Solutions Stats

Some questions raised by my plots for Q10, about solutions (solutions_plots.qmd):
- Are solution scores by job category the same for all possible pairs of job groups?
- Are aspiring contributors significantly more likely than experienced contributors to select solutions related to learning and professional development?
- Are experienced contributors significantly more likely than aspiring contributors to select solutions related to funding?

Set seed

```
set.seed(42)
```

Import packages and utilities

```
project_root <- here::here() # requires that you be somewhere in the
# project directory (not above it)
# packages
suppressMessages(source(file.path(project_root, "scripts/packages.R")))
# functions and objects used across scripts
suppressMessages(source(file.path(project_root, "scripts/utils.R")))
```

Load data

```
solutions <- load_qualtrics_data("clean_data/solutions_Q10.tsv")
other_quant <- load_qualtrics_data("clean_data/other_quant.tsv")
```

Wrangle data

First, let's add a participant ID. We'll need to keep track of these track these since observations from the same participant are not independent. We'll need to model the participants as a random effect.

```
solutions$participantID <- seq(1, nrow(solutions))
```

Next, remove empty rows, i.e. rows from respondents who didn't receive this question. As with many questions in this survey, we can cut some corners in the code because the question was mandatory. For example, no need to worry about incomplete answers.

```
solutions_and_job <- solutions
solutions_and_job$job_category <- other_quant$job_category
names(solutions_and_job)[length(names(solutions_and_job))] <- "job_category"

nrow(solutions_and_job)
```

```
[1] 332
```

```
# from scripts/utils.R
solutions_and_job <- exclude_empty_rows(solutions_and_job, strict=TRUE)
nrow(solutions_and_job)
```

```
[1] 233
```

Good. We know by now that only 233 participants saw this question.

Here's what we have so far:

```
head(solutions_and_job)
```

```
  Computing environments       Publicity Containerization Documentation help
1            Very useful     Very useful      Very useful        Very useful
2                 Useful     Very useful      Very useful    Not very useful
3            Very useful     Very useful      Very useful        Very useful
4        Not very useful          Useful           Useful        Very useful
5                 Useful Not very useful           Useful        Very useful
7        Not very useful Not very useful      Very useful    Not very useful
  A learning community  Event planning Mentoring programs       Education
1          Very useful     Very useful        Very useful     Very useful
2               Useful  Non-applicable        Very useful     Very useful
3               Useful          Useful             Useful Not very useful
4      Not very useful          Useful    Not very useful Not very useful
5      Not very useful Not very useful             Useful     Very useful
7      Not very useful Not very useful    Not very useful Not very useful
  Legal support Industry partnerships Sustainability grants
1   Very useful           Very useful           Very useful
2   Very useful                Useful           Very useful
3   Very useful           Very useful           Very useful
4        Useful       Not very useful           Very useful
5        Useful                Useful           Very useful
7   Very useful       Not very useful           Very useful
  Help finding funding participantID         job_category
1          Very useful             1              Faculty
2               Useful             2             Post-Doc
3          Very useful             3 Other research staff
4          Very useful             4              Faculty
5               Useful             5              Faculty
7          Very useful             7              Faculty
```

Convert to long data, since this makes it easier to remove NAs and is necessary for the statistics.

```
long_data <- solutions_and_job %>%
  pivot_longer(
    cols = -c(participantID, job_category),
    names_to = "solution",
    values_to = "utility"
  )
dim(long_data)
```

```
[1] 2796    4
```

```r
head(long_data)
```

```
# A tibble: 6 x 4
  participantID job_category solution               utility
          <int> <chr>        <chr>                  <chr>
1             1 Faculty      Computing environments Very useful
2             1 Faculty      Publicity              Very useful
3             1 Faculty      Containerization       Very useful
4             1 Faculty      Documentation help     Very useful
5             1 Faculty      A learning community   Very useful
6             1 Faculty      Event planning         Very useful
```

Remove NAs.

```r
long_data <- long_data %>%
    filter(!(utility == "Non-applicable"))
dim(long_data)
```

```
[1] 2602    4
```

That removed about 200 rows, out of more than 2000. So less than 10% of the responses were "non-applicable"s.

Make utility an ordered factor. Solution and job category are not inherently ordered, but we'll make them factors, and the first factor level will be the reference level for that variable. It doesn't really matter which level we use as the reference level.

```r
long_data$utility <- factor(
  long_data$utility,
  levels = c("Not very useful", "Useful", "Very useful"),
  ordered = TRUE
)

long_data$solution <- factor(
  long_data$solution,
  levels = unique(long_data$solution)
)

long_data$job_category <- factor(
  long_data$job_category,
```

```
  levels = unique(long_data$job_category)
)

levels(long_data$solution)
```

```
 [1] "Computing environments" "Publicity"              "Containerization"
 [4] "Documentation help"     "A learning community"   "Event planning"
 [7] "Mentoring programs"     "Education"              "Legal support"
[10] "Industry partnerships"  "Sustainability grants"  "Help finding funding"
```

```
levels(long_data$job_category)
```

```
[1] "Faculty"              "Post-Doc"             "Other research staff"
[4] "Grad Student"         "Non-research Staff"   "Undergraduate"
```

Ok, so it looks like our reference levels are computing environments and faculty. That's fine. It doesn't really matter.

Create candidate models

I'd like to fit a cumulative-logit mixed model, a.k.a. an ordinal regression model, using the `clmm` function from the ordinal package. (I am not using `polr` from the MASS package because it does not allow random effects.) I know we want to include participantID as a random effect, but I'm not really sure how to model solution. I think it would be best to compare different models.

Note that the next few cells take several minutes to run.

Model 1: job_category * solution interaction

Here, I'm modeling job_category and solution as independent fixed effects, and assuming that there is also an effect from the interaction of the two. This way, we get a global slope for job_category, a global slope for solution, a global slope for the interaction (I think), and a global intercept. Adding participant as a random effect allows each participant to have their own deviation from the global intercept.

```
fit1 <- clmm(utility ~ job_category * solution +
               (1 | participantID),
             data = long_data, link = "logit", Hess = TRUE)
```

```
Warning: (1) Hessian is numerically singular: parameters are not uniquely determined
In addition: Absolute convergence criterion was met, but relative criterion was not met
```

Hm. I get a warning that "Hessian is numerically singular: parameters are not uniquely determined" and "Absolute convergence criterion was met, but relative criterion was not met". The internet suggests that this might mean that some job-category × solution combinations have few or zero responses in one of the utility levels, so the full job_category * solution interaction is over-parameterised.

Model 2: solution as a random effect, no correlation between participant intercept and job effect

Here's another formulation. In this case, solution is another random effect, so we only get one global slope from job_category, but each solution intercept (as well as each participant intercept) is allowed to deviate from the global intercept. We assume that across solutions, the deviations in job_cateogry effect from the global effect of job_category are not correlated with that solution's intercept's deviation from the global intercept.

```
fit2 <- clmm(utility ~ job_category +
               (1 | solution) +
               (1 | participantID) +
               (0 + job_category | solution),
             data = long_data, link = "logit", Hess = TRUE)
```

Next, we again have 4 terms, like we did in the first model: a global intercept, slopes for job_category and solution, and a slope for the interaction. Now, we also estimate the deviance of each of these terms from the global baseline for each participant, and we also estimate the correlations between the deviations for each possible combination of the 4 terms, for each participant. Er, I think. (Helpful cheat sheet: https://stats.stackexchange.com/questions/13166/rs-lmer-cheat-sheet)

This one measures a ton of parameters… ABANDONED; NEVER CONVERGED

```
# fit3 <- clmm(utility ~ job_category * solution +       # fixed effects
#                (0 + job_category*solution | participantID),
#              data = long_data, link = "logit", Hess = TRUE)
```

All the models seem to be struggling a bit. Let's explore the data for a moment.

```
# three way cross tabs (xtabs) and flatten the table
# code from: https://ladal.edu.au/tutorials/regression/regression.html
ftable(xtabs(~ job_category + solution + utility, data = long_data))
```

		utility Not very useful	Useful	Very useful
job_category	solution			
Faculty	Computing environments	12	17	29
	Publicity	19	12	24
	Containerization	19	17	18
	Documentation help	21	18	17
	A learning community	21	26	10
	Event planning	24	19	11
	Mentoring programs	24	23	8
	Education	24	21	12
	Legal support	15	28	12
	Industry partnerships	18	15	23
	Sustainability grants	3	10	44
	Help finding funding	5	13	36
Post-Doc	Computing environments	4	3	8
	Publicity	2	6	7
	Containerization	5	4	6
	Documentation help	4	6	5
	A learning community	2	9	4
	Event planning	5	3	6
	Mentoring programs	3	7	5
	Education	2	6	7
	Legal support	2	5	7
	Industry partnerships	4	3	7
	Sustainability grants	0	3	12
	Help finding funding	0	6	9
Other research staff	Computing environments	10	11	19
	Publicity	6	15	16
	Containerization	14	17	8
	Documentation help	8	14	16
	A learning community	8	19	11
	Event planning	13	14	11
	Mentoring programs	12	13	10
	Education	11	15	11
	Legal support	14	11	13
	Industry partnerships	9	12	14
	Sustainability grants	3	7	28
	Help finding funding	2	11	23
Grad Student	Computing environments	1	6	19
	Publicity	2	10	11
	Containerization	3	10	9
	Documentation help	5	8	13
	A learning community	5	9	12

	Event planning	7	6	11
	Mentoring programs	4	10	12
	Education	5	7	14
	Legal support	3	10	12
	Industry partnerships	3	11	12
	Sustainability grants	0	1	25
	Help finding funding	0	5	20
Non-research Staff	Computing environments	13	32	35
	Publicity	26	33	15
	Containerization	33	24	20
	Documentation help	19	39	26
	A learning community	11	43	31
	Event planning	29	30	16
	Mentoring programs	18	35	24
	Education	21	31	30
	Legal support	13	41	26
	Industry partnerships	23	29	18
	Sustainability grants	8	25	39
	Help finding funding	9	31	32
Undergraduate	Computing environments	0	2	5
	Publicity	0	2	4
	Containerization	1	1	4
	Documentation help	1	3	3
	A learning community	2	1	4
	Event planning	2	2	3
	Mentoring programs	0	4	3
	Education	1	4	2
	Legal support	1	3	2
	Industry partnerships	0	0	7
	Sustainability grants	0	1	5
	Help finding funding	0	2	4

Hm. Indeed, the data are sparse in places, particularly for undergraduates. Perhaps we should combine postdocs + staff researchers, as well as undergrads + grad students.

```
combined <- long_data %>%
  mutate(
    job_category = recode(
      job_category,
      "Post-Doc" = "Postdocs and Staff Researchers",
      "Other research staff" = "Postdocs and Staff Researchers"
    )
```

```
  )

combined <- combined %>%
  mutate(
    job_category = recode(
      job_category,
      "Grad Student" = "Student",
      "Undergraduate" = "Student"
    )
  )
```

Now let's run models 1 and 2 again, but with this consolidated dataset.

Model 1b: Model 1, but with consolidated data

```
fit1b <- clmm(utility ~ job_category * solution +
              (1 | participantID),
            data = combined, link = "logit", Hess = TRUE)
```

No warning this time, and I feel like it finished faster. My hunch is that this re-labeled dataset will lead to better results.

Model 2b: Model 2, but with consolidated data

```
fit2b <- clmm(utility ~ job_category +
              (1 | solution) +
              (1 | participantID) +
              (0 + job_category | solution),
            data = combined, link = "logit", Hess = TRUE)
```

So, those are two fairly complex models that I think capture the important variation. Let's compare them to some simpler models.

Model 3: No job category

Let's make a null model where job category doesn't matter. (Using the consolidated data)

```
fit3 <- clmm(utility ~ solution +
               (1 | participantID),
             data = combined, link = "logit", Hess = TRUE)
```

Model 4: No solution category

How about a model where solution doesn't matter?

```
fit4 <- clmm(utility ~ job_category +
               (1 | participantID),
             data = combined, link = "logit", Hess = TRUE)
```

Model 5: job_category + solution

In this minimal model, we include job_category + solution, but without any interaction. This model says that we can predict the rating by simply adding the effect of job category and the effect of solution, with no additional effect from combining a particular job category with a particular solution.

```
fit5 <- clmm(utility ~ job_category + solution +
               (1 | participantID),
             data = combined, link = "logit", Hess = TRUE)
```

Compare model AICs

```
models <- list(
  "fit1"=fit1, # job_category * solution, sparser data
  "fit2"=fit2, # solution as random effect, sparser data
  "fit1b"=fit1b, # job_category * solution, denser data
  "fit2b"=fit2b, # solution as random effect, denser data
  "fit3"=fit3, # Null model: no job
  "fit4"=fit4, # Null model: no solution
  "fit5"=fit5 # Null model: no interaction
)
```

Let's check the AICs. You're not supposed to compare AICs for models fit to different data sets (models 1 and 2 are using the sparser data), but since I've only changed the job_category labels, but not the observations or the number of observations, I think this is ok.

```
sapply(models, function(x) round(AIC(x)))
```

```
 fit1  fit2 fit1b fit2b  fit3  fit4  fit5
 4826  4847  4802  4827  4836  5094  4822
```

The AICs for all the models are fairly similar, except #4, where solution isn't doesn't matter, and job_category alone influences the response. This makes sense. Model 5, where job category and solution have no interaction, does fairly well. Maybe job-solution interactions are subtle.

Model 1b looks the best. According to the internet, a delta AIC of more than ten is pretty substantial, and here we have a difference of 20 between the best and second-best.

Let's check the condition number of the Hessian. I don't really understand what this is, but the clmm2 tutorial says that high numbers, say larger than say 10^4 or 10^6, indicate poor fit.

```
sapply(models, function(x)
summary(x)$info["cond.H"]
)
```

```
Warning in summary.clmm(x): Variance-covariance matrix of the parameters is not
defined

$fit1.cond.H
[1] "NaN"

$fit2.cond.H
[1] "3.9e+02"

$fit1b.cond.H
[1] "2.8e+03"

$fit2b.cond.H
[1] "2.1e+02"

$fit3.cond.H
[1] "1.5e+02"

$fit4.cond.H
[1] "1.2e+02"

$fit5.cond.H
[1] "1.6e+02"
```

Okay, depending on my random seed, fit1 either gives a NaN or a high value here. All the other models look decent.

How else to evaluate the models? The `ordinal` package provides goodness-of-fit functions nominal_test and scale_test, but these only work on clm objects, not clmm objects. Bummer.

Let's use an anova to compare the two models that scored the best. Since they also happen to be nested, an anova works here.

```
anova(fit1b, fit5)
```

```
Likelihood ratio tests of cumulative link models:

      formula:                                                link: threshold:
fit5  utility ~ job_category + solution + (1 | participantID) logit flexible
fit1b utility ~ job_category * solution + (1 | participantID) logit flexible

      no.par    AIC  logLik LR.stat df Pr(>Chisq)
fit5      17 4822.2 -2394.1
fit1b     50 4802.0 -2351.0  86.199 33  1.221e-06 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

That's a very significant p-value. It looks like the interaction term is worth including.

Model 2b had a similar AIC as model 5. While I can't compare model 1b and model 2b with anova, since they're not nested, I can at least glance at the standard errors of the coefficients, which give me a sense of the precision of the coefficient estimates.

```
summary(fit1b$coefficients)
```

```
    Min.  1st Qu.   Median     Mean  3rd Qu.     Max.
-2.15349 -0.68400 -0.05181 -0.07111  0.77637  1.73451
```

```
summary(fit2b$coefficients)
```

```
    Min.  1st Qu.   Median     Mean  3rd Qu.     Max.
-1.38345  0.06018  0.50278  0.30830  0.91531  1.44669
```

Hm. So fit1b had the lowest AIC of all the models and is significantly better at explaining the variation than the equivalent minimal model without an interaction term. However, fit2b has smaller SEs than fit1b, where solution is a random effect. So I find myself in the annoying situation of having two g-o-f tests that don't agree.

Ehh, I guess I'll go with fit1b? The AIC was much better, and I think this model also intuitively makes the most sense. The SEs are a little concerning, but I think these are a less reliable indicator of g-o-f than the AIC.

```
summary(fit1b)
```

```
Cumulative Link Mixed Model fitted with the Laplace approximation

formula: utility ~ job_category * solution + (1 | participantID)
data:    combined

 link  threshold nobs logLik   AIC     niter        max.grad cond.H
 logit flexible  2602 -2350.98 4801.97 10197(40741) 1.22e-03 2.8e+03

Random effects:
 Groups        Name        Variance Std.Dev.
 participantID (Intercept) 2.097    1.448
Number of groups:  participantID 232

Coefficients:
                                                                    Estimate
job_categoryPostdocs and Staff Researchers                         -0.04736
job_categoryStudent                                                 1.66906
job_categoryNon-research Staff                                     -0.08350
solutionPublicity                                                  -0.66811
solutionContainerization                                           -1.06243
solutionDocumentation help                                         -1.21045
solutionA learning community                                       -1.56910
solutionEvent planning                                             -1.83275
solutionMentoring programs                                         -1.93070
solutionEducation                                                  -1.68608
solutionLegal support                                              -1.18188
solutionIndustry partnerships                                      -0.68400
solutionSustainability grants                                       1.73451
solutionHelp finding funding                                        1.08082
job_categoryPostdocs and Staff Researchers:solutionPublicity        0.78228
job_categoryStudent:solutionPublicity                              -0.49909
job_categoryNon-research Staff:solutionPublicity                   -0.74669
```

```
job_categoryPostdocs and Staff Researchers:solutionContainerization      -0.03388
job_categoryStudent:solutionContainerization                             -0.64866
job_categoryNon-research Staff:solutionContainerization                  -0.42332
job_categoryPostdocs and Staff Researchers:solutionDocumentation help     0.94435
job_categoryStudent:solutionDocumentation help                           -0.35912
job_categoryNon-research Staff:solutionDocumentation help                 0.53196
job_categoryPostdocs and Staff Researchers:solutionA learning community   1.02260
job_categoryStudent:solutionA learning community                         -0.10889
job_categoryNon-research Staff:solutionA learning community               1.44068
job_categoryPostdocs and Staff Researchers:solutionEvent planning         0.91886
job_categoryStudent:solutionEvent planning                               -0.22759
job_categoryNon-research Staff:solutionEvent planning                     0.35351
job_categoryPostdocs and Staff Researchers:solutionMentoring programs     1.04164
job_categoryStudent:solutionMentoring programs                            0.45731
job_categoryNon-research Staff:solutionMentoring programs                 1.24157
job_categoryPostdocs and Staff Researchers:solutionEducation              1.16078
job_categoryStudent:solutionEducation                                     0.19222
job_categoryNon-research Staff:solutionEducation                          1.12431
job_categoryPostdocs and Staff Researchers:solutionLegal support          0.54219
job_categoryStudent:solutionLegal support                                -0.35340
job_categoryNon-research Staff:solutionLegal support                      0.77637
job_categoryPostdocs and Staff Researchers:solutionIndustry partnerships  0.34019
job_categoryStudent:solutionIndustry partnerships                        -0.23308
job_categoryNon-research Staff:solutionIndustry partnerships             -0.46161
job_categoryPostdocs and Staff Researchers:solutionSustainability grants -0.05181
job_categoryStudent:solutionSustainability grants                         0.28703
job_categoryNon-research Staff:solutionSustainability grants             -1.21278
job_categoryPostdocs and Staff Researchers:solutionHelp finding funding  -0.02601
job_categoryStudent:solutionHelp finding funding                         -0.76619
job_categoryNon-research Staff:solutionHelp finding funding              -1.03639
                                                                         Std. Error
job_categoryPostdocs and Staff Researchers                                  0.49392
job_categoryStudent                                                         0.61824
job_categoryNon-research Staff                                              0.44158
solutionPublicity                                                           0.40568
solutionContainerization                                                    0.40387
solutionDocumentation help                                                  0.39881
solutionA learning community                                                0.38854
solutionEvent planning                                                      0.40245
solutionMentoring programs                                                  0.39813
solutionEducation                                                           0.39749
solutionLegal support                                                       0.39142
solutionIndustry partnerships                                               0.40142
```

solutionSustainability grants	0.44904
solutionHelp finding funding	0.42632
job_categoryPostdocs and Staff Researchers:solutionPublicity	0.57881
job_categoryStudent:solutionPublicity	0.72018
job_categoryNon-research Staff:solutionPublicity	0.52227
job_categoryPostdocs and Staff Researchers:solutionContainerization	0.57095
job_categoryStudent:solutionContainerization	0.71859
job_categoryNon-research Staff:solutionContainerization	0.52130
job_categoryPostdocs and Staff Researchers:solutionDocumentation help	0.57355
job_categoryStudent:solutionDocumentation help	0.70165
job_categoryNon-research Staff:solutionDocumentation help	0.50803
job_categoryPostdocs and Staff Researchers:solutionA learning community	0.55805
job_categoryStudent:solutionA learning community	0.69278
job_categoryNon-research Staff:solutionA learning community	0.49959
job_categoryPostdocs and Staff Researchers:solutionEvent planning	0.57443
job_categoryStudent:solutionEvent planning	0.71107
job_categoryNon-research Staff:solutionEvent planning	0.51964
job_categoryPostdocs and Staff Researchers:solutionMentoring programs	0.57321
job_categoryStudent:solutionMentoring programs	0.69274
job_categoryNon-research Staff:solutionMentoring programs	0.51079
job_categoryPostdocs and Staff Researchers:solutionEducation	0.57092
job_categoryStudent:solutionEducation	0.69830
job_categoryNon-research Staff:solutionEducation	0.51032
job_categoryPostdocs and Staff Researchers:solutionLegal support	0.56944
job_categoryStudent:solutionLegal support	0.69631
job_categoryNon-research Staff:solutionLegal support	0.50550
job_categoryPostdocs and Staff Researchers:solutionIndustry partnerships	0.58203
job_categoryStudent:solutionIndustry partnerships	0.71261
job_categoryNon-research Staff:solutionIndustry partnerships	0.52272
job_categoryPostdocs and Staff Researchers:solutionSustainability grants	0.63964
job_categoryStudent:solutionSustainability grants	0.99068
job_categoryNon-research Staff:solutionSustainability grants	0.56400
job_categoryPostdocs and Staff Researchers:solutionHelp finding funding	0.60587
job_categoryStudent:solutionHelp finding funding	0.77727
job_categoryNon-research Staff:solutionHelp finding funding	0.54190

	z value
job_categoryPostdocs and Staff Researchers	-0.096
job_categoryStudent	2.700
job_categoryNon-research Staff	-0.189
solutionPublicity	-1.647
solutionContainerization	-2.631
solutionDocumentation help	-3.035
solutionA learning community	-4.038

```
solutionEvent planning                                                  -4.554
solutionMentoring programs                                              -4.849
solutionEducation                                                       -4.242
solutionLegal support                                                   -3.019
solutionIndustry partnerships                                           -1.704
solutionSustainability grants                                            3.863
solutionHelp finding funding                                             2.535
job_categoryPostdocs and Staff Researchers:solutionPublicity             1.352
job_categoryStudent:solutionPublicity                                   -0.693
job_categoryNon-research Staff:solutionPublicity                        -1.430
job_categoryPostdocs and Staff Researchers:solutionContainerization     -0.059
job_categoryStudent:solutionContainerization                            -0.903
job_categoryNon-research Staff:solutionContainerization                 -0.812
job_categoryPostdocs and Staff Researchers:solutionDocumentation help    1.646
job_categoryStudent:solutionDocumentation help                          -0.512
job_categoryNon-research Staff:solutionDocumentation help                1.047
job_categoryPostdocs and Staff Researchers:solutionA learning community  1.832
job_categoryStudent:solutionA learning community                        -0.157
job_categoryNon-research Staff:solutionA learning community              2.884
job_categoryPostdocs and Staff Researchers:solutionEvent planning        1.600
job_categoryStudent:solutionEvent planning                              -0.320
job_categoryNon-research Staff:solutionEvent planning                    0.680
job_categoryPostdocs and Staff Researchers:solutionMentoring programs    1.817
job_categoryStudent:solutionMentoring programs                           0.660
job_categoryNon-research Staff:solutionMentoring programs                2.431
job_categoryPostdocs and Staff Researchers:solutionEducation             2.033
job_categoryStudent:solutionEducation                                    0.275
job_categoryNon-research Staff:solutionEducation                         2.203
job_categoryPostdocs and Staff Researchers:solutionLegal support         0.952
job_categoryStudent:solutionLegal support                               -0.508
job_categoryNon-research Staff:solutionLegal support                     1.536
job_categoryPostdocs and Staff Researchers:solutionIndustry partnerships 0.584
job_categoryStudent:solutionIndustry partnerships                       -0.327
job_categoryNon-research Staff:solutionIndustry partnerships            -0.883
job_categoryPostdocs and Staff Researchers:solutionSustainability grants -0.081
job_categoryStudent:solutionSustainability grants                        0.290
job_categoryNon-research Staff:solutionSustainability grants            -2.150
job_categoryPostdocs and Staff Researchers:solutionHelp finding funding  -0.043
job_categoryStudent:solutionHelp finding funding                         -0.986
job_categoryNon-research Staff:solutionHelp finding funding              -1.912
                                                                        Pr(>|z|)
job_categoryPostdocs and Staff Researchers                              0.923611
job_categoryStudent                                                     0.006941
```

job_categoryNon-research Staff	0.850023
solutionPublicity	0.099586
solutionContainerization	0.008524
solutionDocumentation help	0.002404
solutionA learning community	5.38e-05
solutionEvent planning	5.26e-06
solutionMentoring programs	1.24e-06
solutionEducation	2.22e-05
solutionLegal support	0.002532
solutionIndustry partnerships	0.088390
solutionSustainability grants	0.000112
solutionHelp finding funding	0.011237
job_categoryPostdocs and Staff Researchers:solutionPublicity	0.176523
job_categoryStudent:solutionPublicity	0.488306
job_categoryNon-research Staff:solutionPublicity	0.152797
job_categoryPostdocs and Staff Researchers:solutionContainerization	0.952681
job_categoryStudent:solutionContainerization	0.366692
job_categoryNon-research Staff:solutionContainerization	0.416773
job_categoryPostdocs and Staff Researchers:solutionDocumentation help	0.099662
job_categoryStudent:solutionDocumentation help	0.608771
job_categoryNon-research Staff:solutionDocumentation help	0.295052
job_categoryPostdocs and Staff Researchers:solutionA learning community	0.066882
job_categoryStudent:solutionA learning community	0.875099
job_categoryNon-research Staff:solutionA learning community	0.003930
job_categoryPostdocs and Staff Researchers:solutionEvent planning	0.109686
job_categoryStudent:solutionEvent planning	0.748914
job_categoryNon-research Staff:solutionEvent planning	0.496319
job_categoryPostdocs and Staff Researchers:solutionMentoring programs	0.069187
job_categoryStudent:solutionMentoring programs	0.509161
job_categoryNon-research Staff:solutionMentoring programs	0.015071
job_categoryPostdocs and Staff Researchers:solutionEducation	0.042035
job_categoryStudent:solutionEducation	0.783112
job_categoryNon-research Staff:solutionEducation	0.027585
job_categoryPostdocs and Staff Researchers:solutionLegal support	0.341017
job_categoryStudent:solutionLegal support	0.611776
job_categoryNon-research Staff:solutionLegal support	0.124579
job_categoryPostdocs and Staff Researchers:solutionIndustry partnerships	0.558895
job_categoryStudent:solutionIndustry partnerships	0.743610
job_categoryNon-research Staff:solutionIndustry partnerships	0.377183
job_categoryPostdocs and Staff Researchers:solutionSustainability grants	0.935446
job_categoryStudent:solutionSustainability grants	0.772020
job_categoryNon-research Staff:solutionSustainability grants	0.031531
job_categoryPostdocs and Staff Researchers:solutionHelp finding funding	0.965754

```
job_categoryStudent:solutionHelp finding funding                          0.324256
job_categoryNon-research Staff:solutionHelp finding funding               0.055813

job_categoryPostdocs and Staff Researchers
job_categoryStudent                                                       **
job_categoryNon-research Staff
solutionPublicity                                                         .
solutionContainerization                                                  **
solutionDocumentation help                                                **
solutionA learning community                                              ***
solutionEvent planning                                                    ***
solutionMentoring programs                                                ***
solutionEducation                                                         ***
solutionLegal support                                                     **
solutionIndustry partnerships                                             .
solutionSustainability grants                                             ***
solutionHelp finding funding                                              *
job_categoryPostdocs and Staff Researchers:solutionPublicity
job_categoryStudent:solutionPublicity
job_categoryNon-research Staff:solutionPublicity
job_categoryPostdocs and Staff Researchers:solutionContainerization
job_categoryStudent:solutionContainerization
job_categoryNon-research Staff:solutionContainerization
job_categoryPostdocs and Staff Researchers:solutionDocumentation help     .
job_categoryStudent:solutionDocumentation help
job_categoryNon-research Staff:solutionDocumentation help
job_categoryPostdocs and Staff Researchers:solutionA learning community   .
job_categoryStudent:solutionA learning community
job_categoryNon-research Staff:solutionA learning community               **
job_categoryPostdocs and Staff Researchers:solutionEvent planning
job_categoryStudent:solutionEvent planning
job_categoryNon-research Staff:solutionEvent planning
job_categoryPostdocs and Staff Researchers:solutionMentoring programs     .
job_categoryStudent:solutionMentoring programs
job_categoryNon-research Staff:solutionMentoring programs                 *
job_categoryPostdocs and Staff Researchers:solutionEducation              *
job_categoryStudent:solutionEducation
job_categoryNon-research Staff:solutionEducation                          *
job_categoryPostdocs and Staff Researchers:solutionLegal support
job_categoryStudent:solutionLegal support
job_categoryNon-research Staff:solutionLegal support
job_categoryPostdocs and Staff Researchers:solutionIndustry partnerships
job_categoryStudent:solutionIndustry partnerships
```

```
job_categoryNon-research Staff:solutionIndustry partnerships
job_categoryPostdocs and Staff Researchers:solutionSustainability grants
job_categoryStudent:solutionSustainability grants
job_categoryNon-research Staff:solutionSustainability grants             *
job_categoryPostdocs and Staff Researchers:solutionHelp finding funding
job_categoryStudent:solutionHelp finding funding
job_categoryNon-research Staff:solutionHelp finding funding              .
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Threshold coefficients:
                        Estimate Std. Error z value
Not very useful|Useful  -2.1535     0.3461  -6.223
Useful|Very useful       0.1717     0.3425   0.501
```

This is a lot to interpret. I'll do my best. First, let's just at the main effects, i.e. the effects of job category and solution. In the summary above, each job category is compared to Faculty, our job reference level, for the solution Computing environments, our solution reference level. The "Estimate" for job_categoryStudent is 1.66906, which indicates students have odds of e^1.67=5.3 of rating that solution at least one category higher than faculty.

The solution Publicity has a coefficient of -0.66811, indicating that faculty have odds of e^0.67=2 of rating Publicity one level lower than Computing Environments.

The interactions, e.g. job_categoryPostdocs and Staff Researchers:solutionPublicity, indicate extra log-odds only for that specific job × solution pair beyond the two main effects. So in that example, postdocs and staff researchers have an extra log-odds of 0.78228 (odds of e^0.78228=2.186) of giving publicity a higher rating than computing environments, as compared to faculty.

Interestingly, none of our p-values are super significant for interactions, meaning none of the interactions are really significant on their own. The most significant effects (three asterisks) were all solutions: A learning community (-), Event planning (-), Mentoring programs (-), Education (-), Sustainability grants (+).

So, faculty had significantly higher odds of selecting sustainability grants than computing environments; significantly lower odds of selections education, mentoring, etc. than computing environments.

One job category did get two asterisks:
Coefficients:
Estimate Std. Error z value Pr(>|z|)
job_categoryStudent 1.66906 0.61824 2.700 0.006941 **

So, students had somewhat significantly higher odds of selecting computing environments than faculty.

So, painting this with a really broad brush, we might say that responses vary across solutions more than they vary across job categories, at least in the sense that there are more significant differences within faculty than between faculty vs. students.

Since coefficients are hard to interpret, let's get contrasts using the emmeans package. The contrast essentially indicates the difference between two factor's effect sizes. So instead of comparing the coefficients by eye, we can just calculate contrasts that tell us how big the difference is, for each pair of coefficients.

```
# In the future, we may want to get results on a different scale from the
# log odds scale. By default, "mode" is "latent", but we can change this
# to e.g. mode="prob", which will give the probabilities of each class of
# ordinal response. I haven't implemented this because I don't fully
# understand it--need to read more. See, for example, the "gotcha" with
# mode="prob" described here:
# https://stats.stackexchange.com/questions/615711/why-are-emmip-response-y-axis-numbers-not-
emm <- emmeans(fit1b, ~ job_category * solution)
by_job <- summary(
  pairs(emm, by = "job_category"),
  infer = TRUE # infer CIs
)

by_job
```

```
job_category = Faculty:
 contrast                                        estimate    SE  df asymp.LCL
 Computing environments - Publicity                0.6681 0.406 Inf   -0.6577
 Computing environments - Containerization         1.0624 0.404 Inf   -0.2574
 Computing environments - Documentation help       1.2105 0.399 Inf   -0.0929
 Computing environments - A learning community     1.5691 0.389 Inf    0.2993
 Computing environments - Event planning           1.8328 0.402 Inf    0.5175
 Computing environments - Mentoring programs       1.9307 0.398 Inf    0.6296
 Computing environments - Education                1.6861 0.397 Inf    0.3871
 Computing environments - Legal support            1.1819 0.391 Inf   -0.0973
 Computing environments - Industry partnerships    0.6840 0.401 Inf   -0.6278
 Computing environments - Sustainability grants   -1.7345 0.449 Inf   -3.2020
 Computing environments - Help finding funding    -1.0808 0.426 Inf   -2.4740
 Publicity - Containerization                      0.3943 0.406 Inf   -0.9324
 Publicity - Documentation help                    0.5423 0.401 Inf   -0.7673
 Publicity - A learning community                  0.9010 0.391 Inf   -0.3783
```

Publicity - Event planning	1.1646	0.404	Inf	-0.1571
Publicity - Mentoring programs	1.2626	0.401	Inf	-0.0467
Publicity - Education	1.0180	0.401	Inf	-0.2909
Publicity - Legal support	0.5138	0.394	Inf	-0.7726
Publicity - Industry partnerships	0.0159	0.405	Inf	-1.3082
Publicity - Sustainability grants	-2.4026	0.454	Inf	-3.8850
Publicity - Help finding funding	-1.7489	0.431	Inf	-3.1569
Containerization - Documentation help	0.1480	0.399	Inf	-1.1544
Containerization - A learning community	0.5067	0.389	Inf	-0.7641
Containerization - Event planning	0.7703	0.401	Inf	-0.5416
Containerization - Mentoring programs	0.8683	0.398	Inf	-0.4309
Containerization - Education	0.6237	0.397	Inf	-0.6751
Containerization - Legal support	0.1195	0.391	Inf	-1.1573
Containerization - Industry partnerships	-0.3784	0.403	Inf	-1.6941
Containerization - Sustainability grants	-2.7969	0.453	Inf	-4.2782
Containerization - Help finding funding	-2.1432	0.430	Inf	-3.5472
Documentation help - A learning community	0.3587	0.383	Inf	-0.8935
Documentation help - Event planning	0.6223	0.396	Inf	-0.6718
Documentation help - Mentoring programs	0.7202	0.392	Inf	-0.5620
Documentation help - Education	0.4756	0.392	Inf	-0.8067
Documentation help - Legal support	-0.0286	0.386	Inf	-1.2888
Documentation help - Industry partnerships	-0.5265	0.398	Inf	-1.8259
Documentation help - Sustainability grants	-2.9450	0.449	Inf	-4.4130
Documentation help - Help finding funding	-2.2913	0.425	Inf	-3.6807
A learning community - Event planning	0.2636	0.386	Inf	-0.9966
A learning community - Mentoring programs	0.3616	0.381	Inf	-0.8848
A learning community - Education	0.1170	0.381	Inf	-1.1280
A learning community - Legal support	-0.3872	0.376	Inf	-1.6146
A learning community - Industry partnerships	-0.8851	0.388	Inf	-2.1520
A learning community - Sustainability grants	-3.3036	0.441	Inf	-4.7453
A learning community - Help finding funding	-2.6499	0.417	Inf	-4.0129
Event planning - Mentoring programs	0.0979	0.393	Inf	-1.1879
Event planning - Education	-0.1467	0.394	Inf	-1.4349
Event planning - Legal support	-0.6509	0.389	Inf	-1.9216
Event planning - Industry partnerships	-1.1488	0.400	Inf	-2.4573
Event planning - Sustainability grants	-3.5673	0.455	Inf	-5.0528
Event planning - Help finding funding	-2.9136	0.430	Inf	-4.3174
Mentoring programs - Education	-0.2446	0.389	Inf	-1.5173
Mentoring programs - Legal support	-0.7488	0.384	Inf	-2.0053
Mentoring programs - Industry partnerships	-1.2467	0.396	Inf	-2.5422
Mentoring programs - Sustainability grants	-3.6652	0.451	Inf	-5.1377
Mentoring programs - Help finding funding	-3.0115	0.426	Inf	-4.4025
Education - Legal support	-0.5042	0.384	Inf	-1.7605

```
Education - Industry partnerships                -1.0021 0.396 Inf   -2.2970
Education - Sustainability grants                -3.4206 0.449 Inf   -4.8885
Education - Help finding funding                 -2.7669 0.426 Inf   -4.1579
Legal support - Industry partnerships            -0.4979 0.390 Inf   -1.7718
Legal support - Sustainability grants            -2.9164 0.443 Inf   -4.3647
Legal support - Help finding funding             -2.2627 0.418 Inf   -3.6293
Industry partnerships - Sustainability grants    -2.4185 0.451 Inf   -3.8928
Industry partnerships - Help finding funding     -1.7648 0.427 Inf   -3.1603
Sustainability grants - Help finding funding      0.6537 0.470 Inf   -0.8810
asymp.UCL z.ratio p.value
  1.99388   1.647  0.8916
  2.38229   2.631  0.2623
  2.51378   3.035  0.0985
  2.83887   4.038  0.0031
  3.14797   4.554  0.0003
  3.23179   4.849  0.0001
  2.98509   4.242  0.0013
  2.46104   3.019  0.1028
  1.99583   1.704  0.8669
 -0.26705  -3.863  0.0063
  0.31239  -2.535  0.3177
  1.72106   0.971  0.9983
  1.85201   1.353  0.9719
  2.18026   2.302  0.4752
  2.48636   2.880  0.1481
  2.57192   3.151  0.0709
  2.32682   2.542  0.3137
  1.80019   1.305  0.9787
  1.34002   0.039  1.0000
 -0.92019  -5.297  <.0001
 -0.34099  -4.059  0.0029
  1.45048   0.371  1.0000
  1.77741   1.303  0.9789
  2.08227   1.919  0.7476
  2.16745   2.184  0.5613
  1.92237   1.569  0.9202
  1.39617   0.306  1.0000
  0.93727  -0.940  0.9987
 -1.31564  -6.171  <.0001
 -0.73930  -4.989  <.0001
  1.61076   0.936  0.9988
  1.91639   1.572  0.9195
  2.00251   1.836  0.7984
```

```
   1.75798   1.212  0.9882
   1.23170  -0.074  1.0000
   0.77301  -1.324  0.9762
  -1.47689  -6.556  <.0001
  -0.90183  -5.389  <.0001
   1.52386   0.684  0.9999
   1.60798   0.948  0.9986
   1.36196   0.307  1.0000
   0.84014  -1.031  0.9970
   0.38177  -2.283  0.4886
  -1.86189  -7.488  <.0001
  -1.28693  -6.354  <.0001
   1.38378   0.249  1.0000
   1.14160  -0.372  1.0000
   0.61983  -1.674  0.8803
   0.15980  -2.869  0.1521
  -2.08171  -7.848  <.0001
  -1.50972  -6.782  <.0001
   1.02809  -0.628  1.0000
   0.50767  -1.948  0.7289
   0.04875  -3.145  0.0723
  -2.19270  -8.134  <.0001
  -1.62049  -7.075  <.0001
   0.75208  -1.312  0.9779
   0.29286  -2.529  0.3216
  -1.95267  -7.615  <.0001
  -1.37594  -6.501  <.0001
   0.77600  -1.277  0.9820
  -1.46806  -6.581  <.0001
  -0.89607  -5.411  <.0001
  -0.94419  -5.361  <.0001
  -0.36934  -4.133  0.0021
   2.18833   1.392  0.9653

job_category = Postdocs and Staff Researchers:
 contrast                                          estimate    SE  df asymp.LCL
 Computing environments - Publicity                 -0.1142 0.413 Inf   -1.4630
 Computing environments - Containerization           1.0963 0.405 Inf   -0.2261
 Computing environments - Documentation help         0.2661 0.412 Inf   -1.0819
 Computing environments - A learning community       0.5465 0.401 Inf   -0.7647
 Computing environments - Event planning             0.9139 0.411 Inf   -0.4304
 Computing environments - Mentoring programs         0.8891 0.414 Inf   -0.4635
 Computing environments - Education                  0.5253 0.411 Inf   -0.8162
```

Computing environments - Legal support	0.6397	0.414	Inf	-0.7143
Computing environments - Industry partnerships	0.3438	0.422	Inf	-1.0342
Computing environments - Sustainability grants	-1.6827	0.457	Inf	-3.1760
Computing environments - Help finding funding	-1.0548	0.431	Inf	-2.4642
Publicity - Containerization	1.2105	0.398	Inf	-0.0901
Publicity - Documentation help	0.3803	0.405	Inf	-0.9441
Publicity - A learning community	0.6607	0.394	Inf	-0.6272
Publicity - Event planning	1.0281	0.404	Inf	-0.2932
Publicity - Mentoring programs	1.0032	0.407	Inf	-0.3263
Publicity - Education	0.6395	0.403	Inf	-0.6779
Publicity - Legal support	0.7539	0.407	Inf	-0.5760
Publicity - Industry partnerships	0.4580	0.414	Inf	-0.8965
Publicity - Sustainability grants	-1.5685	0.451	Inf	-3.0414
Publicity - Help finding funding	-0.9406	0.424	Inf	-2.3271
Containerization - Documentation help	-0.8302	0.397	Inf	-2.1278
Containerization - A learning community	-0.5498	0.385	Inf	-1.8064
Containerization - Event planning	-0.1824	0.394	Inf	-1.4698
Containerization - Mentoring programs	-0.2073	0.398	Inf	-1.5070
Containerization - Education	-0.5710	0.394	Inf	-1.8591
Containerization - Legal support	-0.4566	0.398	Inf	-1.7575
Containerization - Industry partnerships	-0.7525	0.406	Inf	-2.0807
Containerization - Sustainability grants	-2.7790	0.446	Inf	-4.2359
Containerization - Help finding funding	-2.1511	0.419	Inf	-3.5201
Documentation help - A learning community	0.2804	0.394	Inf	-1.0061
Documentation help - Event planning	0.6478	0.403	Inf	-0.6701
Documentation help - Mentoring programs	0.6230	0.406	Inf	-0.7036
Documentation help - Education	0.2592	0.403	Inf	-1.0578
Documentation help - Legal support	0.3736	0.407	Inf	-0.9555
Documentation help - Industry partnerships	0.0777	0.414	Inf	-1.2755
Documentation help - Sustainability grants	-1.9488	0.452	Inf	-3.4250
Documentation help - Help finding funding	-1.3209	0.425	Inf	-2.7105
A learning community - Event planning	0.3674	0.391	Inf	-0.9117
A learning community - Mentoring programs	0.3426	0.394	Inf	-0.9454
A learning community - Education	-0.0212	0.391	Inf	-1.2986
A learning community - Legal support	0.0932	0.395	Inf	-1.1971
A learning community - Industry partnerships	-0.2027	0.403	Inf	-1.5203
A learning community - Sustainability grants	-2.2292	0.442	Inf	-3.6743
A learning community - Help finding funding	-1.6013	0.415	Inf	-2.9574
Event planning - Mentoring programs	-0.0248	0.404	Inf	-1.3444
Event planning - Education	-0.3886	0.401	Inf	-1.6983
Event planning - Legal support	-0.2742	0.404	Inf	-1.5961
Event planning - Industry partnerships	-0.5701	0.413	Inf	-1.9197
Event planning - Sustainability grants	-2.5966	0.452	Inf	-4.0723

```
Event planning - Help finding funding           -1.9687 0.425 Inf   -3.3578
Mentoring programs - Education                  -0.3638 0.404 Inf   -1.6826
Mentoring programs - Legal support              -0.2494 0.408 Inf   -1.5820
Mentoring programs - Industry partnerships      -0.5452 0.415 Inf   -1.9026
Mentoring programs - Sustainability grants      -2.5718 0.454 Inf   -4.0560
Mentoring programs - Help finding funding       -1.9439 0.427 Inf   -3.3400
Education - Legal support                        0.1144 0.405 Inf   -1.2080
Education - Industry partnerships               -0.1815 0.413 Inf   -1.5309
Education - Sustainability grants               -2.2080 0.451 Inf   -3.6806
Education - Help finding funding                -1.5801 0.424 Inf   -2.9659
Legal support - Industry partnerships           -0.2959 0.415 Inf   -1.6522
Legal support - Sustainability grants           -2.3224 0.454 Inf   -3.8052
Legal support - Help finding funding            -1.6945 0.427 Inf   -3.0914
Industry partnerships - Sustainability grants   -2.0265 0.459 Inf   -3.5270
Industry partnerships - Help finding funding    -1.3986 0.433 Inf   -2.8134
Sustainability grants - Help finding funding     0.6279 0.465 Inf   -0.8926
asymp.UCL z.ratio p.value
  1.23465  -0.277  1.0000
  2.41869   2.709  0.2214
  1.61409   0.645  1.0000
  1.85772   1.362  0.9705
  2.25821   2.222  0.5336
  2.24157   2.148  0.5877
  1.86684   1.280  0.9817
  1.99370   1.544  0.9283
  1.72186   0.815  0.9997
 -0.18936  -3.682  0.0124
  0.35457  -2.446  0.3749
  2.51112   3.041  0.0968
  1.70463   0.938  0.9987
  1.94858   1.676  0.8792
  2.34938   2.543  0.3131
  2.33273   2.466  0.3616
  1.95691   1.586  0.9144
  2.08368   1.853  0.7885
  1.81244   1.105  0.9945
 -0.09567  -3.480  0.0252
  0.44583  -2.217  0.5370
  0.46735  -2.091  0.6294
  0.70682  -1.430  0.9579
  1.10499  -0.463  1.0000
  1.09248  -0.521  1.0000
  0.71712  -1.449  0.9537
```

```
  0.84430  -1.147  0.9925
  0.57566  -1.852  0.7891
 -1.32207  -6.233  <.0001
 -0.78216  -5.135  <.0001
  1.56693   0.712  0.9999
  1.96566   1.606  0.9073
  1.94950   1.535  0.9312
  1.57620   0.643  1.0000
  1.70266   0.919  0.9990
  1.43091   0.188  1.0000
 -0.47256  -4.314  0.0010
  0.06867  -3.106  0.0807
  1.64648   0.939  0.9987
  1.63053   0.869  0.9994
  1.25625  -0.054  1.0000
  1.38343   0.236  1.0000
  1.11492  -0.503  1.0000
 -0.78411  -5.041  <.0001
 -0.24519  -3.859  0.0064
  1.29476  -0.062  1.0000
  0.92116  -0.970  0.9983
  1.04765  -0.678  0.9999
  0.77950  -1.380  0.9674
 -1.12094  -5.750  <.0001
 -0.57963  -4.632  0.0002
  0.95510  -0.901  0.9991
  1.08327  -0.612  1.0000
  0.81209  -1.313  0.9777
 -1.08750  -5.662  <.0001
 -0.54772  -4.550  0.0003
  1.43676   0.283  1.0000
  1.16790  -0.440  1.0000
 -0.73538  -4.900  0.0001
 -0.19433  -3.726  0.0106
  1.06049  -0.713  0.9999
 -0.83960  -5.118  <.0001
 -0.29759  -3.964  0.0042
 -0.52600  -4.414  0.0006
  0.01619  -3.231  0.0561
  2.14835   1.350  0.9725

job_category = Student:
 contrast                                          estimate    SE  df asymp.LCL
```

Computing environments - Publicity	1.1672	0.595	Inf	-0.7785
Computing environments - Containerization	1.7111	0.595	Inf	-0.2349
Computing environments - Documentation help	1.5696	0.578	Inf	-0.3205
Computing environments - A learning community	1.6780	0.575	Inf	-0.2014
Computing environments - Event planning	2.0603	0.588	Inf	0.1371
Computing environments - Mentoring programs	1.4734	0.569	Inf	-0.3847
Computing environments - Education	1.4939	0.576	Inf	-0.3872
Computing environments - Legal support	1.5353	0.577	Inf	-0.3501
Computing environments - Industry partnerships	0.9171	0.589	Inf	-1.0078
Computing environments - Sustainability grants	-2.0215	0.883	Inf	-4.9085
Computing environments - Help finding funding	-0.3146	0.650	Inf	-2.4381
Publicity - Containerization	0.5439	0.558	Inf	-1.2806
Publicity - Documentation help	0.4024	0.544	Inf	-1.3757
Publicity - A learning community	0.5108	0.540	Inf	-1.2554
Publicity - Event planning	0.8932	0.553	Inf	-0.9130
Publicity - Mentoring programs	0.3062	0.534	Inf	-1.4379
Publicity - Education	0.3267	0.541	Inf	-1.4404
Publicity - Legal support	0.3681	0.539	Inf	-1.3943
Publicity - Industry partnerships	-0.2501	0.554	Inf	-2.0600
Publicity - Sustainability grants	-3.1887	0.864	Inf	-6.0114
Publicity - Help finding funding	-1.4818	0.621	Inf	-3.5124
Containerization - Documentation help	-0.1415	0.542	Inf	-1.9135
Containerization - A learning community	-0.0331	0.539	Inf	-1.7933
Containerization - Event planning	0.3493	0.549	Inf	-1.4456
Containerization - Mentoring programs	-0.2377	0.532	Inf	-1.9754
Containerization - Education	-0.2172	0.540	Inf	-1.9820
Containerization - Legal support	-0.1758	0.539	Inf	-1.9389
Containerization - Industry partnerships	-0.7940	0.554	Inf	-2.6059
Containerization - Sustainability grants	-3.7326	0.865	Inf	-6.5591
Containerization - Help finding funding	-2.0257	0.621	Inf	-4.0543
Documentation help - A learning community	0.1084	0.521	Inf	-1.5942
Documentation help - Event planning	0.4908	0.534	Inf	-1.2546
Documentation help - Mentoring programs	-0.0962	0.514	Inf	-1.7762
Documentation help - Education	-0.0757	0.522	Inf	-1.7807
Documentation help - Legal support	-0.0343	0.523	Inf	-1.7441
Documentation help - Industry partnerships	-0.6525	0.538	Inf	-2.4093
Documentation help - Sustainability grants	-3.5911	0.853	Inf	-6.3793
Documentation help - Help finding funding	-1.8842	0.607	Inf	-3.8665
A learning community - Event planning	0.3824	0.530	Inf	-1.3503
A learning community - Mentoring programs	-0.2046	0.510	Inf	-1.8720
A learning community - Education	-0.1841	0.518	Inf	-1.8773
A learning community - Legal support	-0.1427	0.519	Inf	-1.8402
A learning community - Industry partnerships	-0.7609	0.534	Inf	-2.5051

```
A learning community - Sustainability grants    -3.6995 0.851 Inf   -6.4817
A learning community - Help finding funding     -1.9926 0.603 Inf   -3.9640
Event planning - Mentoring programs             -0.5870 0.524 Inf   -2.2997
Event planning - Education                      -0.5665 0.531 Inf   -2.3032
Event planning - Legal support                  -0.5251 0.533 Inf   -2.2681
Event planning - Industry partnerships          -1.1433 0.547 Inf   -2.9312
Event planning - Sustainability grants          -4.0819 0.861 Inf   -6.8942
Event planning - Help finding funding           -2.3750 0.616 Inf   -4.3880
Mentoring programs - Education                   0.0205 0.511 Inf   -1.6505
Mentoring programs - Legal support               0.0619 0.513 Inf   -1.6137
Mentoring programs - Industry partnerships      -0.5563 0.527 Inf   -2.2797
Mentoring programs - Sustainability grants      -3.4949 0.846 Inf   -6.2610
Mentoring programs - Help finding funding       -1.7880 0.597 Inf   -3.7386
Education - Legal support                        0.0414 0.520 Inf   -1.6592
Education - Industry partnerships               -0.5768 0.534 Inf   -2.3235
Education - Sustainability grants               -3.5154 0.851 Inf   -6.2966
Education - Help finding funding                -1.8085 0.603 Inf   -3.7789
Legal support - Industry partnerships           -0.6182 0.535 Inf   -2.3670
Legal support - Sustainability grants           -3.5568 0.851 Inf   -6.3383
Legal support - Help finding funding            -1.8499 0.604 Inf   -3.8224
Industry partnerships - Sustainability grants   -2.9386 0.859 Inf   -5.7472
Industry partnerships - Help finding funding    -1.2317 0.616 Inf   -3.2446
Sustainability grants - Help finding funding     1.7069 0.899 Inf   -1.2325
asymp.UCL z.ratio p.value
  3.11286   1.960  0.7204
  3.65709   2.874  0.1503
  3.45967   2.714  0.2192
  3.55741   2.918  0.1345
  3.98356   3.501  0.0235
  3.33147   2.591  0.2843
  3.37488   2.595  0.2821
  3.42070   2.661  0.2459
  2.84199   1.557  0.9242
  0.86547  -2.288  0.4849
  1.80887  -0.484  1.0000
  2.36841   0.974  0.9982
  2.18043   0.740  0.9999
  2.27699   0.945  0.9986
  2.69929   1.616  0.9037
  2.05027   0.574  1.0000
  2.09371   0.604  1.0000
  2.13051   0.683  0.9999
  1.55977  -0.452  1.0000
```

```
-0.36610  -3.692  0.0120
 0.54876  -2.385  0.4163
 1.63042  -0.261  1.0000
 1.72715  -0.061  1.0000
 2.14407   0.636  1.0000
 1.49997  -0.447  1.0000
 1.54752  -0.402  1.0000
 1.58724  -0.326  1.0000
 1.01785  -1.432  0.9574
-0.90615  -4.316  0.0010
 0.00283  -3.263  0.0507
 1.81107   0.208  1.0000
 2.23619   0.919  0.9990
 1.58385  -0.187  1.0000
 1.62927  -0.145  1.0000
 1.67553  -0.066  1.0000
 1.10425  -1.214  0.9880
-0.80288  -4.209  0.0015
 0.09807  -3.106  0.0808
 2.11496   0.721  0.9999
 1.46276  -0.401  1.0000
 1.50903  -0.355  1.0000
 1.55480  -0.275  1.0000
 0.98326  -1.426  0.9587
-0.91735  -4.346  0.0008
-0.02126  -3.303  0.0448
 1.12574  -1.120  0.9939
 1.17025  -1.066  0.9960
 1.21799  -0.984  0.9980
 0.64470  -2.090  0.6303
-1.26961  -4.743  0.0001
-0.36200  -3.856  0.0065
 1.69147   0.040  1.0000
 1.73744   0.121  1.0000
 1.16703  -1.055  0.9964
-0.72882  -4.129  0.0022
 0.16259  -2.996  0.1097
 1.74200   0.080  1.0000
 1.16994  -1.079  0.9956
-0.73424  -4.131  0.0021
 0.16195  -2.999  0.1085
 1.13058  -1.155  0.9920
-0.77531  -4.179  0.0017
```

```
   0.12256  -3.065  0.0907
  -0.13005  -3.419  0.0309
   0.78121  -2.000  0.6939
   4.64631   1.898  0.7610

job_category = Non-research Staff:
 contrast                                        estimate    SE  df asymp.LCL
 Computing environments - Publicity                1.4148 0.330 Inf    0.3367
 Computing environments - Containerization         1.4857 0.331 Inf    0.4030
 Computing environments - Documentation help       0.6785 0.316 Inf   -0.3531
 Computing environments - A learning community     0.1284 0.314 Inf   -0.8983
 Computing environments - Event planning           1.4792 0.332 Inf    0.3956
 Computing environments - Mentoring programs       0.6891 0.322 Inf   -0.3615
 Computing environments - Education                0.5618 0.321 Inf   -0.4877
 Computing environments - Legal support            0.4055 0.320 Inf   -0.6415
 Computing environments - Industry partnerships    1.1456 0.336 Inf    0.0490
 Computing environments - Sustainability grants   -0.5217 0.342 Inf   -1.6391
 Computing environments - Help finding funding    -0.0444 0.334 Inf   -1.1376
 Publicity - Containerization                      0.0709 0.331 Inf   -1.0111
 Publicity - Documentation help                   -0.7363 0.318 Inf   -1.7746
 Publicity - A learning community                 -1.2864 0.319 Inf   -2.3278
 Publicity - Event planning                        0.0644 0.331 Inf   -1.0170
 Publicity - Mentoring programs                   -0.7257 0.323 Inf   -1.7827
 Publicity - Education                            -0.8530 0.324 Inf   -1.9112
 Publicity - Legal support                        -1.0093 0.323 Inf   -2.0646
 Publicity - Industry partnerships                -0.2692 0.335 Inf   -1.3652
 Publicity - Sustainability grants                -1.9365 0.345 Inf   -3.0648
 Publicity - Help finding funding                 -1.4592 0.337 Inf   -2.5610
 Containerization - Documentation help            -0.8073 0.320 Inf   -1.8515
 Containerization - A learning community          -1.3573 0.320 Inf   -2.4028
 Containerization - Event planning                -0.0065 0.333 Inf   -1.0935
 Containerization - Mentoring programs            -0.7966 0.325 Inf   -1.8601
 Containerization - Education                     -0.9240 0.325 Inf   -1.9867
 Containerization - Legal support                 -1.0802 0.325 Inf   -2.1410
 Containerization - Industry partnerships         -0.3401 0.338 Inf   -1.4443
 Containerization - Sustainability grants         -2.0075 0.348 Inf   -3.1438
 Containerization - Help finding funding          -1.5302 0.340 Inf   -2.6399
 Documentation help - A learning community        -0.5501 0.303 Inf   -1.5415
 Documentation help - Event planning               0.8008 0.319 Inf   -0.2415
 Documentation help - Mentoring programs           0.0106 0.310 Inf   -1.0033
 Documentation help - Education                   -0.1167 0.310 Inf   -1.1284
 Documentation help - Legal support               -0.2730 0.309 Inf   -1.2814
 Documentation help - Industry partnerships        0.4671 0.324 Inf   -0.5926
```

```
Documentation help - Sustainability grants      -1.2002 0.332 Inf   -2.2844
Documentation help - Help finding funding       -0.7229 0.324 Inf   -1.7816
A learning community - Event planning            1.3508 0.319 Inf    0.3073
A learning community - Mentoring programs        0.5607 0.310 Inf   -0.4514
A learning community - Education                 0.4334 0.309 Inf   -0.5766
A learning community - Legal support             0.2771 0.307 Inf   -0.7271
A learning community - Industry partnerships     1.0172 0.324 Inf   -0.0432
A learning community - Sustainability grants    -0.6501 0.330 Inf   -1.7290
A learning community - Help finding funding     -0.1729 0.323 Inf   -1.2286
Event planning - Mentoring programs             -0.7901 0.325 Inf   -1.8506
Event planning - Education                      -0.9175 0.325 Inf   -1.9789
Event planning - Legal support                  -1.0737 0.324 Inf   -2.1313
Event planning - Industry partnerships          -0.3336 0.337 Inf   -1.4345
Event planning - Sustainability grants          -2.0010 0.346 Inf   -3.1329
Event planning - Help finding funding           -1.5237 0.339 Inf   -2.6301
Mentoring programs - Education                  -0.1274 0.316 Inf   -1.1599
Mentoring programs - Legal support              -0.2836 0.315 Inf   -1.3137
Mentoring programs - Industry partnerships       0.4565 0.329 Inf   -0.6186
Mentoring programs - Sustainability grants      -1.2109 0.338 Inf   -2.3142
Mentoring programs - Help finding funding       -0.7336 0.330 Inf   -1.8110
Education - Legal support                       -0.1563 0.314 Inf   -1.1830
Education - Industry partnerships                0.5838 0.330 Inf   -0.4931
Education - Sustainability grants               -1.0835 0.337 Inf   -2.1850
Education - Help finding funding                -0.6062 0.329 Inf   -1.6830
Legal support - Industry partnerships            0.7401 0.329 Inf   -0.3356
Legal support - Sustainability grants           -0.9272 0.335 Inf   -2.0213
Legal support - Help finding funding            -0.4499 0.328 Inf   -1.5204
Industry partnerships - Sustainability grants   -1.6673 0.350 Inf   -2.8128
Industry partnerships - Help finding funding    -1.1900 0.342 Inf   -2.3089
Sustainability grants - Help finding funding     0.4773 0.347 Inf   -0.6551
asymp.UCL z.ratio p.value
  2.49290   4.289  0.0011
  2.56850   4.484  0.0005
  1.71011   2.149  0.5868
  1.15519   0.409  1.0000
  2.56291   4.461  0.0005
  1.73980   2.143  0.5911
  1.61123   1.749  0.8451
  1.45252   1.266  0.9832
  2.24218   3.414  0.0314
  0.59561  -1.526  0.9337
  1.04871  -0.133  1.0000
  1.15302   0.214  1.0000
```

```
 0.30197  -2.318  0.4638
-0.24500  -4.037  0.0032
 1.14593   0.195  1.0000
 0.33135  -2.244  0.5176
 0.20515  -2.634  0.2602
 0.04603  -3.125  0.0765
 0.82685  -0.803  0.9997
-0.80823  -5.609  <.0001
-0.35749  -4.328  0.0009
 0.23702  -2.526  0.3232
-0.31180  -4.243  0.0013
 1.08047  -0.020  1.0000
 0.26691  -2.448  0.3735
 0.13872  -2.841  0.1627
-0.01946  -3.328  0.0415
 0.76399  -1.007  0.9976
-0.87117  -5.774  <.0001
-0.42047  -4.506  0.0004
 0.44138  -1.813  0.8112
 1.84303   2.511  0.3329
 1.02455   0.034  1.0000
 0.89494  -0.377  1.0000
 0.73545  -0.885  0.9993
 1.52681   1.441  0.9556
-0.11598  -3.618  0.0156
 0.33577  -2.232  0.5264
 2.39437   4.230  0.0014
 1.57286   1.810  0.8127
 1.44328   1.402  0.9634
 1.28125   0.902  0.9991
 2.07760   3.135  0.0744
 0.42867  -1.969  0.7144
 0.88288  -0.535  1.0000
 0.27039  -2.435  0.3822
 0.14395  -2.825  0.1694
-0.01622  -3.318  0.0428
 0.76722  -0.990  0.9979
-0.86907  -5.777  <.0001
-0.41728  -4.501  0.0004
 0.90519  -0.403  1.0000
 0.74647  -0.900  0.9991
 1.53153   1.388  0.9661
-0.10748  -3.586  0.0175
```

```
   0.34391  -2.225  0.5313
   0.87046  -0.497  1.0000
   1.66077   1.772  0.8336
   0.01798  -3.215  0.0588
   0.47058  -1.840  0.7960
   1.81580   2.248  0.5140
   0.16681  -2.770  0.1930
   0.62056  -1.374  0.9686
  -0.52191  -4.757  0.0001
  -0.07115  -3.476  0.0256
   1.60967   1.377  0.9679

Confidence level used: 0.95
Conf-level adjustment: tukey method for comparing a family of 12 estimates
P value adjustment: tukey method for comparing a family of 12 estimates
```

Okay, so here, the "estimate" column shows the difference in estimated marginal means for the two levels of interest, holding the other factor level constant (of my two factors, job and solution). So when the contrast is Computing environments vs. A learning community, the job_category is Faculty, and the estimate is 1.57, this indicates that faculty have a e^1.57 = 4.8 higher odds of rating Computing environments at least one category higher than A learning community. In other words, the odds of a faculty rating Computing environments at least one category higher than A learning community are 4.8:1.

I'd like to plot these data as a heat map. I find it really confusing to rely on the sign of the estimate (+/-) to tell me which solution is preferred. I'd rather have only positive values, and instead of using the sign to indicate which solution is preferred, we'll use the order of the solutions to indicate that. Let's say that the solution on the y-axis is always the preferred solution, so that the color/value merely indicates the extent to which respondents prefer the solution on the y-axis.

```r
nr <- subset(by_job, job_category == "Non-research Staff")
nr$contrast <- as.character(nr$contrast)
soln1 <- unname(sapply(nr$contrast, function(x) strsplit(x, " - ")[[1]][1]))
soln2 <- unname(sapply(nr$contrast, function(x) strsplit(x, " - ")[[1]][2]))
nr2 <- data.frame(
  soln1 = soln1,
  soln2 = soln2,
  value = nr$estimate,
  significant = ifelse(nr$p.value < 0.05, "*", "")
)
head(nr2)
```

```
                  soln1                soln2     value significant
1 Computing environments            Publicity 1.4148004           *
2 Computing environments     Containerization 1.4857438           *
3 Computing environments   Documentation help 0.6784877
4 Computing environments A learning community 0.1284222
5 Computing environments       Event planning 1.4792434           *
6 Computing environments   Mentoring programs 0.6891281
```

```
nr2_clean <- nr2 %>%
  # if value < 0 swap soln1/soln2 and flip the sign--one step at a time
  mutate(
    soln_pref = if_else(value < 0, soln2, soln1),   # preferred solution
    soln_other = if_else(value < 0, soln1, soln2),  # the other solution
    value_pos  = if_else(value < 0, -value, value)  # positive magnitude
  ) %>%

  # keep only the modified columns
  select(
    soln1 = soln_pref,
    soln2 = soln_other,
    value = value_pos,
    significant
  )
tail(nr2)
```

```
                  soln1                  soln2      value significant
61         Legal support Industry partnerships  0.7400995
62         Legal support Sustainability grants -0.9272325
63         Legal support  Help finding funding -0.4499384
64 Industry partnerships Sustainability grants -1.6673321           *
65 Industry partnerships  Help finding funding -1.1900379           *
66 Sustainability grants  Help finding funding  0.4772941
```

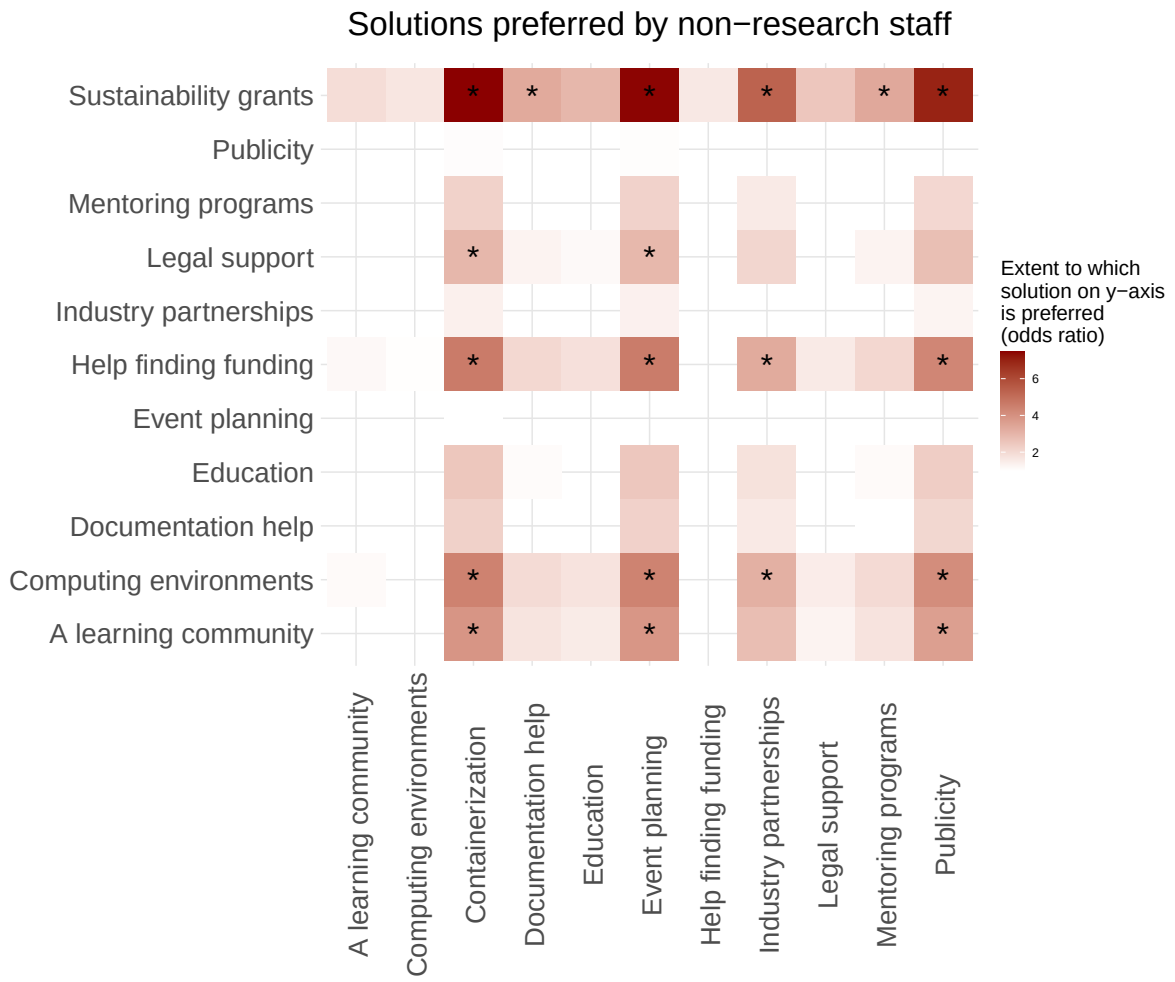
```
tail(nr2_clean)
```

```
                  soln1                  soln2     value significant
61         Legal support Industry partnerships 0.7400995
62 Sustainability grants         Legal support 0.9272325
63  Help finding funding         Legal support 0.4499384
64 Sustainability grants Industry partnerships 1.6673321           *
65  Help finding funding Industry partnerships 1.1900379           *
66 Sustainability grants  Help finding funding 0.4772941
```

```r
# exponentiate log odds to odds
nr2_clean$value <- exp(nr2_clean$value)
```

```r
nr_heatmap <- ggplot(
  data = nr2_clean,
  aes(x = soln2, y = soln1, fill = value)
) +
  geom_tile() +
  geom_text(aes(label = significant), color = "black", size = 8) +
  scale_fill_gradient(low = "white", high = "darkred") +
  ggtitle("Solutions preferred by non-research staff") +
  labs(
    fill = "Extent to which\nsolution on y-axis\nis preferred\n(odds ratio)"
  ) +
  theme(
    axis.title.x = element_blank(),
    axis.title.y = element_blank(),
    axis.text.x = element_text(
      angle = 90,
      vjust = 0.6,
      size = 20
    ),
    axis.text.y = element_text(size = 20),
    axis.ticks.x = element_blank(),
    axis.ticks.y = element_blank(),
    legend.title = element_text(size = 15),
    panel.background = element_blank(),
    panel.grid = element_line(linetype = "solid", color = "gray90"),
    plot.title = element_text(
      hjust = 0.5,
      size = 24,
      margin = margin(b = 15)
    ),
    plot.margin = unit(c(0.3, 0.3, 0.3, 0.3), "cm")
  )

nr_heatmap
```



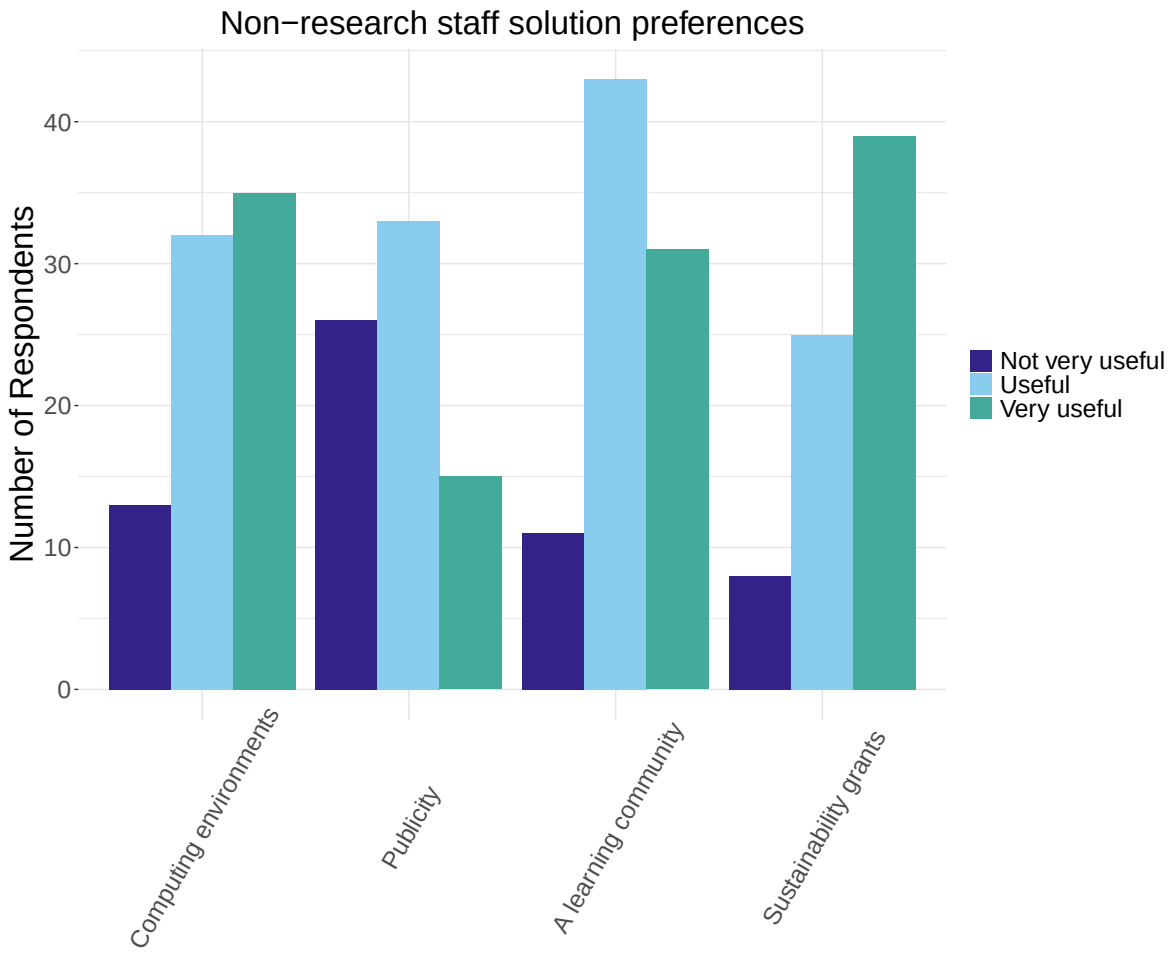

```
save_plot("solns_heatmap_nrstaff.tiff", 12, 10, p=nr_heatmap)
```

I'd like to "validate" this result by eyeballing a plot of the number of "Not very useful", "Useful", and "Very useful" results for non-research staff for a couple of solutions, say, sustainability grants and a learning community. The "favorite" solution question suggested that a learning community was more popular than grants among research staff, so the result here, which suggests grants are the most popular solution, is somewhat surprising.

```
t <- long_data %>%
  filter(job_category == "Non-research Staff") %>%
  filter(solution == "Computing environments" |
         solution == "A learning community" |
         solution == "Sustainability grants" |
         solution == "Publicity")
```

```
gbc <- grouped_bar_chart(
  df = t,
  x_var = "solution",
  fill_var = "utility",
  title = "Non-research staff solution preferences")

gbc
```




```
save_plot("solns_sanity_check_nrstaff.tiff", 12, 10, p=gbc)
```