



## Evaluating the Mental Models Approach to Developing a Risk Communication: A Scoping Review of the Evidence

Journal:	<i>Risk Analysis</i>
Manuscript ID	RA-00474-2015.R1
Wiley - Manuscript type:	Original Research Article
Key Words:	mental models, risk communication, review

SCHOLARONE™  
Manuscripts

Peer Review

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

Evaluating the Mental Models Approach to Developing a Risk  
Communication: A Scoping Review of the Evidence

Peer Review

1  
2  
3 ABSTRACT:  
4

5 Risk communication is fundamental in ensuring people are equipped with the  
6 knowledge needed to navigate varied risks. One generally well-regarded framework for  
7 the development of such communications is the Mental Models Approach to Risk  
8 Communication (MMARC). Developed during the 1990s, the MMARC has been applied  
9 to a range of health, technological and environmental risks. However, as yet, we know  
10 of no attempt to collate and review articles that evaluated communications developed  
11 using the MMARC. The current paper took a first step at addressing this gap by  
12 conducting a scoping review, which aimed to begin to explore the fidelity with which the  
13 approach has been applied, explore whether there appeared to be sufficient studies to  
14 warrant a future systematic review, and identify future research questions. Although the  
15 initial search found over 100 articles explicitly applying the MMARC, only 12 of these  
16 developed a risk-related communication which was tested against a control (and thus  
17 included in the current review). All studies reported a positive effect of the MMARC vs.  
18 control communication for at least some of the outcome measures (knowledge being  
19 the most prevalent). However, there was wide variation between studies including type  
20 of control, outcomes assessed, and only 5 studies reported adopting a randomised  
21 design. The review highlights both the need for greater fidelity in the way future studies  
22 operationalise the MMARC approach, and suggests that a full-scale systematic review  
23 of the MMARC literature appears justified, especially given the possibility of a large grey  
24 literature in this area.  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

KEYWORDS:

mental models, risk communication, scoping review

For Peer Review

## 1. INTRODUCTION

The world contains many hazards. Some are relatively infrequent, such as major earthquakes and nuclear energy disasters, whilst others are encountered daily, for example car driving or food preparation.<sup>(1-4)</sup> For many hazards, people are often unable to personally assess the risk. Reasons for this include a) the hazard being undetectable by the senses (e.g. microscopic foodborne pathogens invisible to the naked eye), b) it being too complex for non-specialists to fully comprehend (e.g. financial risks), and c) the fact that people lead busy lives with many competing pressures on their time and attention.<sup>(5-7)</sup> Regardless of the reason, people often rely on those with a greater knowledge (sometimes referred to as 'experts') to provide them with salient hazard information (although see below for a discussion on two-way communication).<sup>(8)</sup> This process of information exchange about a hazard is referred to as risk communication.<sup>(9-11)</sup>

Notwithstanding the fact that members of the public have a wide range of knowledge on risk topics, it is generally acknowledge that 'experts' tend to have a more detailed understanding of the technical aspects of a risk, for example relating to the hazard's effects and the pathways through which it operates. However, additional factors affect how the public perceives a risk, for example its controllability and their familiarity with the hazard, with which experts might be less familiar.<sup>(12,13)</sup> Given uncertainty over the public's knowledge of a hazard, and these additional factors affecting their perception, a

1  
2  
3 particular challenge for risk communicators is determining appropriate message  
4 content.<sup>(10,14,15)</sup> On the one hand, there is no point in telling people what they already  
5 know, but on the other, information indispensable to understanding a hazard should be  
6 communicated if not already known.  
7  
8  
9  
10  
11

12  
13  
14  
15 Historically, the process of risk communication was often based around a one-way  
16 approach, for example where experts formulated the content of the risk communication  
17 detached from public input (or vice versa).<sup>(8,14)</sup> Now, it is recognised that a two-way  
18 approach (involving both traditional 'expert' and 'lay' perspectives) is more appropriate  
19 because it involves experts working with the public throughout the risk communication  
20 process.<sup>(10,14,15)</sup> Dialogue between these groups helps ensure the risk communication  
21 takes into account the audience's knowledge and concerns, in theory more effectively  
22 communicating appropriate information.<sup>(14,16,17)</sup>  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35

36 One well-established two-way framework for developing risk communication is the  
37 Mental Models Approach (MMARC).<sup>(10,18–20)</sup> The MMARC is based on the idea that  
38 people's views of a concept are based on a complex web of information, drawn from  
39 personal experience and external sources.<sup>(21)</sup> Mental models, as these webs are known,  
40 are not always based on accurate information.<sup>(10)</sup> For example Hagemann & Scholderer  
41 define a mental model as '*a mix of factual knowledge, erroneous assumptions, value*  
42 *judgements, and uncertainty*'.<sup>(22)</sup> The MMARC aims to improve the accuracy of people's  
43 mental models relating to a risk and thus inform their decision-making.<sup>(23)</sup> The MMARC  
44 assumes that a scientifically-accurate decision model ('expert model') will be technically  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

1  
2  
3 more accurate than the public's (i.e. 'decision-maker') mental model of a risk.<sup>(10,24,25)</sup>

4  
5 The challenge of determining risk communication content is therefore tackled by  
6  
7 comparing an expert model with the public's mental models, which forms the first two  
8  
9 parts of the five-step process (see Figure 1).<sup>(10)</sup> The third step is a confirmatory survey  
10  
11 of the target audience to determine the prevalence of knowledge gaps and  
12  
13 misconceptions, and thus prioritisation of the communication's content. The final two  
14  
15 steps involve the development and iterative evaluation of a risk communication explicitly  
16  
17 developed from information gleaned during the earlier steps.  
18  
19  
20  
21

22  
23  
24 The MMARC was developed during the 1990s, and is being increasingly applied to a  
25  
26 diversity of topics (see Figure 2). These topics include health, (e.g. HIV, contraception),  
27  
28 technological (e.g. genetically-modified foods, nuclear energy) and environmental (e.g.  
29  
30 flooding, wildfires) related hazards.<sup>(22,26-31)</sup> In some cases not all steps of the MMARC  
31  
32 are applied. One example is Hagemann & Scholderer, who applied the first two steps of  
33  
34 the MMARC and identified mental models of how experts and the public perceived risks  
35  
36 and benefits associated with a novel potato, genetically-engineered to contain lower  
37  
38 toxin levels than conventional potatoes. However, the authors did not subsequently  
39  
40 design and test a new communication which attempted to build on these earlier  
41  
42 steps.<sup>(22)</sup>  
43  
44  
45  
46  
47  
48  
49

50  
51 The MMARC is well-regarded but, despite this praise, to our knowledge there has been  
52  
53 no attempt to collate studies that have evaluated communications developed using the  
54  
55 MMARC.<sup>(9,32,33)</sup> This is despite the fact that Bostrom *et al.* (1994, p.789) stated that although  
56  
57  
58  
59  
60

1  
2  
3 the MMARC is '*advanced on logical and theoretical grounds...direct empirical evaluation*  
4 *is needed to assess its products*'.<sup>(20)</sup> The current paper aims to fill this gap by reviewing  
5  
6 studies that have evaluated a communication developed using the MMARC.  
7  
8

9  
10 Importantly, we focussed specifically on those studies that included the final step of the  
11  
12 MMARC where a communication developed using information from early stages was  
13  
14 compared to a control communication not developed using the MMARC approach,  
15  
16 rather than those where only the earlier steps were applied (Figure 1). This is to begin  
17  
18 to ascertain the efficacy of communications developed using the MMARC process.  
19  
20 Guidance for assessing MMARC communications already exists, with common  
21  
22 elements including consideration of the target audience, communication format, and  
23  
24 outcome.<sup>(10,18,34)</sup> These elements were thus incorporated into the data extraction stage  
25  
26  
27 of this study.  
28  
29  
30  
31

32  
33  
34 Specifically, we conducted a scoping review to begin mapping out some of the key  
35  
36 research underpinning this area. A scoping review differs from a full-scale systematic  
37  
38 review in several ways and has slightly different aims. For instance, a full-scale  
39  
40 systematic review explicitly attempts to: a) synthesise all research in the field including  
41  
42 that in the grey literature, b) reduce bias in the review process by adopting highly  
43  
44 specialised literature searches often including following up with known authors in the  
45  
46 field, c) conduct inter-rater reliability for data extraction and quality assessment, and d)  
47  
48 when feasible, conduct meta-analyses of the findings. Given the thorough nature of the  
49  
50 process such reviews are extremely resource intensive and can take several years to  
51  
52 complete. Consequently, it is recommended to conduct, and publish the findings of, an  
53  
54  
55  
56  
57  
58  
59  
60



1  
2  
3 initial scoping review, in order to investigate whether investing the resources needed for  
4  
5 a full-scale systematic review is justified.<sup>(35)</sup> In the words of Peters et al. (2015),  
6  
7  
8 *'Scoping reviews are commonly used for 'reconnaissance' – to clarify working*  
9  
10 *definitions and conceptual boundaries of a topic or field... [they] are particularly useful*  
11  
12 *when a body of literature has not yet been comprehensively reviewed ... While scoping*  
13  
14 *reviews may be conducted to determine the value and probable scope of a full*  
15  
16 *systematic review, they may also be undertaken as exercises in themselves to*  
17  
18 *summarize and disseminate research findings, to identify research gaps, and to make*  
19  
20 *recommendations for future research'*.<sup>(35, p.141)</sup> Following this advice, the aim here was  
21  
22 not to try and attempt to conduct a full-scale systematic review, but rather to map the  
23  
24 field out in a way which should both provide some important insights in and of itself but  
25  
26 also help identify exactly where a systematic review might focus on in future.  
27  
28  
29  
30  
31  
32  
33

## 34 **2. METHODS**

35  
36  
37  
38 This study followed the steps outlined in the scoping review literature which consist of a  
39  
40 structured search to identify relevant studies, followed by data charting and  
41  
42 summarising results, as detailed below.<sup>(36–38)</sup> Of note, and reflecting the scoping nature  
43  
44 of the current review, as opposed to the procedures in a full systematic review, all three  
45  
46 stages were conducted by the first author in discussion with the other authors, rather  
47  
48 than multiple authors attempting to replicate the search strategy independently.  
49  
50  
51  
52  
53  
54

### 55 **2.1 Search**

56  
57  
58  
59  
60

1  
2  
3  
4  
5  
6 The search involved a combination of forward citation (to identify references that have  
7 cited a particular source), standard searching (using a database to identify references  
8 that meet particular key words), and hand searching (e.g. identifying references from  
9 the bibliography of a paper). Forward citation was used for four key sources that  
10 outlined the MMARC and was particularly suitable as part of the search strategy  
11 because the emergence of the MMARC is well-defined in these particular sources.<sup>(10,18–</sup>  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

<sup>20)</sup> However, one of these sources for which forward citation was required is the book by Morgan *et al.* (2002), and some academic search engines do not include sources such as books (see Table I).<sup>(10)</sup> It was therefore decided to also use the search engines Web of Science and Google Scholar (which allowed forward citation on most of the key sources). It is recognised that there are differing opinions about the use of Google Scholar in systematic searches, for example due to reproducibility.<sup>(39)</sup> However, it was considered a sound choice for this initial scoping study, was not used in isolation, and is also supported by recent studies comparing search engines.<sup>(40,41)</sup> The search strategy is set out in Table II.

## 2.2 Identify relevant studies

Citations were exported directly from Web of Science to EndNote. For Google Scholar, Zotero was used to export citations via Mozilla Firefox. All references were imported to a single EndNote X7 file. After duplicate references were removed, the inclusion criteria listed in Table III were applied.

1  
2  
3  
4  
5  
6 Following the title and abstract screen, full text copies of articles were obtained and the  
7  
8 same inclusion criteria applied. During the title / abstract sift, if it was clear that a paper  
9  
10 did not report the evaluation of a communication (i.e. it was not relevant to this study's  
11  
12 aims), but it was unclear whether the study was applying the earlier interview and  
13  
14 survey stages of the MMARC, the full text was checked to ensure the correct exclusion  
15  
16 criterion was applied (see Table III).  
17  
18  
19  
20  
21

### 22 **2.3 Data charting**

23  
24  
25  
26

27 Data were extracted from studies meeting the inclusion criteria and summarised under  
28  
29 the following headings which include the PICO structure for evaluating research  
30  
31 (Population, Intervention, Comparison, Outcome):<sup>(42)</sup>  
32  
33  
34  
35

- 36 1. Study description: authors, year, country, topic, whether the study included at  
37  
38 least one author of the original study (i.e. Morgan, Fischhoff, Bostrom and  
39  
40 Atman), and the knowledge measures (i.e. whether direct or indirect).<sup>(10)</sup>  
41  
42
- 43 2. Participants (target audience): from which population the participants who  
44  
45 evaluated the communication were drawn.  
46  
47
- 48 3. Intervention: the MMARC communication, and its format.  
49
- 50 4. Comparison: whether a control communication was used in each study, and if so  
51  
52 its format.  
53  
54  
55  
56  
57  
58  
59  
60

- 1
  - 2
  - 3
  - 4
  - 5
  - 6
  - 7
  - 8
  - 9
  - 10
  - 11
  - 12
  - 13
  - 14
  - 15
  - 16
  - 17
  - 18
  - 19
  - 20
  - 21
  - 22
  - 23
  - 24
  - 25
  - 26
  - 27
  - 28
  - 29
  - 30
  - 31
  - 32
  - 33
  - 34
  - 35
  - 36
  - 37
  - 38
  - 39
  - 40
  - 41
  - 42
  - 43
  - 44
  - 45
  - 46
  - 47
  - 48
  - 49
  - 50
  - 51
  - 52
  - 53
  - 54
  - 55
  - 56
  - 57
  - 58
  - 59
  - 60
5. Outcome: the effectiveness of the MMARC, and what was measured in participants following exposure to the communication (referred to here as the outcome measure), e.g. knowledge, behaviour.
  6. Process: methods / experimental design: how the communication was developed and evaluated (e.g. survey, focus group), and whether randomisation was used.

## 2.4 Summarising the results

In keeping with scoping review recommendations the extracted data was evaluated to identify trends, gaps, and how the findings related to the broader risk communication field. For example, this included how success was measured, whether particular aspects of the communications affected their impact, and key points for future risk communication evaluations. It did not involve detailed analysis of suitability of statistical procedures or appropriateness of sample sizes in the relevant papers. Where study details were unclear, further information was requested from the authors and incorporated (where provided) in the current review.

## 3. RESULTS

All searches were conducted during February 2014. A total of 2,504 references were identified. Figure 3 details the screening procedure used to sift the references identified by the searches. Table IV details the 12 studies that met all inclusion criteria and are therefore included in this review.

### 3.1 Search process

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11 Although we found over 100 papers which reported empirical findings using the  
12 MMARC approach, 90 of these did not include the final steps of the approach, i.e. the  
13 design and evaluation of a novel communication drawing on the findings of the earlier  
14 steps. In fact, we found only 12 studies that actually designed and tested a risk  
15 communication based on the approach. Nonetheless, many of these 90 studies  
16 concluded with advice, which may have since been used by other organisations  
17 involved in risk communication.<sup>(27,43–45)</sup> Also, there may be an assumption when  
18 embarking on the MMARC that sufficient differences exist between the expert model  
19 and the public's (collective) mental model to justify the production of a communication,  
20 which may not always be the case. Although these 90 papers are not discussed further  
21 here, it is important to acknowledge their contribution to the MMARC literature in  
22 providing a wealth of examples in which the earlier MMARC stages were applied (i.e.  
23 steps 1-3 in Figure 1) and which may want to be included in a future systematic review  
24 into the MMARC approach more generally. Furthermore, a future systematic review  
25 may also want to consider a more extensive search process where the authors of  
26 studies that did not include the evaluative step could be contacted, to request potentially  
27 unpublished data exploring an evaluation which could be incorporated into a meta-  
28 analysis.  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

1  
2  
3 A further two studies that met the inclusion criteria were not included in the analysis  
4  
5 (Morgan *et al.*, 1992; Cone *et al.*, 2013), because the findings in the former are reported  
6  
7 in greater detail by Bostrom *et al.* (1994).<sup>(20,23,46)</sup> Additionally, Cone *et al.* 2013 reported  
8  
9 that a communication was developed and evaluated using the MMARC, but referred to  
10  
11 details within another paper submitted for publication and not available for review at the  
12  
13 time of these searches (Cone & Winters, 2014).<sup>(47)</sup> No additional papers were found  
14  
15 after reviewing reference lists (see Table II) of the 12 papers that met the inclusion  
16  
17 criteria, supporting our contention that the current search approach was a satisfactory  
18  
19 first step.  
20  
21  
22  
23  
24  
25  
26

### 27 **3.2 Study description**

28  
29  
30  
31 The 12 studies included in this review were conducted in six countries over the past two  
32  
33 decades, and focussed on a range of topics. The USA accounted for over half (seven)  
34  
35 of all studies, with one study conducted in each of the other five countries (Canada,  
36  
37 Mexico, Germany, Switzerland, UK). All US studies included at least one of the original  
38  
39 study authors (i.e. Morgan, Fischhoff, Bostrom and Atman). The 12 studies were spread  
40  
41 from 1993 (Maharik & Fischhoff) to 2012 (Vogt & Schaefer).<sup>(48,49)</sup> Topics on which the  
42  
43 studies focussed represented a range of risks, including environmental e.g. radon,<sup>(18,20)</sup>  
44  
45 health e.g. xenotransplantation and disease,<sup>(50,51)</sup> and technological e.g. mobile phone  
46  
47 masts and electrical fields.<sup>(52,53)</sup>  
48  
49  
50  
51  
52  
53  
54

### 55 **3.3 Participants (target audience)**

56  
57  
58  
59  
60

1  
2  
3  
4  
5  
6 Our review suggests that only four studies (33%) specifically focused on the key target  
7 audience, both in terms of region and age, at the evaluation stage.<sup>(34,49,51,54)</sup> For  
8 example, Niewöhner *et al.* (2004) evaluated a risk communication about occupational  
9 chemical health risks, specifically rosin-based solder flux in the electronics industry, and  
10 perchlorethylene in the dry cleaning industry, with participants recruited from these  
11 particular industries. In another example, Downs *et al.* developed a MMARC  
12 communication which aimed to inform young women about contraceptives and sexually-  
13 transmitted disease (STD) risk.<sup>(51)</sup> Participants were drawn from this particular  
14 demographic group. In both cases, participants directly represented the target audience  
15 at risk, for whom the communication was intended to improve the mental models. In  
16 contrast, participants in other studies did not represent the target audience of people  
17 whose collective mental models were elicited and recognised by the authors as  
18 incomplete for the topic under investigation.  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38

39 The majority of studies used convenience sampling to recruit participants to take part in  
40 the evaluation of the MMARC communication (see Table IV). In some cases the  
41 limitations of this approach were recognised, i.e. that the views of the sample with  
42 whom the communication was tested may not represent those views of the  
43 communication's intended audience e.g. De Bruin *et al.* (p.1408) and Longstaff  
44 (p.36).<sup>(50,55)</sup> The challenges of recruiting participants from the target population were  
45 described by Niewöhner *et al.*<sup>(34)</sup> The authors reported a low response rate of 7-12% for  
46 return of completed postal surveys during the analysis of the communication related to  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

1  
2  
3 management of chemical risks amongst small companies (the target audience). It was  
4 suggested that tighter profit margins amongst many smaller organisations resulted in a  
5 lower expenditure on health and safety, and a corresponding reluctance amongst  
6 managers of such organisations to participate in safety surveys. The authors also  
7 described how such industries were poorly understood by the research community,  
8 which presents a challenge in identifying suitable companies in the first place.  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19

### 20 **3.4 Intervention (the MMARC communication)**

21  
22  
23  
24 The MMARC communications in the 12 studies varied by format, length and scope. The  
25 format of the MMARC communications was almost exclusively written, except for  
26 Downs *et al.*<sup>(51)</sup> Of these 11 studies, a brochure / booklet was used in six  
27 studies.<sup>(18,20,48,49,52,56)</sup> In one study, a comic book was used to communicate carbon  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60  
61  
62  
63  
64  
65  
66  
67  
68  
69  
70  
71  
72  
73  
74  
75  
76  
77  
78  
79  
80  
81  
82  
83  
84  
85  
86  
87  
88  
89  
90  
91  
92  
93  
94  
95  
96  
97  
98  
99  
100  
101  
102  
103  
104  
105  
106  
107  
108  
109  
110  
111  
112  
113  
114  
115  
116  
117  
118  
119  
120  
121  
122  
123  
124  
125  
126  
127  
128  
129  
130  
131  
132  
133  
134  
135  
136  
137  
138  
139  
140  
141  
142  
143  
144  
145  
146  
147  
148  
149  
150  
151  
152  
153  
154  
155  
156  
157  
158  
159  
160  
161  
162  
163  
164  
165  
166  
167  
168  
169  
170  
171  
172  
173  
174  
175  
176  
177  
178  
179  
180  
181  
182  
183  
184  
185  
186  
187  
188  
189  
190  
191  
192  
193  
194  
195  
196  
197  
198  
199  
200  
201  
202  
203  
204  
205  
206  
207  
208  
209  
210  
211  
212  
213  
214  
215  
216  
217  
218  
219  
220  
221  
222  
223  
224  
225  
226  
227  
228  
229  
230  
231  
232  
233  
234  
235  
236  
237  
238  
239  
240  
241  
242  
243  
244  
245  
246  
247  
248  
249  
250  
251  
252  
253  
254  
255  
256  
257  
258  
259  
260  
261  
262  
263  
264  
265  
266  
267  
268  
269  
270  
271  
272  
273  
274  
275  
276  
277  
278  
279  
280  
281  
282  
283  
284  
285  
286  
287  
288  
289  
290  
291  
292  
293  
294  
295  
296  
297  
298  
299  
300  
301  
302  
303  
304  
305  
306  
307  
308  
309  
310  
311  
312  
313  
314  
315  
316  
317  
318  
319  
320  
321  
322  
323  
324  
325  
326  
327  
328  
329  
330  
331  
332  
333  
334  
335  
336  
337  
338  
339  
340  
341  
342  
343  
344  
345  
346  
347  
348  
349  
350  
351  
352  
353  
354  
355  
356  
357  
358  
359  
360  
361  
362  
363  
364  
365  
366  
367  
368  
369  
370  
371  
372  
373  
374  
375  
376  
377  
378  
379  
380  
381  
382  
383  
384  
385  
386  
387  
388  
389  
390  
391  
392  
393  
394  
395  
396  
397  
398  
399  
400  
401  
402  
403  
404  
405  
406  
407  
408  
409  
410  
411  
412  
413  
414  
415  
416  
417  
418  
419  
420  
421  
422  
423  
424  
425  
426  
427  
428  
429  
430  
431  
432  
433  
434  
435  
436  
437  
438  
439  
440  
441  
442  
443  
444  
445  
446  
447  
448  
449  
450  
451  
452  
453  
454  
455  
456  
457  
458  
459  
460  
461  
462  
463  
464  
465  
466  
467  
468  
469  
470  
471  
472  
473  
474  
475  
476  
477  
478  
479  
480  
481  
482  
483  
484  
485  
486  
487  
488  
489  
490  
491  
492  
493  
494  
495  
496  
497  
498  
499  
500  
501  
502  
503  
504  
505  
506  
507  
508  
509  
510  
511  
512  
513  
514  
515  
516  
517  
518  
519  
520  
521  
522  
523  
524  
525  
526  
527  
528  
529  
530  
531  
532  
533  
534  
535  
536  
537  
538  
539  
540  
541  
542  
543  
544  
545  
546  
547  
548  
549  
550  
551  
552  
553  
554  
555  
556  
557  
558  
559  
560  
561  
562  
563  
564  
565  
566  
567  
568  
569  
570  
571  
572  
573  
574  
575  
576  
577  
578  
579  
580  
581  
582  
583  
584  
585  
586  
587  
588  
589  
590  
591  
592  
593  
594  
595  
596  
597  
598  
599  
600  
601  
602  
603  
604  
605  
606  
607  
608  
609  
610  
611  
612  
613  
614  
615  
616  
617  
618  
619  
620  
621  
622  
623  
624  
625  
626  
627  
628  
629  
630  
631  
632  
633  
634  
635  
636  
637  
638  
639  
640  
641  
642  
643  
644  
645  
646  
647  
648  
649  
650  
651  
652  
653  
654  
655  
656  
657  
658  
659  
660  
661  
662  
663  
664  
665  
666  
667  
668  
669  
670  
671  
672  
673  
674  
675  
676  
677  
678  
679  
680  
681  
682  
683  
684  
685  
686  
687  
688  
689  
690  
691  
692  
693  
694  
695  
696  
697  
698  
699  
700  
701  
702  
703  
704  
705  
706  
707  
708  
709  
710  
711  
712  
713  
714  
715  
716  
717  
718  
719  
720  
721  
722  
723  
724  
725  
726  
727  
728  
729  
730  
731  
732  
733  
734  
735  
736  
737  
738  
739  
740  
741  
742  
743  
744  
745  
746  
747  
748  
749  
750  
751  
752  
753  
754  
755  
756  
757  
758  
759  
760  
761  
762  
763  
764  
765  
766  
767  
768  
769  
770  
771  
772  
773  
774  
775  
776  
777  
778  
779  
780  
781  
782  
783  
784  
785  
786  
787  
788  
789  
790  
791  
792  
793  
794  
795  
796  
797  
798  
799  
800  
801  
802  
803  
804  
805  
806  
807  
808  
809  
810  
811  
812  
813  
814  
815  
816  
817  
818  
819  
820  
821  
822  
823  
824  
825  
826  
827  
828  
829  
830  
831  
832  
833  
834  
835  
836  
837  
838  
839  
840  
841  
842  
843  
844  
845  
846  
847  
848  
849  
850  
851  
852  
853  
854  
855  
856  
857  
858  
859  
860  
861  
862  
863  
864  
865  
866  
867  
868  
869  
870  
871  
872  
873  
874  
875  
876  
877  
878  
879  
880  
881  
882  
883  
884  
885  
886  
887  
888  
889  
890  
891  
892  
893  
894  
895  
896  
897  
898  
899  
900  
901  
902  
903  
904  
905  
906  
907  
908  
909  
910  
911  
912  
913  
914  
915  
916  
917  
918  
919  
920  
921  
922  
923  
924  
925  
926  
927  
928  
929  
930  
931  
932  
933  
934  
935  
936  
937  
938  
939  
940  
941  
942  
943  
944  
945  
946  
947  
948  
949  
950  
951  
952  
953  
954  
955  
956  
957  
958  
959  
960  
961  
962  
963  
964  
965  
966  
967  
968  
969  
970  
971  
972  
973  
974  
975  
976  
977  
978  
979  
980  
981  
982  
983  
984  
985  
986  
987  
988  
989  
990  
991  
992  
993  
994  
995  
996  
997  
998  
999  
1000  
1001  
1002  
1003  
1004  
1005  
1006  
1007  
1008  
1009  
1010  
1011  
1012  
1013  
1014  
1015  
1016  
1017  
1018  
1019  
1020  
1021  
1022  
1023  
1024  
1025  
1026  
1027  
1028  
1029  
1030  
1031  
1032  
1033  
1034  
1035  
1036  
1037  
1038  
1039  
1040  
1041  
1042  
1043  
1044  
1045  
1046  
1047  
1048  
1049  
1050  
1051  
1052  
1053  
1054  
1055  
1056  
1057  
1058  
1059  
1060  
1061  
1062  
1063  
1064  
1065  
1066  
1067  
1068  
1069  
1070  
1071  
1072  
1073  
1074  
1075  
1076  
1077  
1078  
1079  
1080  
1081  
1082  
1083  
1084  
1085  
1086  
1087  
1088  
1089  
1090  
1091  
1092  
1093  
1094  
1095  
1096  
1097  
1098  
1099  
1100  
1101  
1102  
1103  
1104  
1105  
1106  
1107  
1108  
1109  
1110  
1111  
1112  
1113  
1114  
1115  
1116  
1117  
1118  
1119  
1120  
1121  
1122  
1123  
1124  
1125  
1126  
1127  
1128  
1129  
1130  
1131  
1132  
1133  
1134  
1135  
1136  
1137  
1138  
1139  
1140  
1141  
1142  
1143  
1144  
1145  
1146  
1147  
1148  
1149  
1150  
1151  
1152  
1153  
1154  
1155  
1156  
1157  
1158  
1159  
1160  
1161  
1162  
1163  
1164  
1165  
1166  
1167  
1168  
1169  
1170  
1171  
1172  
1173  
1174  
1175  
1176  
1177  
1178  
1179  
1180  
1181  
1182  
1183  
1184  
1185  
1186  
1187  
1188  
1189  
1190  
1191  
1192  
1193  
1194  
1195  
1196  
1197  
1198  
1199  
1200  
1201  
1202  
1203  
1204  
1205  
1206  
1207  
1208  
1209  
1210  
1211  
1212  
1213  
1214  
1215  
1216  
1217  
1218  
1219  
1220  
1221  
1222  
1223  
1224  
1225  
1226  
1227  
1228  
1229  
1230  
1231  
1232  
1233  
1234  
1235  
1236  
1237  
1238  
1239  
1240  
1241  
1242  
1243  
1244  
1245  
1246  
1247  
1248  
1249  
1250  
1251  
1252  
1253  
1254  
1255  
1256  
1257  
1258  
1259  
1260  
1261  
1262  
1263  
1264  
1265  
1266  
1267  
1268  
1269  
1270  
1271  
1272  
1273  
1274  
1275  
1276  
1277  
1278  
1279  
1280  
1281  
1282  
1283  
1284  
1285  
1286  
1287  
1288  
1289  
1290  
1291  
1292  
1293  
1294  
1295  
1296  
1297  
1298  
1299  
1300  
1301  
1302  
1303  
1304  
1305  
1306  
1307  
1308  
1309  
1310  
1311  
1312  
1313  
1314  
1315  
1316  
1317  
1318  
1319  
1320  
1321  
1322  
1323  
1324  
1325  
1326  
1327  
1328  
1329  
1330  
1331  
1332  
1333  
1334  
1335  
1336  
1337  
1338  
1339  
1340  
1341  
1342  
1343  
1344  
1345  
1346  
1347  
1348  
1349  
1350  
1351  
1352  
1353  
1354  
1355  
1356  
1357  
1358  
1359  
1360  
1361  
1362  
1363  
1364  
1365  
1366  
1367  
1368  
1369  
1370  
1371  
1372  
1373  
1374  
1375  
1376  
1377  
1378  
1379  
1380  
1381  
1382  
1383  
1384  
1385  
1386  
1387  
1388  
1389  
1390  
1391  
1392  
1393  
1394  
1395  
1396  
1397  
1398  
1399  
1400  
1401  
1402  
1403  
1404  
1405  
1406  
1407  
1408  
1409  
1410  
1411  
1412  
1413  
1414  
1415  
1416  
1417  
1418  
1419  
1420  
1421  
1422  
1423  
1424  
1425  
1426  
1427  
1428  
1429  
1430  
1431  
1432  
1433  
1434  
1435  
1436  
1437  
1438  
1439  
1440  
1441  
1442  
1443  
1444  
1445  
1446  
1447  
1448  
1449  
1450  
1451  
1452  
1453  
1454  
1455  
1456  
1457  
1458  
1459  
1460  
1461  
1462  
1463  
1464  
1465  
1466  
1467  
1468  
1469  
1470  
1471  
1472  
1473  
1474  
1475  
1476  
1477  
1478  
1479  
1480  
1481  
1482  
1483  
1484  
1485  
1486  
1487  
1488  
1489  
1490  
1491  
1492  
1493  
1494  
1495  
1496  
1497  
1498  
1499  
1500  
1501  
1502  
1503  
1504  
1505  
1506  
1507  
1508  
1509  
1510  
1511  
1512  
1513  
1514  
1515  
1516  
1517  
1518  
1519  
1520  
1521  
1522  
1523  
1524  
1525  
1526  
1527  
1528  
1529  
1530  
1531  
1532  
1533  
1534  
1535  
1536  
1537  
1538  
1539  
1540  
1541  
1542  
1543  
1544  
1545  
1546  
1547  
1548  
1549  
1550  
1551  
1552  
1553  
1554  
1555  
1556  
1557  
1558  
1559  
1560  
1561  
1562  
1563  
1564  
1565  
1566  
1567  
1568  
1569  
1570  
1571  
1572  
1573  
1574  
1575  
1576  
1577  
1578  
1579  
1580  
1581  
1582  
1583  
1584  
1585  
1586  
1587  
1588  
1589  
1590  
1591  
1592  
1593  
1594  
1595  
1596  
1597  
1598  
1599  
1600  
1601  
1602  
1603  
1604  
1605  
1606  
1607  
1608  
1609  
1610  
1611  
1612  
1613  
1614  
1615  
1616  
1617  
1618  
1619  
1620  
1621  
1622  
1623  
1624  
1625  
1626  
1627  
1628  
1629  
1630  
1631  
1632  
1633  
1634  
1635  
1636  
1637  
1638  
1639  
1640  
1641  
1642  
1643  
1644  
1645  
1646  
1647  
1648  
1649  
1650  
1651  
1652  
1653  
1654  
1655  
1656  
1657  
1658  
1659  
1660  
1661  
1662  
1663  
1664  
1665  
1666  
1667  
1668  
1669  
1670  
1671  
1672  
1673  
1674  
1675  
1676  
1677  
1678  
1679  
1680  
1681  
1682  
1683  
1684  
1685  
1686  
1687  
1688  
1689  
1690  
1691  
1692  
1693  
1694  
1695  
1696  
1697  
1698  
1699  
1700  
1701  
1702  
1703  
1704  
1705  
1706  
1707  
1708  
1709  
1710  
1711  
1712  
1713  
1714  
1715  
1716  
1717  
1718  
1719  
1720  
1721  
1722  
1723  
1724  
1725  
1726  
1727  
1728  
1729  
1730  
1731  
1732  
1733  
1734  
1735  
1736  
1737  
1738  
1739  
1740  
1741  
1742  
1743  
1744  
1745  
1746  
1747  
1748  
1749  
1750  
1751  
1752  
1753  
1754  
1755  
1756  
1757  
1758  
1759  
1760  
1761  
1762  
1763  
1764  
1765  
1766  
1767  
1768  
1769  
1770  
1771  
1772  
1773  
1774  
1775  
1776  
1777  
1778  
1779  
1780  
1781  
1782  
1783  
1784  
1785  
1786  
1787  
1788  
1789  
1790  
1791  
1792  
1793  
1794  
1795  
1796  
1797  
1798  
1799  
1800  
1801  
1802  
1803  
1804  
1805  
1806  
1807  
1808  
1809  
1810  
1811  
1812  
1813  
1814  
1815  
1816  
1817  
1818  
1819  
1820  
1821  
1822  
1823  
1824  
1825  
1826  
1827  
1828  
1829  
1830  
1831  
1832  
1833  
1834  
1835  
1836  
1837  
1838  
1839  
1840  
1841  
1842  
1843  
1844  
1845  
1846  
1847  
1848  
1849  
1850  
1851  
1852  
1853  
1854  
1855  
1856  
1857  
1858  
1859  
1860  
1861  
1862  
1863  
1864  
1865  
1866  
1867  
1868  
1869  
1870  
1871  
1872  
1873  
1874  
1875  
1876  
1877  
1878  
1879  
1880  
1881  
1882  
1883  
1884  
1885  
1886  
1887  
1888  
1889  
1890  
1891  
1892  
1893  
1894  
1895  
1896  
1897  
1898  
1899  
1900  
1901  
1902  
1903  
1904  
1905  
1906  
1907  
1908  
1909  
1910  
1911  
1912  
1913  
1914  
1915  
1916  
1917  
1918  
1919  
1920  
1921  
1922  
1923  
1924  
1925  
1926  
1927  
1928  
1929  
1930  
1931  
1932  
1933  
1934  
1935  
1936  
1937  
1938  
1939  
1940  
1941  
1942  
1943  
1944  
1945  
1946  
1947  
1948  
1949  
1950  
1951  
1952  
1953  
1954  
1955  
1956  
1957  
1958  
1959  
1960  
1961  
1962  
1963  
1964  
1965  
1966  
1967  
1968  
1969  
1970  
1971  
1972  
1973  
1974  
1975  
1976  
1977  
1978  
1979  
1980  
1981  
1982  
1983  
1984  
1985  
1986  
1987  
1988  
1989  
1990  
1991  
1992  
1993  
1994  
1995  
1996  
1997  
1998  
1999  
2000  
2001  
2002  
2003  
2004  
2005  
2006  
2007  
2008  
2009  
2010  
2011  
2012  
2013  
2014  
2015  
2016  
2017  
2018  
2019  
2020  
2021  
2022  
2023  
2024  
2025  
2026  
2027  
2028  
2029  
2030  
2031  
2032  
2033  
2034  
2035  
2036  
2037  
2038  
2039  
2040  
2041  
2042  
2043  
2044  
2045  
2046  
2047  
2048  
2049  
2050  
2051  
2052  
2053  
2054  
2055  
2056  
2057  
2058  
2059  
2060  
2061  
2062  
2063  
2064  
2065  
2066  
2067  
2068  
2069  
2070  
2071  
2072  
2073  
2074  
2075  
2076  
2077  
2078  
2079  
2080  
2081  
2082  
2083  
2084  
2085  
2086  
2087  
2088  
2089  
2090  
2091  
2092  
2093  
2094  
2095  
2096  
2097  
2098  
2099  
2100  
2101  
2102  
2103  
2104  
2105  
2106  
2107  
2108  
2109  
2110  
2111  
2112  
2113  
2114  
2115  
2116  
2117  
2118  
2119  
2120  
2121  
2122  
2123  
2124  
2125  
2126  
2127  
2128  
2129  
2130  
2131  
2132  
2133  
2134  
2135  
2136  
2137  
2138  
2139  
2140  
2141  
2142  
2143  
2144  
2145  
2146  
2147  
2148  
2149  
2150  
2151  
2152  
2153  
2154  
2155  
2156  
2157  
2158  
2159  
2160  
2161  
2162  
2163  
2164  
2165  
2166  
2167  
2168  
2169  
2170  
2171  
2172  
2173  
2174  
2175  
2176  
2177  
2178  
2179  
2180  
2181  
2182  
2183  
2184  
2185  
2186  
2187  
2188  
2189  
2190  
2



1  
2  
3 could focus their attention on specific parts of greatest relevance.<sup>(48,51)</sup> For example,  
4 participants viewing the STD risk video were not required to watch the full one hour  
5 length and were directed towards relevant parts.<sup>(51)</sup>  
6  
7  
8  
9

10  
11  
12 Finally, the breadth of the information in each communication was generally wide,  
13 including detail about multiple aspects of a risk. One example was Cousin *et al.* where  
14 the booklet included general information about radiation from mobile phone systems,  
15 the current state of research and scientific uncertainties.<sup>(52)</sup> The one exception to this  
16 pattern was Read & Morgan, where the communication focussed on correcting a  
17 specific component of the audience's mental models of electric fields (range  
18 dependency, i.e. the relationship between magnetic field strength and electricity source  
19 distance).<sup>(53)</sup> In this case, because one specific misunderstanding had been identified in  
20 the public's collective mental model the communication was correspondingly tightly  
21 focussed on this one specific area.  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38

### 39 **3.5 Comparison (the control communication)**

40  
41  
42  
43 Over half (eight of twelve) studies included here used at least one control.<sup>(18,20,34,48,49,51–</sup>  
44  
45  
46 <sup>53)</sup> In all of these, except Niewöhner *et al.* and Read & Morgan, multiple controls were  
47 used.<sup>(34,53)</sup> The highest number of controls used was seven, where in all cases the  
48 MMARC was identified as structurally superior to the control brochures (communication  
49 structure was the outcome measure).<sup>(18)</sup> The most frequently used control (in seven of  
50 the studies) was an alternative communication; in contrast Read & Morgan did not  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

1  
2  
3 provide instruction for their control group.<sup>(53)</sup> Controls were matched to the MMARC  
4  
5 communication in at least one of three different ways. Firstly, the control could be topic-  
6  
7 matched i.e. if the MMARC communication focussed on radon, a control communication  
8  
9 that also focussed on radon was selected. All seven studies with an alternative  
10  
11 communication used a topic-matched control. In six studies this was an existing  
12  
13 brochure, the exception being Cousin *et al.* where a control text about a topic unrelated  
14  
15 to mobile phones (a Swiss abbey) was used.<sup>(52)</sup> Secondly, in five studies the controls  
16  
17 were also format-matched (i.e. if the MMARC was a brochure, so too was the control  
18  
19 communication).<sup>(18,20,34,48,49)</sup> Thirdly, one study used a content-matched control, where a  
20  
21 book was developed to provide the same informational content as the MMARC video.<sup>(51)</sup>  
22  
23  
24 In all studies, the MMARC communication performed equal to or better than the control  
25  
26 communication(s) for the outcome measures assessed.  
27  
28  
29  
30  
31  
32  
33

### 3.6 Outcome

34  
35  
36  
37  
38 Amongst the 12 studies reviewed here, 14 different outcome measures were used to  
39  
40 assess the communications developed via the MMARC. Multiple measures were used  
41  
42 by 75% of the studies. All 12 studies reported a positive effect of the MMARC  
43  
44 communication for at least some (it not all) of the outcome measures against which it  
45  
46 was tested (Table IV). There did not appear to be pattern in the outcome of the seven  
47  
48 studies that included one of the original study authors compared to those that did not,  
49  
50 with predominantly positive effects of the MMARC communication seen in both groups.  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

1  
2  
3 Knowledge was the most frequent outcome measure and used in all but one study, i.e.  
4  
5 Atman *et al.* who assessed the communication's design and structure.<sup>(18)</sup> In the  
6  
7 remaining 11 studies, most reported a significant improvement in participant knowledge  
8  
9 following exposure to the MMARC communication compared to the control or baseline.  
10  
11 Two studies concluded that whilst participants in both the MMARC and control  
12  
13 conditions scored significantly higher knowledge, the difference between conditions was  
14  
15 not significant.<sup>(49,51)</sup> Knowledge assessments were in most cases direct i.e. topic  
16  
17 specific, apart from one study (Table V).<sup>(34)</sup> The measures were often developed by the  
18  
19 authors based on prior interview findings (as would be expected using the MMARC).  
20  
21 One example was Galada *et al.* who asked participants about the sources and effects of  
22  
23 carbon monoxide.<sup>(54)</sup> Across all 11 studies questions were presented in a variety of  
24  
25 formats, including multiple choice, and dichotomous assessments such as  
26  
27 true/false.<sup>(52,56)</sup> Additionally, scales were used allowing participants to express  
28  
29 uncertainty, such as Bostrom *et al.* who used a five-point scale (true, maybe true, don't  
30  
31 know, maybe false, false), and Vogt & Schaefer used a four-point scale where the  
32  
33 neutral option was removed.<sup>(20,49)</sup>

34  
35  
36  
37  
38  
39  
40  
41  
42  
43 The most frequent secondary outcome measure was participants' attitude towards the  
44  
45 communication topic (e.g. nuclear energy use in space in Maharik and Fischhoff),  
46  
47 assessed in three studies.<sup>(48,49,54)</sup> In all cases there was a positive relationship between  
48  
49 the MMARC communication and participant attitude, although in Maharik & Fischhoff  
50  
51 and Vogt & Schaefer there was no significant difference in the extent to which the  
52  
53 MMARC and control communications appeared to influence participant attitude.<sup>(48,49)</sup>  
54  
55  
56  
57  
58  
59  
60

1  
2  
3 Another secondary outcome, behaviour, was assessed in one study which investigated  
4 sexually transmitted disease.<sup>(51)</sup> Here, self-reported sexual behaviour of females was  
5 assessed, and complimented by clinical testing at baseline and at six months after  
6 exposure to the MMARC communication. Although the MMARC communication was not  
7 associated with a significant knowledge increase above the control communications (a  
8 book and brochure), for participant behaviour the difference was significant, with clinical  
9 testing showing participants who viewed the control were twice as likely to be diagnosed  
10 with an STD compared to those viewing the MMARC communication.  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23

### 24 **3.7 Process, methods and experimental design**

25  
26  
27  
28  
29 The process used to create the MMARC communication varied between studies. As  
30 shown in Figure 1, developing a communication in line with the MMARC involves five  
31 distinct steps. In some of the 12 studies reviewed here, it is not clear to what extent  
32 each of these steps was followed, and thus to what extent each of the 12 studies  
33 evaluated a communication that is the product of the full MMARC. For example, six  
34 studies reported that they developed the communication through comparing expert and  
35 public mental models, which *is* in line with Morgan *et al.*'s process.<sup>(18,20,34,49,51,54)</sup>  
36  
37 However, in other studies a slightly different approach was taken (albeit still within the  
38 broad scope of the MMARC), in that the communication reflected uncertainties in public  
39 mental models. One example was Longstaff, where the confirmatory survey (which  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

1  
2  
3 usually precedes development of the communication, see Figure 1) was combined with  
4  
5 testing the communication.<sup>(55)</sup><sup>1</sup>  
6  
7  
8  
9

10 In general, quantitative methods were used to evaluate the MMARC communication  
11 (Table IV). The exceptions to this were Atman *et al.*, Bostrom *et al.* and Niewöhner *et*  
12 *al.*<sup>(18,20,34)</sup> The first two of these three studies used mixed methods (i.e. quantitative and  
13 qualitative), and Niewöhner *et al.* used solely qualitative methods.<sup>(34)</sup> The qualitative  
14 methods included analysing communication design, where it was concluded that the  
15 MMARC communication was better structured to provide the information salient to  
16 participants' mental models.<sup>(18)</sup> A think-aloud protocol was another qualitative method,  
17 whereby participants verbalised their thoughts as they read each communication.<sup>(20)</sup>  
18 Similar 'think aloud' methods were used by Niewöhner *et al.*, alongside user evaluation  
19 sessions, in which groups of two to four participants discussed positive and negative  
20 aspects of each communication.<sup>(34)</sup>  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38

39 Most of the 12 studies used between-participant designs to compare the effects of  
40 MMARC and control communications, except Atman *et al.* who compared  
41 communication design and layout within participants.<sup>(18)</sup> A longitudinal component was  
42 present in two studies.<sup>(49,51)</sup> Downs *et al.* provided participants with the opportunity to  
43 review the communication at intervals after the initial session and so 'top-up' their  
44 exposure.<sup>(51)</sup> This revealed differences in participants' self-reported behaviour,  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54

---

55  
56 <sup>1</sup> In some papers where the initial steps of the MMARC process were mentioned only briefly, a reference was  
57 provided for the full details e.g. Cousin *et al.* (2011) and Vogt & Schaefer (2012) built on findings published in  
58 previous studies.<sup>(29,49,52,72)</sup>  
59  
60

1  
2  
3 specifically that participants who viewed the MMARC communication were significantly  
4  
5 less likely to report sexual behaviour during the first three months than participants in  
6  
7 the control group. However, a significant difference between the groups was not  
8  
9 observed for the latter three months, or for some other self-reported behaviours (e.g.  
10  
11 condom use). Vogt and Schaefer also reported a longitudinal study, where two  
12  
13 brochures about contraceptives were compared.<sup>(49)</sup> Researchers measured participant  
14  
15 knowledge, attitude and intentions at three points: before the intervention (baseline),  
16  
17 directly after reading the brochure, and three months later.  
18  
19  
20  
21  
22  
23

24 One aspect of internal validity, namely randomisation, was also compared between  
25  
26 studies. Less than half (five) the studies stated that participants were randomly  
27  
28 allocated to the MMARC and control communication conditions.<sup>(20,49–52)</sup> In short, this  
29  
30 one common elements of experimental design was the exception rather than the rule for  
31  
32 the studies reviewed here.  
33  
34  
35  
36  
37

#### 38 **4. DISCUSSION**

39  
40  
41  
42  
43 The MMARC is a widely used and recommended framework for developing risk  
44  
45 communications.<sup>(10,33)</sup> The need for such communications arises as the public are often  
46  
47 unable to personally assess the numerous hazards they face, instead often relying on  
48  
49 'expert' information to safely navigate these risks. One particular challenge in the  
50  
51 development of such communications is understanding what the public wants and  
52  
53 needs to know. The MMARC aims to remedy this issue by providing a framework to  
54  
55  
56  
57  
58  
59  
60

1  
2  
3 develop and evaluate targeted communications. The aim of the current paper was to  
4  
5 conduct an initial scoping review of the relevant literature in order to map out the field,  
6  
7 identify similarities and differences in the ways in which extant studies have applied the  
8  
9 MMARC, and explore whether a full systematic review might be feasible and desirable  
10  
11 in future. Our focus was on those studies which had used the approach to actually  
12  
13 develop and test a risk communication, rather than those who had only used the earlier  
14  
15 steps in the model and not proceeded to these final stages (Figure 1). Perhaps the most  
16  
17 striking finding of our scoping review was just how few of the studies that claimed to be  
18  
19 using the MMARC actually went on to develop and evaluate a risk communication.  
20  
21 Moreover, the fidelity with which the MMARC was applied in these 12 studies was  
22  
23 extremely varied. Nevertheless, the generally positive results from these few studies  
24  
25 suggests that a more detailed and systematic investigation into the approach may be  
26  
27 warranted. Below we discuss some of these findings and why we think further synthesis  
28  
29 work is justified, as well as identifying those issues we think need particular attention  
30  
31 going forward.  
32  
33  
34  
35  
36  
37  
38  
39  
40

#### 41 **4.1 Measuring success of the MMARC**

42  
43  
44

45 Overall, results indicated that risk communications developed using the MMARC were  
46  
47 successful in significantly improving participants' knowledge. Therefore, our initial  
48  
49 tentative conclusion, based on this limited set of studies, is that the MMARC might  
50  
51 indeed be a useful framework within which to develop a risk communication. However,  
52  
53 there are two important caveats, relating to *how* success was determined, and to *what*  
54  
55  
56  
57  
58  
59  
60

1  
2  
3 the communication was compared. Firstly, determining success using knowledge  
4 provides only a partial indication of a communication's impact. That is, it demonstrates  
5 information transfer. However, the communication may have additional effects not  
6 captured via knowledge assessment, but with implications for risk avoidance e.g.  
7 participants' attitudes and / or behaviour towards a risk are modified. The findings of, for  
8 example, Read & Morgan are therefore limited, in that only knowledge was measured  
9 and not, for example, whether participants' attitudes towards magnetic fields had  
10 changed.<sup>(53)</sup>  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23

24 Further, although measuring knowledge change is a fundamental part of measuring the  
25 success of any MMARC communication, the type of knowledge assessed is also  
26 important. For instance, two types of knowledge have been discussed in the literature:  
27 direct (subject-specific) and indirect (broader scientific), and each has different  
28 relationships with people's action and attitudes.<sup>(57-59)</sup> Whilst assessing direct knowledge  
29 (as was the case in most of the studies reviewed here; Table V) may suggest the  
30 potential effects of the communication on participant, directly evaluating secondary  
31 outcomes can provide a more comprehensive understanding of a communication's  
32 impact (i.e. indirect knowledge).  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47

48 When secondary outcomes are considered, results from the current study still point to  
49 the MMARC as being a potentially useful approach to developing successful risk  
50 communications.<sup>(49,51,52,54)</sup> However, the relationship between knowledge and secondary  
51 outcomes in the 12 studies was variable, with some showing a significant change in  
52  
53  
54  
55  
56  
57  
58  
59  
60



1  
2  
3 participant attitudes (Galada *et al.*) while in others no significant effect on attitudes was  
4  
5 found (Maharik & Fischhoff).<sup>(48,54)</sup> However, whereas knowledge was assessed  
6  
7 relatively consistently across all studies except one (Atman *et al.*), the choice of  
8  
9 secondary outcome(s) was topic dependent and thus highly variable across studies.<sup>(18)</sup>  
10  
11 For example, where individual health risks were the focus of the communication,  
12  
13 behaviour (or behavioural intention) was assessed.<sup>(49,51)</sup> This allowed Downs *et al.* to  
14  
15 determine the communication's effect on both participants' self-reported behaviour,  
16  
17 which they combined with clinical validation to provide a strong assessment of the  
18  
19 communication's impact.<sup>(51)</sup> On the other hand, where Maharik & Fischhoff trialled a  
20  
21 communication relating to nuclear energy use in space, they used the potentially more  
22  
23 appropriate secondary measure of participant attitude towards the technology (given  
24  
25 that no direct behavioural relationship was possible).<sup>(48)</sup> Whilst measuring behaviour is  
26  
27 suitable for assessing MMARC communications about individual health risks (e.g.  
28  
29 smoking, alcohol consumption), where the individual can more easily adjust their  
30  
31 behaviour and influence risk exposure, for societal technological risks (e.g. nuclear  
32  
33 energy), attitudes may be a more apt measure.  
34  
35  
36  
37  
38  
39  
40  
41  
42

43 In a sense, it only matters if a communication influences, for instance, attitudes, if  
44  
45 influencing attitudes was an explicit goal of the communication. Nonetheless, for the  
46  
47 good of the field in general, it might be worthwhile studies consistently measuring a  
48  
49 range of constructs, to a) explore the underlying psychological processes behind  
50  
51 changes in the main outcome variables (if they are different from, say, attitudes), b)  
52  
53 because a communication may have unanticipated impacts, which the assessment of  
54  
55  
56  
57  
58  
59  
60

1  
2  
3 other secondary outcomes (e.g. attitudes) would help identify, and c) to allow later  
4  
5 synthesis across multiple studies containing operationalisations of the same kinds of  
6  
7 construct. With such an idea in mind what would a (semi-) standardised set of outcome  
8  
9 variables look like? One possibility would be to build on the three evaluative criteria  
10  
11 identified by Fischhoff: materiality, proximity and comprehensibility (relating respectively  
12  
13 to whether a communication contains information relevant to its audience, can be  
14  
15 accessed, and finally understood).<sup>(25)</sup> These criteria might form a useful checklist to aid  
16  
17 researchers in deciding the most appropriate outcomes to assess in future evaluations  
18  
19 e.g. in deciding which secondary outcomes should be included alongside knowledge.  
20  
21  
22  
23  
24  
25  
26

27 The second caveat relating to support for the MMARC is linked to *what* the MMARC  
28  
29 communication was compared to. When deciding whether to embark on the time- and  
30  
31 resource-intensive MMARC, this decision should be made with an idea of alternative  
32  
33 risk communication development frameworks in mind.<sup>(60)</sup> A quicker, perhaps nearly as  
34  
35 effective approach might also be a viable option for researchers. However, one  
36  
37 limitation of studies in the current review is that the framework underlying the control  
38  
39 communications' development was rarely stated.<sup>(20,52)<sup>2</sup></sup> This makes it challenging to  
40  
41 assess whether the MMARC is more suitable than an alternative framework if the  
42  
43 alternative is not clearly described. Our findings thus agree with other recent reviews of  
44  
45 risk-benefit communications, which also identified a gap in reporting the underlying  
46  
47  
48  
49  
50  
51  
52  
53  
54

---

55  
56 <sup>2</sup> A framework was hinted at in Vogt and Schaefer who stated that the alternative intervention 'followed  
57 standard recommendations for [Evidence-Based Patient Interventions]', and provided a reference but no  
58 further details.<sup>(49)</sup>  
59  
60

1  
2  
3 framework.<sup>(61,62)<sup>3</sup></sup>

4 An additional challenge related to the control communication is the  
5 unavoidable bias in measuring knowledge change when the researchers develop both  
6 the MMARC communication, and the questions by which it is assessed. If questions  
7 assess information contained solely in the MMARC communication it would not be  
8 surprising if there would be a greater chance of identifying a difference compared to the  
9 control(s) than if the communications are content-matched. This was the case in Downs  
10 *et al.*, where there was no significant difference in knowledge between participants  
11 exposed to the control compared to those exposed to the intervention.<sup>(51)</sup> The  
12 implication of the method determining its own criteria for success is that comparisons  
13 between studies are more difficult, because the assessments are specific to each  
14 communication. One option for improving comparability between studies could be to  
15 standardise response scales (discussed further in Section 4.4). The lack of content-  
16 matched controls (apart from Downs *et al.*, as mentioned above) also presents a  
17 challenge to being able to draw firm conclusions about which elements of each  
18 communication were associated with any change in outcome measures.<sup>(51)</sup> This is a  
19 challenge any future systematic review would need to address.

20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42

43 Moreover, in terms of future research, there may be solutions to these dual challenges  
44 of alternative risk communication framework, and fair comparison with the control  
45 communication. Firstly, future MMARC evaluations could endeavour to use a control  
46 where an alternative risk communication framework was identified. This may not always  
47 be possible, in which case there is also a broader need for developing, evaluating and  
48  
49  
50  
51  
52  
53  
54

---

55  
56  
57 <sup>3</sup> These reviews were topic-focussed, relating to environmental and food risk communication respectively,  
58 unlike the current paper which attempted to review a specific framework, i.e. the MMARC.  
59  
60

1  
2  
3 reporting alternative risk communication frameworks, to provide the evidence required  
4  
5 to inform framework selection. Reporting which framework has been followed is crucial  
6  
7 to facilitate a fair comparison of the MMARC with alternative frameworks. Without this  
8  
9 information, even a larger sample of studies will not provide greater clarity as to the  
10  
11 relative efficacy of the MMARC. Unbiased assessment of the control communication is  
12  
13 an inherent challenge in evaluating risk communications. In addition to the use of a  
14  
15 content-matched communication as in Downs *et al.*, another recommendation for future  
16  
17 studies is to measure subjective knowledge i.e. how well-informed people feel, rather  
18  
19 than their objective (factual) knowledge.<sup>(51,63,64)</sup> Although not the case in the 12 studies  
20  
21 reviewed here (11 of which measured objective knowledge), subjective knowledge has  
22  
23 been included as an outcome measure in other risk communication assessments.<sup>(63,64)</sup>  
24  
25 Applying this measure in future assessments could provide a more complete  
26  
27 understanding of a communication's impact.  
28  
29  
30  
31  
32  
33  
34  
35

#### 36 **4.2 What aspects of the communication affected its impact?**

37  
38  
39  
40  
41 As the 12 MMARC communications in this review were associated with near ubiquitous  
42  
43 improvements in participant knowledge and secondary outcomes, it is challenging to  
44  
45 identify which specific communication facets (e.g. length, use of graphic or text) were  
46  
47 responsible for success.<sup>4</sup> It may of course be the *combination* of factors that resulted in  
48  
49 improvements in participant mental models. Although reviewing the fine detail of the  
50  
51  
52  
53  
54

---

55  
56 <sup>4</sup> The successes may also represent an example of the file drawer effect, with evaluations not achieving  
57 statistical significance less likely to be published.<sup>(73)</sup> Again a future systematic review could take steps to  
58 uncover this grey and unpublished literature.  
59  
60

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

communications developed in each of the 12 studies was outside the scope of this paper, we would recommend that any future systematic review sought to undertake such an analysis. Nevertheless, the studies reported numerous features of the communications, which can inform the development and evaluation of future MMARC communications, including length, format (i.e. use of graphic, presentation), and channel (i.e. whether paper or video).

Whilst the communications' length varied between studies (from 1 to over 50 pages for written communications), it is not clear whether longer or shorter was superior. The next factor was format / presentation, which did appear important (e.g. Atman *et al.*; Longstaff; De Bruin *et al.*), although the exact effect was complex.<sup>(18,50,55)</sup> Specifically, graphic presentations, or text-graphic combinations were found superior to text alone by De Bruin *et al.*, in contrast to another recent study comparing format where graphic communications were insufficient to rectify misunderstandings about Carbon Capture and Storage (Seigo *et al.*).<sup>(50,65)</sup> Fitzpatrick-Lewis *et al.*, in their review of risk communications, suggested mixed formats are superior to single for effective information transfer. Lastly, the 12 studies largely focussed on written communications (e.g. brochures in Fleishman *et al.*), with video used only once (Downs *et al.*).<sup>(51,56)</sup> However, participants exposed to the video format displayed significantly different behaviour to those exposed to the (written) controls, suggesting the format may have influenced the evaluation outcome.<sup>(51)</sup> There were no web-based communications which, given the increase in society's use of social media etc., means there is currently a gap in evidence assessing this channel's effectiveness in disseminating MMARC

1  
2  
3 communications.<sup>(66–68)</sup> Future, more up-to-date systematic searches of the published  
4  
5 and unpublished literature may begin to reveal such studies.  
6  
7

8  
9  
10 The upshot of these findings is that an effective MMARC communication contains not  
11  
12 just relevant information, but presents it clearly. Future communications should consider  
13  
14 length, combinations of text and graphics, and use of channels such as web-based  
15  
16 communications. The precise combination will however depend on the target  
17  
18 population's needs and preferences. Understanding the most appropriate format(s) for a  
19  
20 given hazard can begin early in the MMARC process, for example Morss et al, included  
21  
22 a diverse range of stakeholders during development of the expert model, resulting in  
23  
24 valuable perspectives as to how flood risk warnings could be better communicated.<sup>(69)</sup>  
25  
26  
27 Such an approach also demonstrates the need for two-way communication at an early  
28  
29 stage and a need to move away from the simple expert-lay dichotomy. In addition to  
30  
31 audience knowledge requirements (including experts' requirements), the researchers  
32  
33 also identified needs such as ensuring the messages strike the right balance between  
34  
35 sufficient warning and unnecessary precaution.  
36  
37  
38  
39  
40  
41  
42

43  
44 Similarly to communication format, the target audience also plays a key role in  
45  
46 determining the communication's content. MMARC communications are, by their nature,  
47  
48 focussed towards a particular population's inaccurate or under-developed mental  
49  
50 models. However, the 12 studies varied in whether they trialled the communication with  
51  
52 participants from the target population. There was no clear pattern between the  
53  
54 outcome of the MMARC assessment and whether participants represented the target  
55  
56  
57  
58  
59  
60

1  
2  
3 population. In spite of this, the use of participants from the target population appears  
4 essential to precisely determine the MMARC communication's impact. The importance  
5 of this comes back to one of the basic tenets of the MMARC as described by Morgan *et*  
6 *al.*: '[communications] need testing with people drawn from the target audience'  
7  
8 (p.103).<sup>(10)</sup> If a communication is released to a population with whom it was not tested,  
9 there would be considerable uncertainty as to its impact i.e. whether it increases /  
10 decreases / has no effect on knowledge, or some other unanticipated reaction. For this  
11 reason, future evaluations should recruit participants representative of the target  
12 population.  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26

27 Recruiting participants from the target audience can nevertheless pose a challenge for  
28 researchers. Such challenges were described by Niewöhner *et al.* in recruiting people  
29 from small- and medium-sized businesses despite offering a financial incentive, and  
30 using both telephone and postal requests for participation.<sup>(34)</sup> These methods for  
31 encouraging participation represented best practice amongst the 12 studies, and should  
32 be considered in future MMARC evaluations. Additionally snowballing, where  
33 participants recommend a colleague, may help increase participation in similar  
34 circumstances. Other techniques future MMARC studies might consider when recruiting  
35 representative samples include market research companies, where specific  
36 demographic groups may be targeted. However, whilst market research is a useful tool,  
37 as with other approaches it can be challenging to obtain adequate sample response  
38 rates.<sup>(70)</sup>  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

### 4.3 Strengthening future evaluations

Two ways in which future MMARC evaluations could improve relate to their methods and study design. Firstly, quantitative methods dominated the 12 studies reviewed here, with qualitative methods used in only a quarter of the evaluations. Our findings support those of Scammell, who reviewed use of qualitative methods in environmental health research and concluded such methods were underutilised.<sup>(71)</sup> The benefit of qualitative methods is that potentially unanticipated effects of the MMARC communication can be identified and corrected during the trial phase, and before wider dissemination. This should provide the communicators and other stakeholders with greater confidence that their message will have the intended effect. Niewöhner *et al.* described how they learnt as much about how the target audience perceived risks from their (qualitative) evaluation than during earlier unstructured interviews.<sup>(34)</sup> Quantitative methods are nevertheless fundamental in evaluating MMARC communications, and a *dual* approach, incorporating qualitative methods, would improve future evaluations. Studies applying a qualitative element should inform future MMARC assessments, for example including a 'read-aloud' component.<sup>(20,34)</sup> This involved participants reading the communication and concurrently verbalising their thoughts, thus providing the researchers with an approximate explorative assessment of the communication's impact, and the opportunity to capture unexpected reactions.

Future MMARC evaluations could also improve study design rigour for the elements considered in this review. The two studies focussing on health risks were also the



1  
2  
3 strongest in terms of study design (Downs *et al.*; Vogt & Schaefer).<sup>(49,51)</sup> That is, both  
4  
5 were longitudinal randomised controlled trials (RCT), and thus represented best  
6  
7 practice. The implications of not randomising the communication's distribution is the  
8  
9 potential introduction of bias through incidental, but systematic, variation between the  
10  
11 groups. This potentially means another factor (i.e. not the intervention) could be  
12  
13 responsible for any relationship identified by the study, and thus caution must be  
14  
15 applied when considering the outcomes of such studies in the current review. Downs *et*  
16  
17 *al.* described that no theoretical risk communication approach has demonstrated  
18  
19 superiority due to a lack of RCTs, and concluded that comparing the MMARC  
20  
21 communication with communications developed using other theoretical approaches is  
22  
23 necessary to determine whether one framework is better than another.<sup>(51)</sup> Our findings  
24  
25 support their conclusion. Future studies should utilise RCT study design to ensure  
26  
27 robustness of findings and improve internal validity. This would also aid any future  
28  
29 systematic meta-analysis of results.  
30  
31  
32  
33  
34  
35  
36  
37  
38

39 Longitudinal design also provided unique insights about the MMARC communication's  
40  
41 impact (Downs *et al.*; Vogt & Schaefer).<sup>(49,51)</sup> Specifically, the longitudinal analysis  
42  
43 revealed whether the communications had a lasting effect on participants, and the  
44  
45 degree to which each communication differed in its long-term impact. This is important  
46  
47 because risk communicators will often be interested in creating a lasting rather than  
48  
49 fleeting impact on their audience. Lasting impacts ensure the population remains  
50  
51 informed, and additionally are more efficient if the first communication was sufficiently  
52  
53 effective that repeated communication efforts could be avoided. Ideally, future studies  
54  
55  
56  
57  
58  
59  
60

1  
2  
3 should follow a similar structure to these where outcome measures are measured at  
4  
5 several intervals following exposure to the communication, and the results validated  
6  
7 (e.g. Downs *et al.* who used clinical testing as this was relevant to their study).<sup>(51)</sup> If  
8  
9 resources do not permit such a detailed follow-up, measurement of participant  
10  
11 willingness to change behaviour, alongside knowledge can provide a second best  
12  
13 alternative, as in Galada *et al.*<sup>(54)</sup>  
14  
15  
16  
17

18  
19  
20 A final point relevant to reporting methods and study design, is a call for future studies  
21  
22 to describe more clearly which MMARC components were employed in the  
23  
24 communication's development. Guidance in the definitive MMARC book by Morgan *et*  
25  
26 *al.* suggests researchers can adapt the process to their needs.<sup>(10)</sup> Some of the studies  
27  
28 reviewed here, e.g. Fleishman *et al.*; Maharik & Fischhoff were vague about their  
29  
30 process beyond stating that the MMARC was followed.<sup>(48,56)</sup> Others, such as Longstaff,  
31  
32 indicated where they deviated from the MMARC process, for example combining the  
33  
34 confirmatory survey with trialling the MMARC communication.<sup>(55)</sup> Some aspects of the  
35  
36 process may be more important than others in creating an effective communication. If  
37  
38 more studies reported the precise steps they followed, it may be possible to determine  
39  
40 which aspects were of most importance, thus allowing future justified refinement of the  
41  
42 MMARC without sacrificing its efficacy.  
43  
44  
45  
46  
47  
48  
49  
50

#### 51 **4.4 Towards a revised framework for assessing impact of a communication**

52  
53  
54  
55  
56  
57  
58  
59  
60

1  
2  
3 A framework for the assessment of MMARC communications would help standardise  
4 the evaluation procedure. Currently, a variety of methods and outcome measures were  
5 used to assess the MMARC. This would represent a distinct improvement on Niewöhner  
6  
7  
8  
9  
10 *et al.* (2004)'s observation that risk communication evaluation is often neglected and  
11 lacks robustness. However, it still presents a challenge in comparing studies and in  
12 identifying the most important components that contributed to a communication's  
13 success. Clearer guidance on evaluating MMARC communications would provide a  
14 valuable starting point.<sup>(10,20,34)</sup> For instance, further work should consolidate methods,  
15 suggest reporting criteria, and define common scales to evaluate outcome measures  
16 such as knowledge, attitudes, and intentions. By their nature, risk communications are  
17 topic specific, with assessments necessarily driven by idiosyncratic factors. However,  
18 several scales could be developed depending on discipline e.g. to measure attitude  
19 towards technological, health or environmental risks. A common framework would  
20 facilitate comparison of the MMARC, and thus identify and address common  
21 challenges, and advancing risk communication efforts. Additionally, such a framework  
22 may also be of use in evaluating alternative risk communication frameworks.  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42

#### 43 **4.5 Limitations**

44  
45  
46  
47  
48 The current method of a scoping review is the recommended way of mapping out a  
49 research field when a full scale systematic review has yet to be conducted.<sup>(35–38)</sup> Such  
50 an approach helps to scope out commonalities and issues within a field, identify future  
51 research needs, and is also used to help researchers decide whether or not to invest  
52  
53  
54  
55  
56  
57  
58  
59  
60

1  
2  
3 the time and resources needed for a full scale systematic review. Importantly, we feel  
4 that the findings of the current review suggest that a full scale systematic review are  
5 justified because the majority of the studies did show encouraging outcomes (in terms  
6 of knowledge increase) but that there was enough heterogeneity across studies to  
7 warrant further investigation into identifying best practice. Nevertheless, in keeping with  
8 all scoping reviews, the current review has several important limitations that any future  
9 systematic review should seek to address.  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19

20  
21  
22 First, although the search strategy was designed to be comprehensive and involved  
23 several databases and used various techniques (e.g. standard searching, forward  
24 citations), it is possible some papers or studies were missed. A subsequent systematic  
25 review may wish to consider additional databases in the searches, include grey  
26 literature e.g. through reaching out to the relevant research community (e.g. Society for  
27 Risk Analysis mailing lists), and consult study authors to find out whether, for instance,  
28 the 90 papers that only reported the early stages of the MMARC did in fact go on to test  
29 a communication developed using these findings but did not publish the results. Such a  
30 future review might also be able to begin a meta-analysis of data incorporating studies  
31 conducted, for government agencies for example, but not published in the scientific  
32 literature.  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49

50  
51 A second limitation relates to reliability. Specifically, the results were screened, and data  
52 extraction was conducted by the first author in consultation with the other authors.  
53  
54

55  
56 Ideally a future systematic review would involve multiple researchers independently  
57  
58  
59  
60

1  
2  
3 searching the literature for relevant studies, evaluating found studies against agreed  
4 inclusion criteria, and extracting the data from included papers. The reliability of these  
5 processes could then be assessed, for instance by calculating and reporting Cohen's  
6 kappa to assess inter-rater agreement.  
7  
8  
9  
10  
11

12  
13  
14  
15 Thirdly, the current review's focus was restricted to considering only those studies that  
16 have completed the final evaluative step of the MMARC. This is only one way of  
17 assessing the MMARC. The excluded studies that applied earlier steps of the MMARC  
18 may nonetheless hold valuable insights into the effectiveness of the framework even at  
19 the early stages. Clearly this would be a much larger undertaking than a focus on only  
20 those studies that actually designed and tested a communication developed using the  
21 MMARC, but might nonetheless be informative in terms of discovering its effectiveness,  
22 compared to alternatives, at the early stages of the process of eliciting 'expert' and 'lay'  
23 knowledge.  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38

39 Finally, we also recognise that a relatively large number of the papers covered in this  
40 review were conducted by the original authors of the approach, which may have  
41 introduced bias (i.e. that the authors may have developed a method that they were able  
42 to implement with great fidelity but was not easily translatable to other settings). Despite  
43 the fact that our review found no evidence to suggest studies by these authors  
44 produced more positive findings than those by other authors, we also recognise that a  
45 future, more systematic review, would take into account the potential biasing effects of  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

1  
2  
3 authorship. Further, it also highlights the need for multiple groups to adopt and try and  
4  
5 replicate the basic approach to ensure it is generalizable across contexts and cultures.  
6  
7  
8

## 9 10 **5. CONCLUSION**

11  
12  
13  
14  
15 The current scoping review set out to investigate whether the MMARC appears, in  
16  
17 general, to provide an effective framework for the development of risk communications.  
18  
19 On balance, and given the inherent limitations in the current review protocols, we feel  
20  
21 there is enough support for the approach in the currently reviewed studies to warrant  
22  
23 the investment of time and resources needed for a full scale systematic review of the  
24  
25 approaches' effectiveness in developing risk communications, or at the very least in  
26  
27 eliciting lay and expert mental models about a variety of risks. The MMARC is, by its  
28  
29 very nature, a very in-depth, multi stage process which requires considerable  
30  
31 commitment from a research team. Knowing whether or not this effort is likely to be  
32  
33 rewarded will no doubt be a critical factor in whether more teams use it to systematically  
34  
35 develop communications. Although the findings from the current scoping review provide  
36  
37 several indications that it might be an approach worth pursuing, far more studies are  
38  
39 needed, especially one that adopt standardised evaluation protocols, before any firm  
40  
41 conclusions can be made. Further, before recommended a wave of new research using  
42  
43 the approach, we would also suggest that our findings give sufficient justification for a  
44  
45 full scale systematic review of the field to now be conducted which would be able to  
46  
47 shed an even clearer light on the full range of MMARC research that has been  
48  
49 conducted to date, and also highlight best practice among this extant literature base.  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

For Peer Review

## REFERENCES

1. Adak GK, Meakins SM, Yip H, Lopman BA, O'Brien SJ. Disease risks from foods, England and Wales, 1996-2000. *Emerg Infect Dis.* 2005;11(3):365–72.
2. Burgherr P, Hirschberg S. A comparative analysis of accident risks in fossil, hydro, and nuclear energy chains. *Human and Ecological Risk Assessment.* 2008;14(5):947–73.
3. Milton JC, Shankar VN, Mannering FL. Highway accident severities and the mixed logit model: an exploratory empirical analysis. *Accident Analysis & Prevention.* 2008;40(1):260–6.
4. Vere-Jones D. Forecasting earthquakes and earthquake risk. *International Journal of Forecasting.* 1995;11(4):503–38.
5. Alessandri TM, Ford DN, Lander DM, Leggio KB, Taylor M. Managing risk and uncertainty in complex capital projects. *Quarterly Review of Economics and Finance.* 2004;44(5 SPEC.ISS.):751–67.
6. Bellou M, Kokkinos P, Vantarakis A. Shellfish-Borne Viral Outbreaks: A Systematic Review. *Food and Environmental Virology.* 2013;5(1):13–23.
7. Maule AJ, Hockey GRJ, Bdzola L. Effects of time-pressure on decision-making under uncertainty: changes in affective state and information processing strategy. *Acta Psychologica.* 2000 Jun;104(3):283–301.
8. Stern PC, Fineberg H V., editors. *Understanding Risk. Informing Decisions in a Democratic Society.* Washington D.C.: National Academy Press; 1996.
9. Arvai JL. Rethinking of risk communication: lessons from the decision sciences. *Tree Genetics & Genomes.* 2007;3(2):173–85.
10. Morgan MG, Fischhoff B, Bostrom A, Atman CJ. *Risk communication: A mental models approach.* Cambridge University Press; 2002.
11. Bier VM. On the state of the art: risk communication to the public. *Reliability Engineering & System Safety.* 2001;71(2):139–50.
12. Slovic P. Perception of risk. *Science.* 1987;236(4799):280–5.
13. Ueland Ø, Gunnlaugsdottir H, Holm F, Kalogeras N, Leino O, Luteijn JM, et al. State of the art in benefit risk analysis: Consumer perception. *Food and Chemical Toxicology.* 2012;50(1):67–76.
14. Fischhoff B. *Risk Perception and Communication Unplugged: Twenty Years of Process.* *Risk Analysis.* 1995;15(2):137–45.
15. Bostrom A, Löfstedt RE. Communicating risk: Wireless and hardwired. *Risk Analysis.* 2003;23(2):241–8.
16. Breakwell GM. Risk communication: factors affecting impact. *British Medical Bulletin.* 2000 Jan;56(1):110–20.
17. Leiss W. Effective risk communication practice. *Toxicology Letters.* 2004;149(1–3):399–404.
18. Atman CJ, Bostrom A, Fischhoff B, Morgan MG. *Designing Risk Communications - Completing and Correcting Mental Models of Hazardous Processes, Part I.* *Risk Analysis.*



- 1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60
- 1994 Oct;14(5):779–88.
19. Bostrom A, Fischhoff B, Morgan MG. Characterizing mental models of hazardous processes: A methodology and an application to radon. *Journal of Social Issues*. 1992;48(4):85–100.
  20. Bostrom A, Atman CJ, Fischhoff B, Morgan MG. Evaluating Risk Communications - Completing and Correcting Mental Models of Hazardous Processes, Part II. *Risk Analysis*. 1994;14(5):789–98.
  21. Jones N, Ross H, Lynam T, Perez P, Leitch A. Mental models: an interdisciplinary synthesis of theory and methods. *Ecology and Society*. 2011;16(1):46.
  22. Hagemann KS, Scholderer J. Hot Potato: Expert-Consumer Differences in the Perception of a Second-Generation Novel Food. *Risk Analysis*. 2009;29(7):1041–55.
  23. Morgan G, Fischhoff B, Bostrom A, Lave L, Atman C. Communicating Risk to the Public. First, Learn what people know and believe. *Environmental Science & Technology*. 1992;26(11):2048–56.
  24. Bruine de Bruin W, Bostrom A. Assessing what to address in science communication. *Proc Natl Acad Sci U S A*. 2013;110 Suppl:14062–8.
  25. Fischhoff B. The sciences of science communication. *Proceedings of the National Academy of Sciences of the United States of America*. 2013;110 Suppl:14033–9.
  26. Chakrapani V, Newman PA, Singhal N, Nelson R, Shunmugam M. “If It’s Not Working, Why Would They Be Testing It?”: mental models of HIV vaccine trials and preventive misconception among men who have sex with men in India. *BMC Public Health*. 2013;13(1):731.
  27. Hagemann KS, Scholderer J. Consumer versus expert hazard identification: A mental models study of mutation-bred rice. *Journal of Risk Research*. 2007;10(4):449–64.
  28. Skarlatidou A, Cheng T, Haklay M. What Do Lay People Want to Know About the Disposal of Nuclear Waste? A Mental Model Approach to the Design and Development of an Online Risk Communication. *Risk Analysis*. 2012;32(9):1496–511.
  29. Vogt C, Schaefer M. Seeing things differently: Expert and consumer mental models evaluating combined oral contraceptives. *Psychology & Health*. 2012;27(12):1405–25.
  30. Wagner K. Mental Models of Flash Floods and Landslides. *Risk Analysis*. 2007;27(3):671–82.
  31. Zaksek M, Arvai JL. Toward improved communication about wildland fire: mental models research to identify information needs for natural resource management. *Risk Analysis*. 2004;24(6):1503–14.
  32. McComas KA. Defining Moments in Risk Communication Research: 1996 to 2005. *Journal of Health Communication*. 2006;11(1):75–91.
  33. Ropeik D. The Perception Gap: Recognizing and managing the risks that arise when we get risk wrong. *Food and Chemical Toxicology*. 2012;50(5):1222–5.
  34. Niewöhner J, Cox P, Gerrard S, Pidgeon N. Evaluating the efficacy of a mental models approach for improving occupational chemical risk protection. *Risk Analysis*. 2004;24(2):349–61.

- 1
  - 2
  - 3
  - 4
  - 5
  - 6
  - 7
  - 8
  - 9
  - 10
  - 11
  - 12
  - 13
  - 14
  - 15
  - 16
  - 17
  - 18
  - 19
  - 20
  - 21
  - 22
  - 23
  - 24
  - 25
  - 26
  - 27
  - 28
  - 29
  - 30
  - 31
  - 32
  - 33
  - 34
  - 35
  - 36
  - 37
  - 38
  - 39
  - 40
  - 41
  - 42
  - 43
  - 44
  - 45
  - 46
  - 47
  - 48
  - 49
  - 50
  - 51
  - 52
  - 53
  - 54
  - 55
  - 56
  - 57
  - 58
  - 59
  - 60
35. Peters MDJ, Godfrey CM, Khalil H, McInerney P, Parker D, Soares CB. Guidance for conducting systematic scoping reviews. *International Journal of Evidence-Based Healthcare*. 2015;13(3):141–6.
36. Anaby D, Hand C, Bradley L, DiRezze B, Forhan M, DiGiacomo A, et al. The effect of the environment on participation of children and youth with disabilities: a scoping review. *Disability and Rehabilitation*. 2013;35(19):1589–98.
37. Arksey H, O'Malley L. Scoping studies: towards a methodological framework. *International Journal of Social Research Methodology*. 2005;8(1):19–32.
38. Levac D, Colquhoun H, O'Brien KK. Scoping studies: advancing the methodology. *Implementation Science*. 2010;5(1):69.
39. Giustini D, Boulos MNK. Google Scholar is not enough to be used alone for systematic reviews. *Online Journal of Public Health Informatics*. 2013;5(2):214.
40. Bajpai AK, Davuluri S, Haridas H, Kasliwal G, Deepti H, Sreelakshmi KS, et al. In search of the right literature search engine(s). *Nature Precedings*.
41. Beckmann M, Wehrden H. Where you search is what you get: literature mining: Google Scholar versus Web of Science using a data set from a literature search in vegetation science. *Journal of Vegetation Science*. 2012;23(6):1197–9.
42. Schardt C, Adams MB, Owens T, Keitz S, Fontelo P. Utilization of the PICO framework to improve searching PubMed for clinical questions. *BMC Medical Informatics and Decision Making*. 2007;7(1):16.
43. Dunk MJ, Owen A, McMath SM, Arikans J. Remediation of polluted surface water outfalls—customer communication and changes in behaviour. *Water and Environment Journal*. 2012;26(2):191–9.
44. Tagashira N, Senda Y. What information should be provided in communications on biomass power generation? *Applied Energy*. 2011;88(7):2519–29.
45. Thorne SE, Linda V, Cory MB, Sarah L. Developing consumer-focused risk communication strategies related to food terrorism. *International Journal of Food Safety, Nutrition and Public Health*. 2011;4(1):45–62.
46. Cone J, Rowe S, Borberg J, Stancioff E, Doore B, Grant K. Reframing Engagement Methods for Climate Change Adaptation. *Coastal Management*. 2013;41(4):345–60.
47. Cone J, Winters KW. Planning and evaluating science videos to aid in understanding science and decisions.
48. Maharik M, Fischhoff B. Risk knowledge and risk attitudes regarding nuclear energy sources in space. *Risk Analysis*. 1993;13(3):345–53.
49. Vogt C, Schaefer M. Knowledge matters - Impact of two types of information brochure on contraceptive knowledge, attitudes and intentions. *European Journal of Contraception and Reproductive Health Care*. 2012;17(2):135–43.
50. De Bruin WB, Guevenc U, Fischhoff B, Armstrong CM, Caruso D. Communicating About Xenotransplantation: Models and Scenarios. *Risk Analysis*. 2009 Aug;29(8):1105–15.
51. Downs JS, Murray PJ, de Bruin W, Penrose J, Palmgren C, Fischhoff B. Interactive video behavioral intervention to reduce adolescent females' STD risk: A randomized controlled trial. *Social Science & Medicine*. 2004;59(8):1561–72.

- 1
- 2
- 3 52. Cousin M-E, Dohle S, Siegrist M. The impact of specific information provision on base
- 4 station siting preferences. *Journal of Risk Research*. 2011;14(6):703–15.
- 5
- 6 53. Read D, Morgan MG. The efficacy of different methods for informing the public about the
- 7 range dependency of magnetic fields from high voltage power lines. *Risk Analysis*.
- 8 1998;18(5):603–10.
- 9
- 10 54. Galada HC, Gurian PL, Corella-Barud V, Perez FG, Velazquez-Angulo G, Flores S, et al.
- 11 Applying the mental models framework to carbon monoxide risk in northern Mexico. *Pan*
- 12 *American Journal of Public Health*. 2009 Mar;25(3):242–53.
- 13
- 14 55. Longstaff HA. Frankenfish, Monsatan, and Killer Canola Making Good Decisions in the
- 15 Midst of Environmental Controversy. *Journal of Environmental Informatics*. 2005;6(1):33–
- 16 45.
- 17
- 18 56. Fleishman LA, De Bruin WB, Morgan MG. Informed Public Preferences for Electricity
- 19 Portfolios with CCS and Other Low-Carbon Technologies. *Risk Analysis*.
- 20 2010;30(9):1399–410.
- 21
- 22 57. Guy S, Kashima Y, Walker I, O'Neill S. Investigating the effects of knowledge and
- 23 ideology on climate change beliefs. *European Journal of Social Psychology*.
- 24 2014;44(5):421–9.
- 25
- 26 58. Shi J, Visschers VHM, Siegrist M, Arvai J. Knowledge as a driver of public perceptions
- 27 about climate change reassessed. *Nature Climate Change*. 2016;(April).
- 28
- 29 59. Tobler C, Visschers VHM, Siegrist M. Consumers' knowledge about climate change.
- 30 *Climatic Change*. 2012;114(2):189–209.
- 31
- 32 60. Cao Y, McGill WL. LinkIT: A Ludic Elicitation Game for Eliciting Risk Perceptions. *Risk*
- 33 *Analysis*. 2013;33(6):1066–82.
- 34
- 35 61. Fitzpatrick-Lewis D, Yost J, Ciliska D, Krishnaratne S. Communication about
- 36 environmental health risks: A systematic review. *Environmental Health*. 2010;9(67):1–15.
- 37
- 38 62. Frewer LJ, Fischer ARH, Brennan M, Banati D, Lion R, Meertens RM, et al. Risk/Benefit
- 39 Communication about Food - A Systematic Review of the Literature. *Critical Reviews in*
- 40 *Food Science and Nutrition*. 2015;
- 41
- 42 63. Zhang M, Liu GL. The effects of consumers' subjective and objective knowledge on
- 43 perceptions and attitude towards genetically modified foods: objective knowledge as a
- 44 determinant. *International Journal of Food Science and Technology*. 2015;50(5):1198–
- 45 205.
- 46
- 47 64. Pieniak Z, Aertsens J, Verbeke W. Subjective and objective knowledge as determinants
- 48 of organic vegetables consumption. *Food Quality and Preference*. 2010;21(6):581–8.
- 49
- 50 65. Seigo SL, Dohle S, Diamond L, Siegrist M. The effect of figures in CCS communication.
- 51 *International Journal of Greenhouse Gas Control*. 2013;16:83–90.
- 52
- 53 66. Krimsky S. Risk communication in the internet age: The rise of disorganized skepticism.
- 54 *Environmental Hazards*. 2007;7(2):157–64.
- 55
- 56 67. Rutsaert P, Regan Á, Pieniak Z, McConnon Á, Moss A, Wall P, et al. The use of social
- 57 media in food risk and benefit communication. *Trends in Food Science & Technology*.
- 58 2013;30(1):84–91.
- 59
- 60 68. Veil SR, Buehner T, Palenchar MJ. A Work-In-Process Literature Review: Incorporating

- 1  
2  
3 Social Media in Risk and Crisis Communication. *Journal of contingencies and crisis*  
4 *management*. 2011;19(2):110–22.  
5  
6 69. Morss RE, Demuth JL, Bostrom A, Lazo JK, Lazrus H. Flash Flood Risks and Warning  
7 Decisions: A Mental Models Study of Forecasters, Public Officials, and Media  
8 Broadcasters in Boulder, Colorado. *Risk Analysis*. 2015;  
9  
10 70. Baker R, Blumberg SJ, Brick JM, Couper MP, Courtright M, Dennis JM, et al. Research  
11 synthesis: AAPOR report on online panels. *Public Opinion Quarterly*. 2010;74(4):1–71.  
12  
13 71. Scammell MK. Qualitative environmental health research: an analysis of the literature,  
14 1991 to 2008. *Environmental Health Perspectives*. 2010;118(8):1146–54.  
15  
16 72. Cousin M-E, Siegrist M. Risk perception of mobile communication: a mental models  
17 approach. *Journal of Risk Research*. 2010;13(5):599–620.  
18  
19 73. Rosenthal R. The file drawer problem and tolerance for null results. *Psychological*  
20 *Bulletin*. 1979;86:638–41.  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

TABLES

Table I. Search engine selection: the number of references that cited each of the four key sources. Searches run February 2014. \*These are a 'calculated set of PubMed citations closely related to the selected article(s) retrieved using a word weight algorithm'.

Key sources	Search engine and number of times each source was cited		
	Google Scholar	Web of Science	PubMed
Morgan <i>et al.</i> 2002 <sup>(10)</sup>	812	Item not found	Item not found
Atman <i>et al.</i> 1994 <sup>(18)</sup>	144	62	103*
Bostrom <i>et al.</i> 1994 <sup>(20)</sup>	106	55	93*
Bostrom <i>et al.</i> 1992 <sup>(19)</sup>	275	129	Item not found

For Peer Review

Table II. Search strategy used to identify references for consideration

Search type	Search date	Source(s)	Publication dates	Search terms
Standard	4 February 2014	Web of Science, Google Scholar	All	"mental models approach" "risk communication"
Forward citation for four sources in Table I	4 February 2014	As above	All	Not applicable
Hand searching	19 February 2014	Morgan <i>et al.</i> 2002	All (up to source publication date of 2002)	Not applicable
Hand searching	26-27 February 2014	Reference lists of the 12 included papers	All	Not applicable

For Peer Review

Table III. Inclusion criteria applied to search results.

Inclusion criterion	Detail
Written in English	References not written in English were excluded.
Complete reference	References should be sufficiently complete to allow source identification. Incomplete references were excluded.
Reference type	Must be peer-reviewed journal article. Book chapters, theses, conference proceedings, reports etc. were excluded.
Topic	Studies must report the evaluation of a communication developed in line with the MMARC, and if not were excluded.

For Peer Review

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49

Table IV. Summary of MMARC evaluation studies included in this review. \*How the MMARC communication was developed: A=after comparing expert and public mental models; B=with expert input; C=in line with the MMARC. 1=quantitative methods; 2=qualitative methods. + positive; - negative; +/- mixed; = no difference.

For Peer Review



Study description			Participants (target audience)	Intervention(s) (MMARC communication)	Comparison(s) (Risk Analysis)	Outcome(s)		Process		
Authors; year; country	Original study author?	Risk topic				Measures	Effect of MMARC	MMARC?*	Methods	Randomisation?
Altman <i>et al.</i> 1994 USA <sup>(18)</sup> 4 5	Y	Radon	n/a	Brochures	7 brochures	Communication coverage <sup>1</sup>	=	A	Desk-based comparison of each communication	n/a
						Communication structure <sup>2</sup>	+			
Bostrom <i>et al.</i> 1994 USA <sup>(20)</sup> 8 9 10 11 12 13 14	Y	Radon	Convenience: undergraduate students (social science communications)	Brochures	1 brochure; 1 'filler task'	Knowledge <sup>1</sup>	+	A	Multiple evaluation methods: think-aloud protocols, multiple choice test, true/false test, open-ended recall questions, problem-solving questions	Y
						Positive/negative comments <sup>2</sup>	+			
Gosin <i>et al.</i> 2011 Switzerland <sup>(52)</sup> 17 18 19 20	N	Mobile phone masts	Public convenience sample (recruited at a variety of locations)	Booklet	1 neutral text; 1 newspaper article	Knowledge <sup>1</sup>	+	C	Between subject design experiment; data collected during interviews	Y
						Perception <sup>1</sup>	+			
						Mast decision evidence-based <sup>1</sup>	+			
De Bruin <i>et al.</i> 2009 USA <sup>(50)</sup> 23 24 25 26	Y	Xenotransplantation	Primarily students (participants recruited at a university)	Graphic only; text only; graphic and text, written on sheets of paper	None. (Compared MMARC communication formats.)	Depth of understanding (knowledge) <sup>1</sup>	+	B	Between subject design experiment; open-book written test	Y
						Ease of processing <sup>1</sup>	=			
						Xenotransplantation evaluation <sup>1</sup>	+			
Downs <i>et al.</i> 2004 USA <sup>(51)</sup> 28 29 30 31	Y	Sexually transmitted disease	Urban adolescent girls	Video	1 book; 1 brochure	Knowledge <sup>1</sup>	=	A	Longitudinal experiment with a baseline assessment and 3 subsequent data collection points	Y
						Behaviour <sup>1</sup>	+			
						Disease acquisition <sup>1</sup>	+			
Rishman <i>et al.</i> 2010 USA <sup>(56)</sup> 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49	Y	Energy technologies	Public convenience sample (recruited from community groups)	Brochures	None. (Compared to 50% correct answers).	Knowledge <sup>1</sup>	+	B	Participants received the communications prior to assessment.	N
						Technology ranking <sup>1</sup>	=			



Table V. Detail of knowledge measures applied in each study. Direct knowledge relates specifically to the study topic, whereas indirect/proxy knowledge is a measure of a participant's broader scientific literacy,

Study	Knowledge measures	
	Direct	Indirect / proxy
Atman <i>et al.</i> 1994 <sup>(18)</sup>	n/a – did not assess participants' knowledge	
Bostrom <i>et al.</i> 1994 <sup>(20)</sup>	58-item true/false test addressing both common radon misconceptions and expert concepts	None
	7-item multiple choice test (including radon health effects, detection and mitigation)	
Cousin <i>et al.</i> 2011 <sup>(52)</sup>	13-item test relating to the technical functionality of mobile communications (true, wrong, don't know)	Two 3-item scales measuring mobile phone and base station health concerns
De Bruin <i>et al.</i> 2009 <sup>(50)</sup>	14-item open-ended knowledge test of xenotransplantation cause and effect variables	None
	7-item knowledge test with a 7-point response scale assessing direction of influence of xenotransplantation variables	
	5-item test assessing probability of several health outcomes following xenotransplantation (0-100%)	
	Scenario (participants asked to draft a scenario based on information they were provided as part of the assessment)	
Downs <i>et al.</i> 2004 <sup>(51)</sup>	40-item true/false test of reproductive health	None
	15-item multiple choice test relating to eight diseases	
Fleishman <i>et al.</i> 2010 <sup>(56)</sup>	15-item (true/false) test about energy technology, focussing on misconceptions	None
Galada <i>et al.</i> 2009 <sup>(54)</sup>	22-item test including carbon monoxide production, health effects and mitigation	None
Longstaff 2005 <sup>(55)</sup>	Multiple choice questions relating to salmon production misconceptions (number of items not provided)	None
Maharik and Fischhoff 1993 <sup>(48)</sup>	66-item test with a 5-point response scale (true, maybe true, don't know, false, maybe false) covering expert model concepts and misconceptions	None
Niewöhner <i>et al.</i> 2004 <sup>(34)</sup>	Questionnaires assessing respondents' knowledge background (unclear whether this was actionable or indirect)	

	Discussion groups (user evaluation sessions) assessing participants understanding of chemical risk (unclear whether this was actionable or indirect)	
	Verbal protocols assessing comprehension of the communication (unclear whether this was actionable or indirect)	
Read and Morgan 1998 <sup>(53)</sup>	2 knowledge measures assessing respondents' knowledge of magnetic field strength and distance	None
Vogt and Schaefer 2012 <sup>(49)</sup>	39-item knowledge test assessing participant's knowledge of the benefits and risks of combined oral contraceptives	None

For Peer Review

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23  
24  
25  
26  
27  
28  
29  
30  
31  
32  
33  
34  
35  
36  
37  
38  
39  
40  
41  
42  
43  
44  
45  
46  
47  
48  
49  
50  
51  
52  
53  
54  
55  
56  
57  
58  
59  
60

## FIGURES

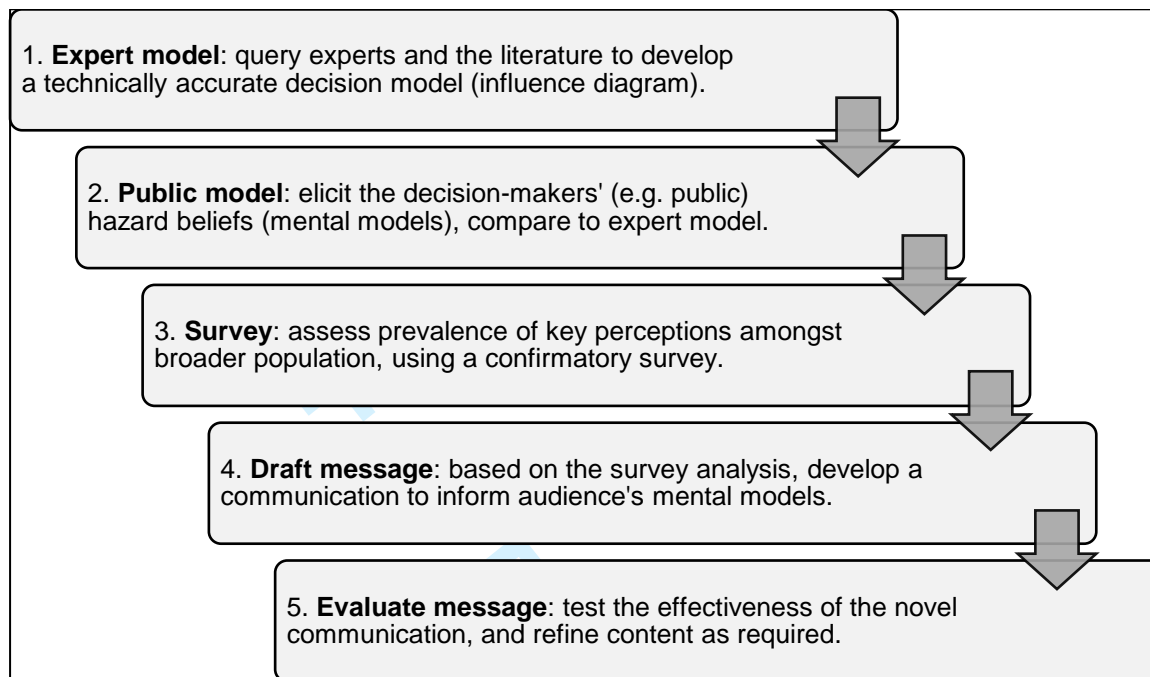


Figure 1. Outline of the Mental Models Approach to Risk Communication, adapted from Morgan *et al.* 2002.<sup>(10)</sup>

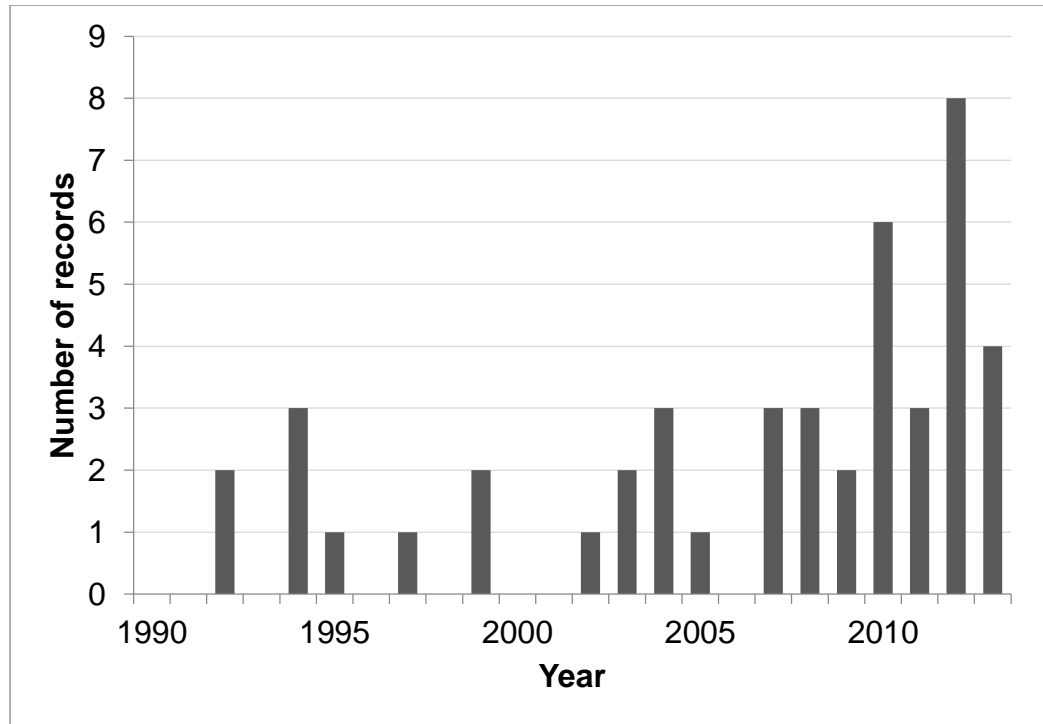


Figure 2. MMARC publications by year. Results from searches on Web of Science database on 4 July 2014 with search term "mental models approach" in topic field. This figure was intended to provide an indication of the pattern of MMARC publications over time, rather than an exhaustive assessment of the literature (importantly the searches described in Section 2.1 applied a broader range of searches).

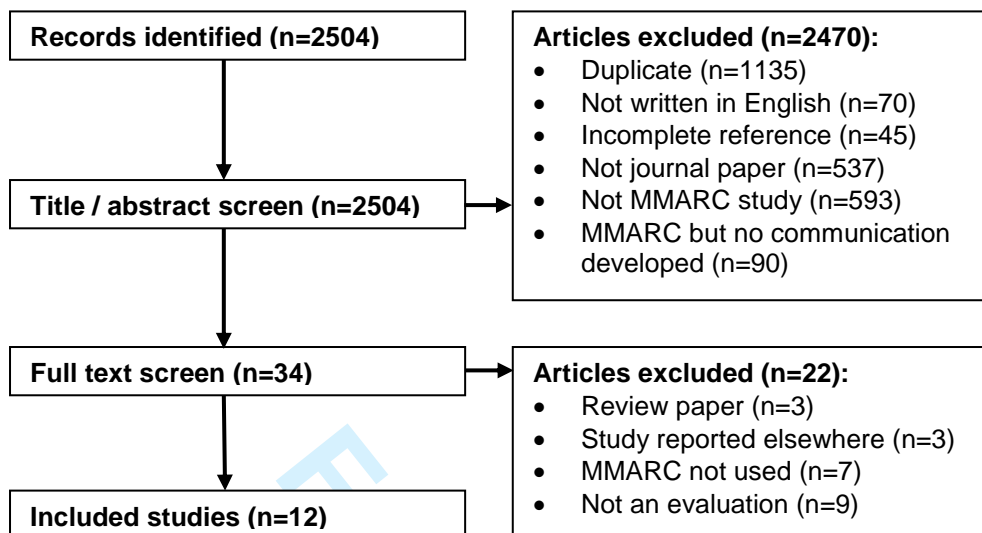


Figure 3. Screening procedure for search results.