# Towards more effective identification keys - a study of people identifying plant species characters: supporting material of statistics and results 

## A. Splitting participants into knowledge groups

We split participants into groups based on the self-assessment they provided in the first part of the questionnaire. These questions inquired about: (a) the number of species they were familiar with, (b) their experience with identification keys, (c) a self-assessment of plant knowledge, and (d) whether they are professionally involved with plants. We used a generalization of Gower's dissimilarity index to account for the mixture of ordinal and factor variables [2]. The resulting dissimilarity matrix was clustered using the partitioning around medoids algorithm (PAM) [1] and the average silhouette width was calculated to assess the quality of differing cluster numbers. We found a three-cluster solution to yield the highest value silhouette score of 0.63 and we therefore split participants into three different expertise groups based on their self-reported experience with plant identification.

## B. Testing significance differences between expertise groups and plant organ related characters

A Kolmogorov-Smirnov test shows that our measured variables, i.e., answer correctness, self-assessed difficulty, self-assessed certainty, number of image views, and response time, are not normally distributed. Therefore, we compare groups in terms of these variables with non-parametric MannWhitney U tests (organ: leaf versus flower related characters) and Kruskal-Wallis tests (between three expertise groups).

## C. Fitting a generalized linear mixed-effect model

Furthermore, we fit a generalized linear mixed-effect model (GLMM) with binomial error a priori utilizing all explanatory variables to model the probability of a character identification being conducted correctly. We consider the participants' identity and the species identity as random effects. We simplified the initial model using the Akaike information criterion (AIC) computed via R's MuMIn package [3]. We retain all models with $\Delta \mathrm{AIC}<6$ to be $95 \%$ sure that the most parsimonious models are maintained within the best supported model set [4]. Model averaging was used to calculate averaged parameter estimates and assess the relative importance (RI) of parameters using the natural averaging method [5]. Parameters within the resulting averaged model are considered significant if the p-value is $<0.05$. The amount of variance explained by the fixed effects only and the combined fixed and random effects of the binomial GLMM models are calculated as marginal $R_{G L M M(m)}^{2}$ and conditional $R_{G L M M(c)}^{2}$ respectively following Nagakawa and Schlielzeth's method [6]. All analysis was performed with R version 4.0.2 [7].

The global model explained about $32 \%$ of the variation in the data $\left(R_{G L M M(c)}^{2}=0.32\right)$ while about $10 \%$ was explained by the fixed factors $\left(R_{G L M M(m)}^{2}=0.10\right)$. We produced a candidate model set consisting of all simplified versions of the global model and compared them based on their AIC. The top four models with $\triangle$ AIC $<6$ (cp. Tab. S2.1) were used to produce model averaged parameter estimates. "Difficulty", "certainty", "time", "organ", "number of character states" were all retained in
each model within the candidate model set and had a relative importance (RI) of 1 in the final averaged model. Skill level and the number of viewed images were retained in $50 \%$ of candidate models with a RI of 0.75 and 0.29 respectively. The model-averaged parameter estimates highlight how correctness is strongly related to "certainty" followed by "number of character states" and "organ" with the steepest decline, while skill level and the number of pictures viewed had no statistically significant influence on correctness (Tab. S2.2).

|  | df | $\operatorname{logLik}$ | AIC $\downarrow$ | $\Delta$ AIC | weight |
| :--- | :--- | :--- | :--- | :--- | :--- |
| Ability to correctly identify plant character states |  |  |  |  |  |
| user group + difficulty + certainty + time + organ + | 9 | -5347.91 | 10713.8 | 0 | 0.53 |
| \# character states |  |  |  |  |  |
| user group + difficulty + certainty + time + organ + | 10 | -5347.79 | 10715.6 | 1.76 | 0.22 |
| \# character states + \# viewed images <br> difficulty + certainty + time + organ + \# character | 8 | -5349.99 | 10716.0 | 2.15 | 0.18 |
| states <br> difficulty + certainty + time + organ + \# character | 9 | -5349.94 | 10717.9 | 4.06 | 0.07 |
| states + \# viewed images <br> user group + certainty + time + organ + \# character <br> states | 8 | -5355.72 | 10727.4 | 13.60 | 0.00 |

Table S2.1. Results of top 5 models based on AIC ( $\mathrm{df}=$ degrees of freedom, logLik $=\log$-likelihood, AIC $=$ Akaike information criterion, weight $=$ Akaike weight $)$

|  | Parameter <br> Estimate | Standard <br> Error | Adjusted <br> Standard <br> Error | z-value | p-value |  |
| :--- | ---: | ---: | ---: | ---: | :--- | :---: |
|  |  |  |  |  |  |  |
|  | 3.38 | 0.16 | 0.16 | 21.60 | $<0.001^{* * *}$ |  |
| intercept | 0.06 | 0.05 | 0.05 | 1.23 | 0.22 |  |
| user group | -0.19 | 0.05 | 0.05 | 3.88 | $<0.001^{* * *}$ |  |
| difficulty | -0.12 | 0.02 | 0.02 | 7.59 | $<0.001^{* * *}$ |  |
| \# character |  |  |  |  |  |  |
| states | -0.29 | 0.06 | 0.06 | 4.70 | $<0.001^{* * *}$ |  |
| organ (leaf) | -0.39 | 0.05 | 0.05 | 8.23 | $<0.001^{* * *}$ |  |
| certainty | -0.01 | 0.00 | 0.00 | 6.13 | $<0.001^{* * *}$ |  |
| time | 0.00 | 0.01 | 0.01 | 0.21 | 0.84 |  |
| \# viewed images |  |  |  |  |  |  |

marginal $\mathrm{R}_{G L M M(m)}^{2}$ of fixed effects only $=0.10$
conditional $\mathrm{R}_{G L M M(c)}^{2}$ of fixed and random effects $=0.32$
Table S2.2. Summary of results after model averaging for ability to correctly identify plant character states

## D. Character identification and plant organs

Figure S2.1 provides an overview across all evaluated characters grouped by organ. For each character, a bar visualizes average identification correctness across all participants and their perceived difficulty encoded as bar color. Further columns refer to the number of character states and other metrics as known from the previous result tables.

## E. Character state identification and species

Figure S2.2 shows identification correctness in relation to character state, rather than characters as shown in Figure S2.1. Furthermore the correctness of the character states is separated per species. Characters are again grouped into flower-related (upper part (a)) and leaf-related (lower part (b)) and shown from left to right. For each character CLxx and CFxx, different colors refer to results per character state and individual data points refer to the average identification correctness of this character state while identified from the same displayed species. The bubbles show the mean value independent of the species. The raw data of this plot is available in Table S 2 of the supplementary material.


| 1.6 | 1.5 | 3.0 | 18.5 | How are the leaf sections arranged? |
| :---: | :---: | :---: | :---: | :---: |
| 1.7 | 1.6 | 4.7 | 19.5 | Does the plant have vines? |
| 1.4 | 1.4 | 2.9 | 16.2 | How are the leaflets arranged? |
| 1.6 | 1.6 | 4.2 | 19.1 | Are the leaves stalked or sitting directly on the stem? |
| 1.6 | 1.5 | 3.5 | 20.8 | How are the leaves structured? |
| 1.5 | 1.4 | 3.5 | 14.5 | Are the leaves elongated or rounded? |
| 1.8 | 1.8 | 3.1 | 20.3 | Which is the shape of the incised leaf? |
| 1.7 | 1.7 | 3.4 | 20.7 | How are the compound leaves structured? |
| 1.7 | 1.7 | 3.3 | 24.6 | Which is the basic shape of the leaflets? |
| 1.6 | 1.6 | 3.6 | 20.9 | Are the leaflets stalked? |
| 1.4 | 1.4 | 3.0 | 14.3 | Is the basic shape of the entire compound leaf elongated or rounded? |
| 1.6 | 1.6 | 4.8 | 21.7 | Does the plant have spikes or thorns? |
| 1.3 | 1.3 | 2.9 | 12.8 | Are the leaflets elongated or rounded? |
| 1.8 | 1.9 | 3.2 | 24.6 | Which shape does a single leaflet have? |
| 2.0 | 2.0 | 3.4 | 34.5 | How are the leaf sections shaped? |
| 1.8 | 1.8 | 3.8 | 20.8 | Are all leaflets equally sized? |
| 1.7 | 1.7 | 4.0 | 26.1 | How are the leaf topsides colored? |
| 1.8 | 1.8 | 3.1 | 25.0 | Which is the shape of the leaf margin? |
| 1.9 | 1.9 | 3.2 | 20.8 | How deep are the leaf incisions? |
| 2.0 | 2.0 | 3.5 | 27.3 | Which is the shape of the leaf venation? |
| 1.6 | 1.6 | 3.6 | 20.0 | Is the terminal leaf section enlarged? |
| 1.9 | 1.9 | 3.8 | 29.6 | Which is the basic shape of single leaves? |
| 1.8 | 1.9 | 3.8 | 24.1 | Which is the location of the broadest part of the leaf? |
| 1.3 | 1.3 | 3.2 | 11.1 | Is the flower upright or nodding? |
| 1.5 | 1.4 | 3.4 | 13.9 | Is the inflorescence elongated or rounded? |
| 1.6 | 1.6 | 3.6 | 18.7 | Do the flowers of the inflorescence lie on more than one level? |
| 1.6 | 1.6 | 3.1 | 15.9 | Does the flower have labiate structures? |
| 1.4 | 1.4 | 2.6 | 12.8 | Which is the basic color of the flower? |
| 1.5 | 1.5 | 2.9 | 21.2 | How many petals does the flower have? |
| 1.7 | 1.7 | 3.5 | 18.1 | Is there a calyx present? |
| 2.0 | 2.0 | 4.1 | 21.9 | Is a conspicous flower corolla discernible? |
| 1.8 | 1.7 | 3.0 | 18.4 | How is the symmetry of the flower? |
| 1.8 | 1.7 | 3.0 | 16.6 | Does the flower have wing-shaped structures? |
| 1.9 | 1.9 | 3.6 | 21.3 | Are any twigs visible within the inflorescence? |
| 1.5 | 1.6 | 3.4 | 15.9 | Is the flower single-colored or multi-colored? |
| 1.6 | 1.7 | 3.9 | 17.6 | Are the flowers solitary or arranged as inflorescences? |
| 2.1 | 2.2 | 4.0 | 22.1 | Does the flower have a spur? |
| 1.7 | 1.7 | 2.6 | 24.6 | Which is the shape of the petals' front margin? |
| 1.8 | 1.8 | 3.8 | 24.6 | How are the flowers arranged? |
| 2.0 | 2.0 | 3.5 | 21.7 | Are the petals at least partially fused or are they completely separated? |
| 2.1 | 2.1 | 3.1 | 24.3 | How are the composite flowerheads structured? |
| 2.0 | 1.9 | 3.6 | 27.9 | Which is the basic type of the flower? |
| 1.7 | 1.7 | 3.2 | 19.4 | Is the petal margin smooth or does it have certain structures? |


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Fig. S2.1. Accuracies of answers given by the 484 participants in identifying plant characters. Bars indicate the percentage of correctly answered questions. Colors indicate mean difficulty per character rated by participants on a scale from 1 (easy) to 4 (difficult). The upper bars refer to leaf characters, while the lower refer to flower characters.

mean accuracy per character state per species
mean accuracy per character state across all respective species

Fig. S2.2. Accuracies per character, character state, and species grouped into (a) flower-related and (b) leaf-related characters. Points show the mean accuracy per character state-species combination and lines visualize variability of accuracy among species. Bubbles show the overall mean value per character state across all respective species. Multiple points representing equal accuracies are drawn next to each other.

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