

**ANNOUNCEMENT****Introducing M-Tool: A standardised and inclusive mental model mapping tool**

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*Abstract*

Stakeholder mental model elicitation can produce valuable insights into perceptions of complex systems such as ecosystems, economies, or the climate. These mental models can uncover crucial differences in perceptions between stakeholders and prevalent misunderstandings of the system, which can ultimately contribute to successful resource management. This paper introduces a novel tool to capture mental models: M-Tool. M-Tool was designed to be user-friendly for diverse samples, and standardized to ease aggregation and comparison of mental models. With this tool, participants create influence diagrams with a fixed set of pictograms representing the system variables, and weighted arrows to display their relations. M-Tool can be used to identify differences or changes in mental models or to co-produce knowledge with stakeholders and develop strategies to address challenges within the system. This paper describes how to tailor the tool to a research project and discusses how M-Tool may be suitable for diverse research applications.

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**Introduction**

Mental models are internal representations of an external system, which consists of causal beliefs about the functioning of a system (Bostrom, 2017). These cognitive structures form the foundation for explaining events, reasoning and predicting future developments (Jones et al., 2014), and guide decision-making and behaviour (Goldberg et al., 2020). Mental models provide rich insights into a system based on observation and experience (Forrester, 1992), and therefore, eliciting stakeholders' mental models increases the understanding of a system (Doyle & Ford, 1998). Furthermore, mental model elicitation can foster system thinking (Goldberg et al., 2020), help demonstrate consistencies and disparities in perceptions between individuals (van den Broek, 2018), or help to identify misperceptions that can be addressed in risk communication (Morgan et al., 2002). Furthermore, mental model elicitation can be a valuable tool in knowledge co-production and increases the likelihood that findings will successfully be applied to manage the system (Rouwette, 2016).

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The importance of mental model elicitation for understanding and managing a complex system has resulted in a proliferation of mental model mapping methods (Groesser & Schaffernicht, 2012; Moon et al., 2019). Researchers often use diagram drawing methods to generate visual representations of mental models. Specifically, influence diagrams are directed graphs that show the structure of the mental model, including the constituent variables and the (causal) relations between those variables depicted by arrows (Atman et al., 1994). Current influence diagram drawing software available to map mental models includes the *Mental Modeller*, in which participants generate the system variables and connect these with weighted arrows (Gray et al., 2013), and *eCASS* in which different types of system variables are entered by the respondents and linked with unweighted arrows (Kovacs et al., 2017). Although these methods have proven fruitful in producing mental model insights on a wide range of topics (e.g. Gray et al., 2014; Wood et al., 2017), the resulting mental models may be difficult to compare as respondents tend to enter their own system variables with these methods. Furthermore, these methods have not been designed to assess mental models of low literacy samples. Therefore, mental model researchers have called for further development of visual mental model elicitation methods to ensure robust and reliable elicitation and allow systematic cross-group comparisons (Schaffernicht & Groesser, 2011).

Here, we introduce *M-Tool*, an elicitation software designed to be user-friendly for different types of users and standardised to facilitate rigorous comparisons of mental models. Hence, M-Tool may be particularly valuable for researchers interested in comparing mental models across diverse samples, including those with low literacy. Indeed, a first application of the tool with a sample of Tanzanian fishers has provided support for M-Tool's usability and validity (van den Broek et al., 2021). M-Tool software can be downloaded for free in the App store and Google Play Store, and a web-based application can be found on [www.m-tool.org](http://www.m-tool.org). The tool was developed by Heidelberg University, the Tanzanian Fisheries Research Institute and Lambdaforge as part of the MultiTip project.

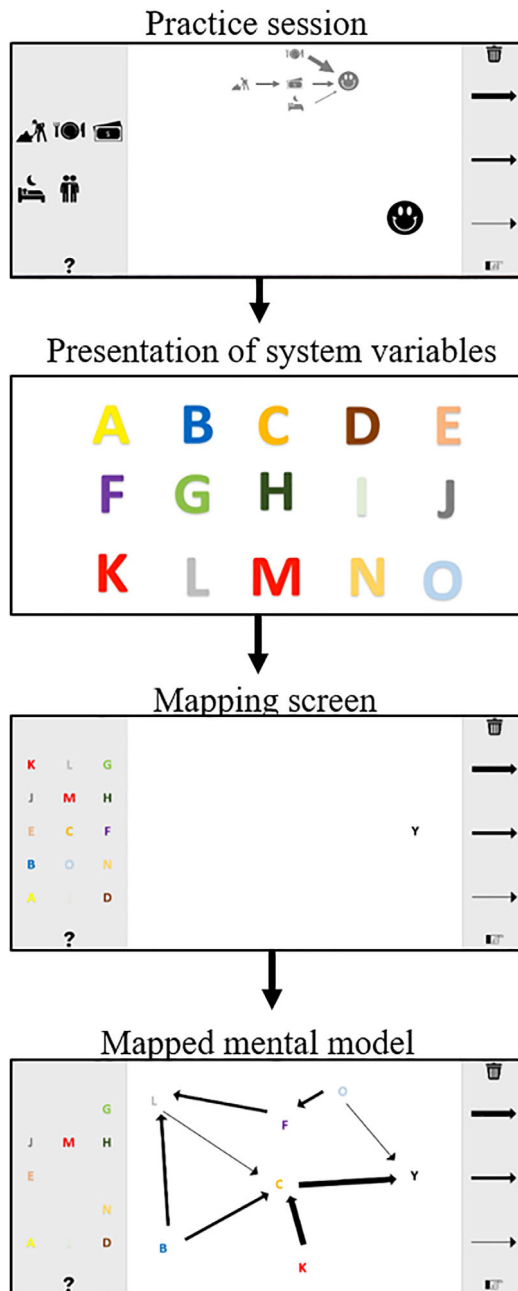
To ensure comparability of mental models, participants do not enter the mental model components themselves but choose from a set of pictograms representing the system components that the researcher has specified beforehand. Participants create their influence diagram by indicating directions of causality with arrowheads and the strength of the influence with weighted arrows. M-Tool can be used to capture perceptions of any system, including the drivers, consequences, actors, actions, and resources, by populating the tool with the relevant concepts. This paper provides a short introduction to M-Tool and guides researchers to tailor the tool to their research question.

### *Designing M-Tool*

M-Tool was designed to facilitate (1) user-friendliness for lower literate populations and (2) a standardised approach to ensure comparability of mental

models. M-Tool does not require respondents' literacy due to its video instructions, pictograms to display the relevant system variables, and audio descriptions

Fig 1. Example of the sequence of M-Tool's components presented to the participant [Color figure can be viewed at wileyonlinelibrary.com]



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of each pictogram. Furthermore, to ensure comparability, researchers provide participants with a set of system variables (based on the literature or a small-scale pre-study) to construct their mental model. The fixed set of mental model components eases mental model aggregation and comparability since the researcher does not need to interpret participant-generated system variables.

M-Tool has been developed into an offline mobile application and a web-based application that include a mental model mapping task. For this task, participants first view a video introducing the tool by demonstrating a practice task they need to replicate (see Figure 1). Next, participants watch a video explaining the pictograms they will use in the main mental model mapping task. This is followed by the mapping screen, where the participants create their mental model. During the mapping task, audio instructions remind participants how to move relevant system variables to the middle of the screen, choose and connect the arrows, listen to the explanations of the pictograms again and delete pictograms or arrows.

The researcher chooses the number of system variables provided, the type of arrows available to the participants (e.g. positive and negative influences, double-headed arrows), and whether and where to include a target variable. For example, a target variable, such as climate change, can be placed on the right to prompt participants to demonstrate the process that causes climate change, or it can be placed on the left to get participants to show the consequences of climate change. M-Tool also captures the time that participants take to create their models, which can be informative of the mapping process (LaMere et al., 2020). The web-based application also allows the researcher to link M-Tool data to an external survey.

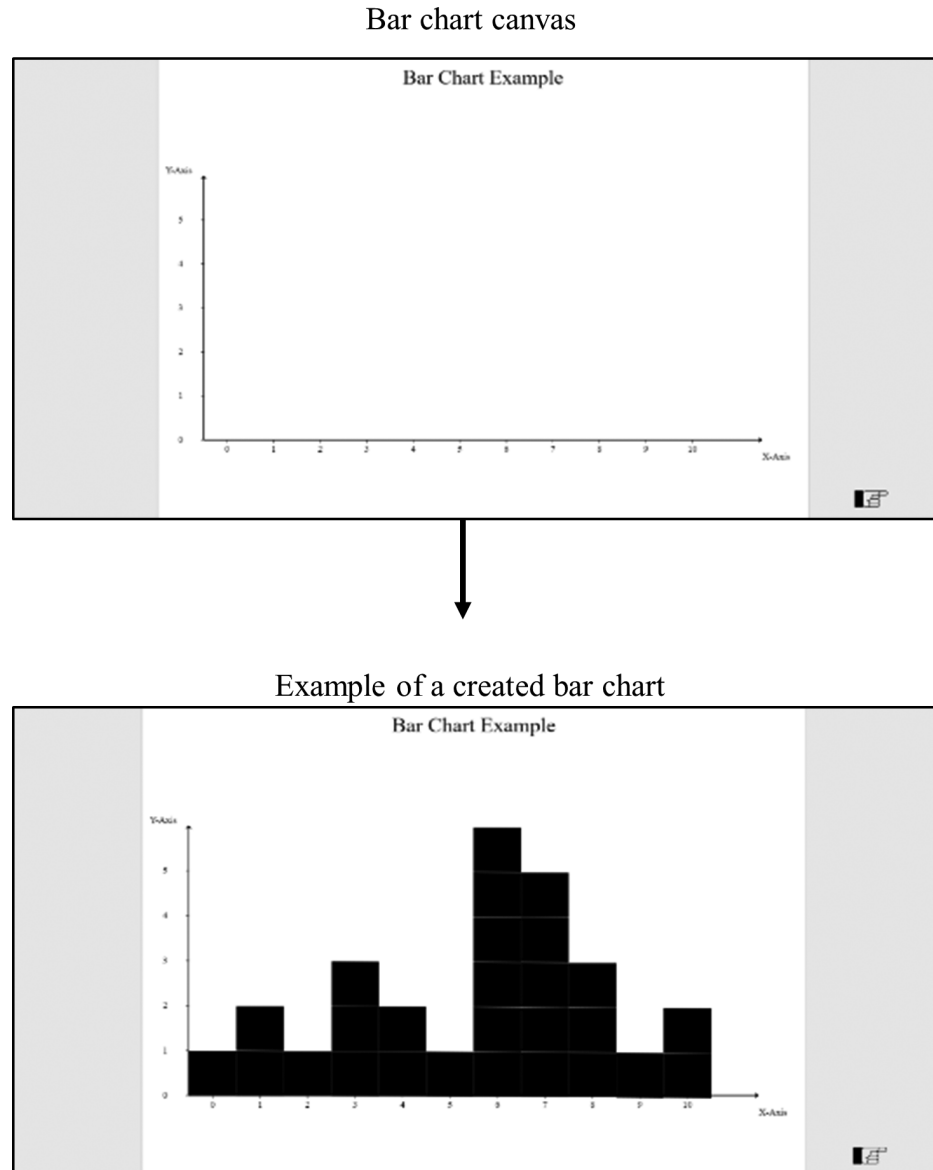
The web-based M-Tool application also includes a bar chart drawing task. In this task, participants display their views on the relation between two variables, for example, the fluctuation of a particular resource over time. Participants first view a video that introduces the bar chart task and defines the variables. Then, participants work on their own bar chart by indicating the height for every labeled, pre-specified point on the x-axis (see Figure 2). The researcher specifies (1) the variables by populating the x-axis and y-axis, (2) the increments on the x-and y- axis, and (3) the icon that is used in the task to create the bars (simple bars or a specific pictogram).

## **Guide for researchers**

### *Mental model mapping*

The following four steps can guide the researcher to tailor M-tool for data collection and analysis.

Fig 2. Example of the bar chart canvas and created bar chart in M-Tool



### *Step 1: Generate system variables*

First, a set of relevant system variables needs to be developed. These variables can be co-created with the mental model target group, for example, through short interviews or surveys (e.g. “What are the elements of [a system]?”; “What

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factors do you think drive...?"; "What are the consequences of ...?"). Alternatively, a researcher may be interested to see if the target group draws specific connections between system variables found in the literature.

#### *Step 2: Create media files*

Once the system variables are established, the researcher creates the media files needed to tailor the tool to their research project. The system variables are transformed into pictograms (e.g., by a graphic designer), and audio recordings explaining the meaning of each pictogram are created. These audio descriptions and pictograms are combined in a video that presents the pictograms to the participant before starting the mental model mapping task. Furthermore, the researcher can adapt the audio instructions of the welcome screen, the introduction video, practice task and mapping screen to the language and instruction needs of the target group.

#### *Step 3: Populate M-Tool*

Media files are uploaded in the tool to create the participant survey. The researcher chooses to include one or two mapping screens and whether to include the bar chart task. Furthermore, a target variable and its location are determined and the type of arrows that the participant will use are set up. The researcher chooses whether to include an informed consent form and integrate a link to an external survey. For more technical details on setting up the tool, please see the manual included in the application.

#### *Step 3.1: Optional bar chart*

To set up the bar chart task, the researcher indicates the chart's title, the titles of the axes, start and endpoints for each axis, and the increments for the x- and y-axis. For example, in Figure 2, the x-axis starts at 0 and ends at 10 with increments of 1. The y-axis in this example starts at 0 and ends at 5, with increments of 1. This means that the participant has to indicate a value between 0 and 5 for 10 different pre-specified points on the x-axis. While the default option of the icon creates simple black bars, such as in Figure 2, it is also possible to use a specific icon (e.g. indicating a unit of resources or the target variable of the mapping task).

#### *Step 4: Use M-Tool with stakeholders*

The researcher can now share the created study with participants by sending them a link to the study when using the web-based application or setting up the tool on a tablet using the mobile application.

Fig 3. Example of the dataset generated with M-Tool by a participant (see Figure 1 and 2)

	A	B	C	D	E	F	G	H	I	J	K
1	User_ID	Total_Start	Total_Duration	Type	Start	Duration	From	To	Weight	X-Axis	Y-Axis
2	49597315-dd4d-4e11-aba3-ed05dd836c94	Mon Sep 20 2021 16:40:15	178.50	mapping1	Mon Sep 20 2021 16:40:45	92.3	O	Y	1		
3	49597315-dd4d-4e11-aba3-ed05dd836c94	Mon Sep 20 2021 16:40:15	178.50	mapping1	Mon Sep 20 2021 16:40:45	92.3	C	Y	3		
4	49597315-dd4d-4e11-aba3-ed05dd836c94	Mon Sep 20 2021 16:40:15	178.50	mapping1	Mon Sep 20 2021 16:40:45	92.3	K	C	3		
5	49597315-dd4d-4e11-aba3-ed05dd836c94	Mon Sep 20 2021 16:40:15	178.50	mapping1	Mon Sep 20 2021 16:40:45	92.3	B	C	2		
6	49597315-dd4d-4e11-aba3-ed05dd836c94	Mon Sep 20 2021 16:40:15	178.50	mapping1	Mon Sep 20 2021 16:40:45	92.3	B	L	2		
7	49597315-dd4d-4e11-aba3-ed05dd836c94	Mon Sep 20 2021 16:40:15	178.50	mapping1	Mon Sep 20 2021 16:40:45	92.3	L	C	1		
8	49597315-dd4d-4e11-aba3-ed05dd836c94	Mon Sep 20 2021 16:40:15	178.50	mapping1	Mon Sep 20 2021 16:40:45	92.3	F	L	2		
9	49597315-dd4d-4e11-aba3-ed05dd836c94	Mon Sep 20 2021 16:40:15	178.50	mapping1	Mon Sep 20 2021 16:40:45	92.3	O	F	2		
10	49597315-dd4d-4e11-aba3-ed05dd836c94	Mon Sep 20 2021 16:40:15	178.50	barChart	Mon Sep 20 2021 16:42:20	53.5				0	1
11	49597315-dd4d-4e11-aba3-ed05dd836c94	Mon Sep 20 2021 16:40:15	178.50	barChart	Mon Sep 20 2021 16:42:20	53.5				1	2
12	49597315-dd4d-4e11-aba3-ed05dd836c94	Mon Sep 20 2021 16:40:15	178.50	barChart	Mon Sep 20 2021 16:42:20	53.5				2	1
13	49597315-dd4d-4e11-aba3-ed05dd836c94	Mon Sep 20 2021 16:40:15	178.50	barChart	Mon Sep 20 2021 16:42:20	53.5				3	3
14	49597315-dd4d-4e11-aba3-ed05dd836c94	Mon Sep 20 2021 16:40:15	178.50	barChart	Mon Sep 20 2021 16:42:20	53.5				4	2
15	49597315-dd4d-4e11-aba3-ed05dd836c94	Mon Sep 20 2021 16:40:15	178.50	barChart	Mon Sep 20 2021 16:42:20	53.5				5	1
16	49597315-dd4d-4e11-aba3-ed05dd836c94	Mon Sep 20 2021 16:40:15	178.50	barChart	Mon Sep 20 2021 16:42:20	53.5				6	6
17	49597315-dd4d-4e11-aba3-ed05dd836c94	Mon Sep 20 2021 16:40:15	178.50	barChart	Mon Sep 20 2021 16:42:20	53.5				7	5
18	49597315-dd4d-4e11-aba3-ed05dd836c94	Mon Sep 20 2021 16:40:15	178.50	barChart	Mon Sep 20 2021 16:42:20	53.5				8	3
19	49597315-dd4d-4e11-aba3-ed05dd836c94	Mon Sep 20 2021 16:40:15	178.50	barChart	Mon Sep 20 2021 16:42:20	53.5				9	1
20	49597315-dd4d-4e11-aba3-ed05dd836c94	Mon Sep 20 2021 16:40:15	178.50	barChart	Mon Sep 20 2021 16:42:20	53.5				10	2

### Step 5: Analysing mental model data

A CSV file of the data can be downloaded within the tool, consisting of a long data structure with an edge list of the data. The data consists of a row for each connection drawn in the model for each participant, showing where the connection started and ended, and the weight given to each connection (see Figure 3). This data file can directly be read into analysis software such as R and centrality indices can be computed using the M-Tool data analysis script (van Boxtel & van den Broek, 2021). Graph theory provides established guidelines for aggregating and analysing mental models by comparing mental model complexity or the centrality of the system variables in the mental models across stakeholder groups (Özesmi & Özesmi, 2004).

#### Step 5.1: Analysing the bar chart data

The bar chart data is listed in the last two columns of the CSV data file. Specifically, the participant's response is listed in the y-Axis column for each x-value specified by the researcher. The headings of the columns reflect the titles of the two axes. The data can be analysed to quantify the perceived relationship between the x-axis and y-axis, for example, through correlational or regression analysis.

### M-Tool applications

M-Tool can be tailored to capture perceptions of any system, lay theory about how things work, or causal process in a specific domain. Due to the standardized format, the tool is particularly apt to compare mental models between groups of respondents (e.g. diverse types of stakeholders, experts vs. the general public, across cultures, communities from different geographical areas, different ages), or to identify misunderstandings in system thinking. Furthermore, since

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mental models are subject to change due to learning (Pearson & Moon, 2014), researchers can use the tool to assess changes in mental models over time or assess the impact of an intervention on the respondents' mental model. Moreover, M-Tool can be used to start a conversation between stakeholders on the functioning of a system, co-produce knowledge about the system of interest, and develop strategies to address challenges within the system.

Recent research projects have applied M-Tool (1) to assess the effect of Tanzanian fisher's experience, migration and region of residence on mental models of the Nile perch stock at Lake Victoria (van den Broek et al., 2021), (2) to understand consumer's mental models on the plant-based protein transition (van den Boom et al., 2021), and (3) to map citizens' mental models of COVID-19 transmission (de Ridder et al., 2021).

## Conclusion

Mental models shape how stakeholders explain events, reason, and predict future developments about complex systems, be it economies, lakes, or the climate. M-Tool ensures comparability across participants and provides a method to solicit mental models of low-literacy populations, which ultimately ensures more diverse samples. The tool can easily be used by researchers in a wide range of settings, with or without an internet connection. We hope that this short hands-on guide inspires researchers to use M-Tool to research stakeholders' understanding of complex systems.

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