensory (fidelity)	Emotional (int. plausib.)	Cognitive (ext. plausib.)	Reasoning			Sensory (immmediacy)	Emotional (intimicy)	Cognitive (credibility)	Reasoning	Behavioral		Sensory (immmediacy)	Emotional (intimicy)	Cognitive (credibility)	Reasoning	Behavioral
Spatial Presence Questionnaires	SUS [39]	○		●														
	PQ (v.3) [38]	○	●	○	○	●												
	IPQ [22]	●	○	●		○												
	MEC-SPQ [40]	●	●	●	○	●												
	Place Probe [41]	●	○		○	○												
Social Presence Questionnaires	SP Survey [45]						●	○	○									
	SBT [46]						●	○			○							
	NM-SPI [47]						○	●			○	●					○	
	MPS [49]	○	○	●	○	○	●		○		○	●						
	SocialVR-Q [13]						●	●		○	○	○	●					