

Incorporating design information

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Workflow

1. Introduction
2. Importing & transforming data
3. **Incorporating design information**
4. Pre-processing and plotting your data
5. Processing your data
6. Analyzing your data

7. Statistics, merging other data, and other resources

If you haven't already, load the necessary packages.

```
library(gcplyr)
```

Including design elements

During analysis of growth curve data, we often want to incorporate information about the experimental design. For example, which bacteria are present in which wells, or which wells have received certain treatments. `gcplyr` enables incorporation of design elements in two ways:

1. Design elements can be imported from files
2. Design elements can be generated programmatically using `make_design`

Reading design elements from files

Users have two options for how to read design elements from files, depending on the shape of the design files that they have created:

- If design files are block-shaped, they can be read with `import_blockdesigns`
- If design files are tidy-shaped, they can simply be read with `read_tidys`

Importing block-shaped design files

To import block-shaped design files, you can use the `import_blockdesigns` function, which will return a tidy-shaped designs data frame (or list of data frames).

`import_blockdesigns` only requires a list of filenames (or relative file paths) and will return a data.frame (or list of data frames) in a **tidy format** that you can save in R. That's right, it reads in block-shaped designs but returns a tidy-shaped data frame!

A basic example Let's take a look at an example. First, we need to create an example file for the sake of this tutorial. **Don't worry how the below code works**, just imagine that you've created this file in Excel.

```
write.csv(  
  file = "mydesign.csv",  
  x = matrix(rep(c("Tr1", "Tr2"), each = 48),  
             nrow = 8, ncol = 12, dimnames = list(LETTERS[1:8], 1:12)))
```

Now let's take a look at what the file looks like:

```
print_df(read.csv("mydesign.csv", header = FALSE, colClasses = "character"))  
#>   1  2  3  4  5  6  7  8  9 10 11 12  
#> A Tr1 Tr1 Tr1 Tr1 Tr1 Tr1 Tr2 Tr2 Tr2 Tr2 Tr2 Tr2  
#> B Tr1 Tr1 Tr1 Tr1 Tr1 Tr1 Tr2 Tr2 Tr2 Tr2 Tr2 Tr2  
#> C Tr1 Tr1 Tr1 Tr1 Tr1 Tr1 Tr2 Tr2 Tr2 Tr2 Tr2 Tr2  
#> D Tr1 Tr1 Tr1 Tr1 Tr1 Tr1 Tr2 Tr2 Tr2 Tr2 Tr2 Tr2
```

```
#> E Tr1 Tr1 Tr1 Tr1 Tr1 Tr1 Tr2 Tr2 Tr2 Tr2 Tr2 Tr2
#> F Tr1 Tr1 Tr1 Tr1 Tr1 Tr1 Tr1 Tr2 Tr2 Tr2 Tr2 Tr2 Tr2
#> G Tr1 Tr1 Tr1 Tr1 Tr1 Tr1 Tr1 Tr2 Tr2 Tr2 Tr2 Tr2 Tr2
#> H Tr1 Tr1 Tr1 Tr1 Tr1 Tr1 Tr1 Tr2 Tr2 Tr2 Tr2 Tr2 Tr2
```

Here we can see that our design has Treatment 1 on the left-hand side of the plate (wells in columns 1 through 6), and Treatment 2 on the right-hand side of the plate (wells in columns 7 through 12). Let's import this design using `import_blockdesigns`. Since this block contains the treatment numbers, we've given the `block_names` as "Treatment_numbers". If no `block_names` is provided, `import_blockdesigns` will automatically name it according to the file name.

```
my_design <- import_blockdesigns(files = "mydesign.csv",
                                block_names = "Treatment_numbers")
head(my_design, 20)
#>      Well Treatment_numbers
#> 1      A1                Tr1
#> 2      A2                Tr1
#> 3      A3                Tr1
#> 4      A4                Tr1
#> 5      A5                Tr1
#> 6      A6                Tr1
#> 7      A7                Tr2
#> 8      A8                Tr2
#> 9      A9                Tr2
#> 10     A10               Tr2
#> 11     A11               Tr2
#> 12     A12               Tr2
#> 13     B1                Tr1
#> 14     B2                Tr1
#> 15     B3                Tr1
#> 16     B4                Tr1
#> 17     B5                Tr1
#> 18     B6                Tr1
#> 19     B7                Tr2
#> 20     B8                Tr2
```

Importing multiple block-shaped design elements What do you do if you have multiple design components? For instance, what if you have several different bacterial strains each with several different treatments? In that case, simply save each design component as a separate file, and import them all in one go with `import_blockdesigns`.

First, let's create another example designs file. Again, **don't worry how the below code works**, just imagine that you've created this file in Excel.

```
write.csv(
  file = "mydesign2.csv",
  x = matrix(rep(c("StrA", "StrB", "StrC", "StrD"), each = 24),
             nrow = 8, ncol = 12, dimnames = list(LETTERS[1:8], 1:12),
             byrow = TRUE))
```

Now let's take a look at what the file looks like:

```
print_df(read.csv("mydesign2.csv", header = FALSE, colClasses = "character"))
#>   1    2    3    4    5    6    7    8    9   10   11   12
#> A StrA StrA StrA StrA StrA StrA StrA StrA StrA StrA StrA StrA
#> B StrA StrA StrA StrA StrA StrA StrA StrA StrA StrA StrA StrA
#> C StrB StrB StrB StrB StrB StrB StrB StrB StrB StrB StrB StrB
#> D StrB StrB StrB StrB StrB StrB StrB StrB StrB StrB StrB StrB
#> E StrC StrC StrC StrC StrC StrC StrC StrC StrC StrC StrC StrC
#> F StrC StrC StrC StrC StrC StrC StrC StrC StrC StrC StrC StrC
#> G StrD StrD StrD StrD StrD StrD StrD StrD StrD StrD StrD StrD
#> H StrD StrD StrD StrD StrD StrD StrD StrD StrD StrD StrD StrD
```

Here we can see that our design has Strain A in the first two rows, Strain B in the next two rows, and so on.

Let's now import both designs using `import_blockdesigns`. Since our two blocks contain the treatment numbers and then the strain letters, we've given the `block_names` as `c("Treatment_numbers", "Strain_letters")`. If no `block_names` is provided, `import_blockdesigns` will automatically name it according to the file name.

```
my_design <-
  import_blockdesigns(files = c("mydesign.csv", "mydesign2.csv"),
                     block_names = c("Treatment_numbers", "Strain_letters"))
head(my_design, 20)
#>   Well Treatment_numbers Strain_letters
#> 1    A1                Tr1          StrA
#> 2    A2                Tr1          StrA
#> 3    A3                Tr1          StrA
#> 4    A4                Tr1          StrA
#> 5    A5                Tr1          StrA
#> 6    A6                Tr1          StrA
#> 7    A7                Tr2          StrA
#> 8    A8                Tr2          StrA
#> 9    A9                Tr2          StrA
#> 10   A10               Tr2          StrA
#> 11   A11               Tr2          StrA
#> 12   A12               Tr2          StrA
#> 13   B1                Tr1          StrA
#> 14   B2                Tr1          StrA
#> 15   B3                Tr1          StrA
#> 16   B4                Tr1          StrA
#> 17   B5                Tr1          StrA
#> 18   B6                Tr1          StrA
#> 19   B7                Tr2          StrA
#> 20   B8                Tr2          StrA
```

Notes for more advanced use Note that `import_blockdesigns` is essentially a wrapper function that calls `read_blocks`, `paste_blocks`, `trans_block_to_wide`, `trans_wide_to_tidy`, and then `separate_tidys`. Any arguments for those functions can be passed to `import_blockdesigns`.

For instance, if your design files do not start on the first row and first column, you can specify a `startrow` or `startcol` just like when you were using `read_blocks`. Or if your designs are located in a sheet other than the first sheet, you can specify `sheet`.

Additionally, if you've already pasted together your design elements yourself, then you should specify what string is being used as a separator via the `sep` argument (that gets passed to `separate_tidys`).

If you find yourself needing even more control over the process of importing block-shaped design files, each of the functions is available for users to call themselves. So you can run the steps manually, first reading with `read_blocks`, pasting as needed with `paste_blocks`, transforming to tidy with `trans_block_to_wide` and `trans_wide_to_tidy`, and finally separating design elements with `separate_tidys`.

Importing tidy-shaped design files

Just like measures data, to import tidy-shaped designs you could use the built-in R functions like `read.table`. However, if you need a few more options, you can use the `gcplyr` function `read_tidys`. Unlike the built-in option, `read_tidys` can import multiple tidy-shaped files at once, can add the filename as a column in the resulting `data.frame`, and can handle files where the tidy-shaped information doesn't start on the first row and column.

`read_tidys` only requires a filename (or vector of filenames, or relative file paths) and will return a `data.frame` (or list of `data.frames`) that you can save in R.

Once these design elements have been read into the R environment, you won't need to transform them. So you can skip down to learning how to merge them with your data in the **Merging spectrophotometric and design data** section.

Generating designs in R

If you'd rather make your design `data.frames` in R, `gcplyr` has a helper function that makes it easy to do so: `make_design`. `make_design` can create:

- block-shaped `data.frames` with your design information (e.g. for outputting to files)
- tidy-shaped `data.frames` with your design information (e.g. for merging with tidy-shaped plate reader data)

An example with a single design

Let's start with a simple example demonstrating the basic use of `make_design` (we'll move on to more complicated designs afterwards).

For example, let's imagine a growth curve experiment where a 96 well plate (12 columns and 8 rows) has a different bacterial strain in each row, but the first and last columns and first and last rows were left empty.

Row names	Column 1	Column 2	Column 3	...	Column 11	Column 12
Row A	Blank	Blank	Blank	...	Blank	Blank
Row B	Blank	Strain #1	Strain #1	...	Strain #1	Blank
Row B	Blank	Strain #2	Strain #2	...	Strain #2	Blank
...
Row G	Blank	Strain #5	Strain #5	...	Strain #5	Blank
Row G	Blank	Strain #6	Strain #6	...	Strain #6	Blank
Row H	Blank	Blank	Blank	...	Blank	Blank

Typing a design like this manually into a spreadsheet can be tedious. But generating a design `data.frame` using `make_design` is easier.

`make_design` first needs some general information, like the `nrows` and `ncols` in the plate, and the `output_format` you'd like (typically `blocks` or `tidy`).

Then, for each different design component, `make_design` needs five different pieces of information:

- a vector containing the possible values
- a vector specifying which rows these values should be applied to
- a vector specifying which columns these values should be applied to
- a string or vector of the pattern of these values
- a Boolean for whether this pattern should be filled byrow (defaults to TRUE)

```
my_design_blk <- make_design(
  output_format = "blocks",
  nrows = 8, ncols = 12,
  Bacteria = list(c("Str1", "Str2", "Str3",
                    "Str4", "Str5", "Str6"),
                 2:7,
                 2:11,
                 "123456",
                 FALSE)
)
```

So for our example above, we can see:

- the possible values are `c("Strain 1", "Strain 2", "Strain 3", "Strain 4", "Strain 5", "Strain 6")`
- the rows these values should be applied to are rows `2:7`
- the columns these values should be applied to are columns `2:11`
- the pattern these values should be filled in by is `"123456"`
- and these values should *not* be filled by row, they should be filled by column

This entire list is passed with a name (here, “Bacteria”), that will be used as the resulting column header.

What does the result look like?

```
my_design_blk
#> [[1]]
#> [[1]]$data
#>   1  2    3    4    5    6    7    8    9    10   11   12
#> A NA NA   NA   NA   NA   NA   NA   NA   NA   NA   NA   NA
#> B NA "Str1" "Str1" "Str1" "Str1" "Str1" "Str1" "Str1" "Str1" "Str1" "Str1" "Str1" NA
#> C NA "Str2" "Str2" "Str2" "Str2" "Str2" "Str2" "Str2" "Str2" "Str2" "Str2" "Str2" NA
#> D NA "Str3" "Str3" "Str3" "Str3" "Str3" "Str3" "Str3" "Str3" "Str3" "Str3" "Str3" NA
#> E NA "Str4" "Str4" "Str4" "Str4" "Str4" "Str4" "Str4" "Str4" "Str4" "Str4" "Str4" NA
#> F NA "Str5" "Str5" "Str5" "Str5" "Str5" "Str5" "Str5" "Str5" "Str5" "Str5" "Str5" NA
#> G NA "Str6" "Str6" "Str6" "Str6" "Str6" "Str6" "Str6" "Str6" "Str6" "Str6" "Str6" NA
#> H NA NA   NA   NA   NA   NA   NA   NA   NA   NA   NA   NA
#>
#> [[1]]$metadata
#> block_name
#> "Bacteria"
```

We can see that `make_design` has created a block-shaped `data.frame` containing the design elements as requested, and has attached a `metadata` containing the `block_name` (this is useful for later transformation to tidy-shaped, or if you’re generating multiple design elements).

A few notes on the pattern

One of the most important elements of every argument passed to `make_design` is the string or vector specifying the pattern of values.

Oftentimes, it will be most convenient to simply use single-characters to correspond to the values. This is the default behavior of `make_design`, which splits the pattern string into individual characters, and then uses those characters to correspond to the indices of the values you provided.

For instance, in the example above, I used the numbers 1 through 6 to correspond to the values "Strain 1", "Strain 2", "Strain 3", "Strain 4", "Strain 5", "Strain 6".

It's important to **note that the "0" character is reserved for NA values**. There is an example of this later.

If you have more than 9 values, you can use letters (uppercase and/or lowercase). In that case, you just have to specify a `lookup_tbl_start` so that the function knows what letter you're using as the 1 index. If no `lookup_tbl_start` is specified, the default is to count numbers first, then uppercase letters, then lowercase letters. For instance, in the previous example, I could have equivalently done:

```
my_design_blk <- make_design(  
  output_format = "blocks",  
  nrows = 8, ncols = 12, lookup_tbl_start = "A",  
  Bacteria = list(  
    c("Str1", "Str2", "Str3", "Str4", "Str5", "Str6"),  
    2:7,  
    2:11,  
    "ABCDEF",  
    FALSE)  
)
```

Or I could have done:

```
my_design_blk <- make_design(  
  output_format = "blocks",  
  nrows = 8, ncols = 12, lookup_tbl_start = "a",  
  Bacteria = list(  
    c("Str1", "Str2", "Str3", "Str4", "Str5", "Str6"),  
    2:7,  
    2:11,  
    "abcdef",  
    FALSE)  
)
```

Alternatively, you can use a separating character like a comma to delineate your indices. If you are doing so in order to use multicharacter indices (like numbers with more than one digit), all your indices will have to be numeric.

```
my_design_blk <- make_design(  
  output_format = "blocks",  
  nrows = 8, ncols = 12, pattern_split = ",",  
  Bacteria = list(  
    c("Str1", "Str2", "Str3", "Str4", "Str5", "Str6"),  
    2:7,  
    2:11,  
    "1,2,3,4,5,6",  
    FALSE)  
)
```

If you find it easier to input the pattern as a vector rather than as a string that needs to be split, you can do that too. Just like when passing a string, if you're not using numbers, then uppercase letters, then lowercase letters for your indices, make sure to specify a different `lookup_tbl_start`:

```
my_design_blk <- make_design(
  output_format = "blocks",
  nrows = 8, ncols = 12,
  Bacteria = list(
    c("Str1", "Str2", "Str3", "Str4", "Str5", "Str6"),
    2:7,
    2:11,
    c(1,2,3,4,5,6),
    FALSE)
)
```

Continuing with the example: multiple designs

Now let's return to our example growth curve experiment. Imagine that now, *in addition* to having a different bacterial strain in each row, we also have a different media in each column in the plate.

Row names	Column 1	Column 2	Column 3	...	Column 11	Column 12
Row A	Blank	Blank	Blank	...	Blank	Blank
Row B	Blank	Media #1	Media #2	...	Media #10	Blank
...
Row G	Blank	Media #1	Media #2	...	Media #10	Blank
Row H	Blank	Blank	Blank	...	Blank	Blank

We can generate both the bacterial strain design and the media design simply by adding an additional argument to our `make_design` call.

```
my_design_blk <- make_design(
  output_format = "blocks",
  nrows = 8, ncols = 12, lookup_tbl_start = "a",
  Bacteria = list(c("Str1", "Str2", "Str3",
    "Str4", "Str5", "Str6"),
    2:7,
    2:11,
    "abcdef",
    FALSE),
  Media = list(c("Med1", "Med2", "Med3",
    "Med4", "Med5", "Med6",
    "Med7", "Med8", "Med9",
    "Med10", "Med11", "Med12"),
    2:7,
    2:11,
    "abcdefghij")
)

my_design_blk
#> [[1]]
#> [[1]]$data
```



```

#>   1  2    3    4    5    6    7    8    9   10   11   12
#> A NA NA    NA    NA    NA    NA    NA    NA    NA    NA    NA    NA
#> B NA "Str1" "Str1" "Str1" "Str1" "Str1" "Str1" "Str1" "Str1" "Str1" "Str1" "Str1" NA
#> C NA "Str2" "Str2" "Str2" "Str2" "Str2" "Str2" "Str2" "Str2" "Str2" "Str2" "Str2" NA
#> D NA "Str3" "Str3" "Str3" "Str3" "Str3" "Str3" "Str3" "Str3" "Str3" "Str3" "Str3" NA
#> E NA "Str4" "Str4" "Str4" "Str4" "Str4" "Str4" "Str4" "Str4" "Str4" "Str4" "Str4" NA
#> F NA "Str5" "Str5" "Str5" "Str5" "Str5" "Str5" "Str5" "Str5" "Str5" "Str5" "Str5" NA
#> G NA "Str6" "Str6" "Str6" "Str6" "Str6" "Str6" "Str6" "Str6" "Str6" "Str6" "Str6" NA
#> H NA NA    NA    NA    NA    NA    NA    NA    NA    NA    NA    NA
#>
#> [[1]]$metadata
#> block_name
#> "Bacteria"
#>
#>
#> [[2]]
#> [[2]]$data
#>   1  2    3    4    5    6    7    8    9   10   11   12
#> A NA NA    NA    NA    NA    NA    NA    NA    NA    NA    NA    NA
#> B NA "Med1" "Med2" "Med3" "Med4" "Med5" "Med6" "Med7" "Med8" "Med9" "Med10" NA
#> C NA "Med1" "Med2" "Med3" "Med4" "Med5" "Med6" "Med7" "Med8" "Med9" "Med10" NA
#> D NA "Med1" "Med2" "Med3" "Med4" "Med5" "Med6" "Med7" "Med8" "Med9" "Med10" NA
#> E NA "Med1" "Med2" "Med3" "Med4" "Med5" "Med6" "Med7" "Med8" "Med9" "Med10" NA
#> F NA "Med1" "Med2" "Med3" "Med4" "Med5" "Med6" "Med7" "Med8" "Med9" "Med10" NA
#> G NA "Med1" "Med2" "Med3" "Med4" "Med5" "Med6" "Med7" "Med8" "Med9" "Med10" NA
#> H NA NA    NA    NA    NA    NA    NA    NA    NA    NA    NA    NA
#>
#> [[2]]$metadata
#> block_name
#> "Media"

```

Here we can see that two blocks have been created, one with our bacterial strains, and one with our media.

Now, imagine after the experiment we discover that Bacterial Strain 4 and Media #6 were contaminated, and we'd like to exclude them from our analyses by marking them as NA in the design. We can simply modify our pattern string, placing a 0 anywhere we would like an NA to be filled in.

```

my_design_blk <- make_design(
  output_format = "blocks",
  nrows = 8, ncols = 12, lookup_tbl_start = "a",
  Bacteria = list(c("Str1", "Str2", "Str3",
                    "Str4", "Str5", "Str6"),
                  2:7,
                  2:11,
                  "abc0ef",
                  FALSE),
  Media = list(c("Med1", "Med2", "Med3",
                  "Med4", "Med5", "Med6",
                  "Med7", "Med8", "Med9",
                  "Med10", "Med11", "Med12"),
               2:7,
               2:11,
               "abcde0ghij")
)

```

```

my_design_blk
#> [[1]]
#> [[1]]$data
#>   1  2    3    4    5    6    7    8    9    10   11   12
#> A NA NA   NA   NA   NA   NA   NA   NA   NA   NA   NA   NA
#> B NA "Str1" "Str1" "Str1" "Str1" "Str1" "Str1" "Str1" "Str1" "Str1" "Str1" "Str1" NA
#> C NA "Str2" "Str2" "Str2" "Str2" "Str2" "Str2" "Str2" "Str2" "Str2" "Str2" "Str2" NA
#> D NA "Str3" "Str3" "Str3" "Str3" "Str3" "Str3" "Str3" "Str3" "Str3" "Str3" "Str3" NA
#> E NA NA   NA   NA   NA   NA   NA   NA   NA   NA   NA   NA
#> F NA "Str5" "Str5" "Str5" "Str5" "Str5" "Str5" "Str5" "Str5" "Str5" "Str5" "Str5" NA
#> G NA "Str6" "Str6" "Str6" "Str6" "Str6" "Str6" "Str6" "Str6" "Str6" "Str6" "Str6" NA
#> H NA NA   NA   NA   NA   NA   NA   NA   NA   NA   NA   NA
#>
#> [[1]]$metadata
#> block_name
#> "Bacteria"
#>
#>
#> [[2]]
#> [[2]]$data
#>   1  2    3    4    5    6    7  8    9    10   11   12
#> A NA NA   NA   NA   NA   NA   NA NA   NA   NA   NA   NA
#> B NA "Med1" "Med2" "Med3" "Med4" "Med5" NA "Med7" "Med8" "Med9" "Med10" NA
#> C NA "Med1" "Med2" "Med3" "Med4" "Med5" NA "Med7" "Med8" "Med9" "Med10" NA
#> D NA "Med1" "Med2" "Med3" "Med4" "Med5" NA "Med7" "Med8" "Med9" "Med10" NA
#> E NA "Med1" "Med2" "Med3" "Med4" "Med5" NA "Med7" "Med8" "Med9" "Med10" NA
#> F NA "Med1" "Med2" "Med3" "Med4" "Med5" NA "Med7" "Med8" "Med9" "Med10" NA
#> G NA "Med1" "Med2" "Med3" "Med4" "Med5" NA "Med7" "Med8" "Med9" "Med10" NA
#> H NA NA   NA   NA   NA   NA   NA NA   NA   NA   NA   NA
#>
#> [[2]]$metadata
#> block_name
#> "Media"

```

Now we can see that our design has been easily modified to place NA's for those wells, which we can use after merging our designs with our data to exclude all of those wells from analyses.

However, the real strength of `make_design` is that it is not limited to simple alternating patterns. The pattern specified can be any pattern, which `make_design` will replicate sufficient times to cover the entire set of listed wells.

```

my_design_blk <- make_design(
  output_format = "blocks",
  nrows = 8, ncols = 12, lookup_tbl_start = "a",
  Bacteria = list(c("Str1", "Str2"),
    2:7,
    2:11,
    "abaaabbbab",
    FALSE),
  Media = list(c("Med1", "Med2", "Med3"),
    2:7,
    2:11,
    "aabbbc000abc"))

```

```

my_design_blk
#> [[1]]
#> [[1]]$data
#>   1  2    3    4    5    6    7    8    9    10   11   12
#> A NA NA   NA   NA   NA   NA   NA   NA   NA   NA   NA   NA
#> B NA "Str1" "Str2" "Str1" "Str1" "Str1" "Str1" "Str2" "Str1" "Str1" "Str1" NA
#> C NA "Str2" "Str2" "Str1" "Str2" "Str2" "Str2" "Str2" "Str1" "Str2" "Str2" NA
#> D NA "Str1" "Str1" "Str1" "Str1" "Str2" "Str1" "Str1" "Str1" "Str1" "Str2" NA
#> E NA "Str1" "Str2" "Str2" "Str2" "Str2" "Str1" "Str2" "Str2" "Str2" "Str2" NA
#> F NA "Str1" "Str1" "Str2" "Str1" "Str1" "Str1" "Str1" "Str2" "Str1" "Str1" NA
#> G NA "Str2" "Str2" "Str2" "Str1" "Str2" "Str2" "Str2" "Str2" "Str1" "Str2" NA
#> H NA NA   NA   NA   NA   NA   NA   NA   NA   NA   NA   NA
#>
#> [[1]]$metadata
#> block_name
#> "Bacteria"
#>
#>
#> [[2]]
#> [[2]]$data
#>   1  2    3    4    5    6    7    8    9    10   11   12
#> A NA NA   NA   NA   NA   NA   NA   NA   NA   NA   NA   NA
#> B NA "Med1" "Med1" "Med2" "Med2" "Med2" "Med3" NA   NA   NA   "Med1" NA
#> C NA "Med2" "Med3" "Med1" "Med1" "Med2" "Med2" "Med2" "Med3" NA   NA   NA
#> D NA NA   "Med1" "Med2" "Med3" "Med1" "Med1" "Med2" "Med2" "Med2" "Med3" NA
#> E NA NA   NA   NA   "Med1" "Med2" "Med3" "Med1" "Med1" "Med2" "Med2" NA
#> F NA "Med2" "Med3" NA   NA   NA   "Med1" "Med2" "Med3" "Med1" "Med1" NA
#> G NA "Med2" "Med2" "Med2" "Med3" NA   NA   NA   "Med1" "Med2" "Med3" NA
#> H NA NA   NA   NA   NA   NA   NA   NA   NA   NA   NA   NA
#>
#> [[2]]$metadata
#> block_name
#> "Media"

```

gcplyr also includes an optional helper function for `make_design` called `make_designpattern`. `make_designpattern` just helps by reminding the user what arguments are necessary for each design and ensuring they're in the correct order. For example, the following produces the same `data.frame` as the above code:

```

my_design_blk <- make_design(
  output_format = "blocks",
  nrows = 8, ncols = 12, lookup_tbl_start = "a",
  Bacteria = make_designpattern(
    values = c("Str1", "Str2", "Str3",
               "Str4", "Str5", "Str6"),
    rows = 2:7, cols = 2:11, pattern = "abc0ef",
    byrow = FALSE),
  Media = make_designpattern(
    values = c("Med1", "Med2", "Med3",
               "Med4", "Med5", "Med6",
               "Med7", "Med8", "Med9",
               "Med10", "Med11", "Med12"),
    rows = 2:7, cols = 2:11, pattern = "abcde0ghij"))

```

```

my_design_blk
#> [[1]]
#> [[1]]$data
#>   1  2    3    4    5    6    7    8    9    10   11   12
#> A NA NA   NA   NA   NA   NA   NA   NA   NA   NA   NA   NA
#> B NA "Str1" "Str1" "Str1" "Str1" "Str1" "Str1" "Str1" "Str1" "Str1" "Str1" "Str1" NA
#> C NA "Str2" "Str2" "Str2" "Str2" "Str2" "Str2" "Str2" "Str2" "Str2" "Str2" "Str2" NA
#> D NA "Str3" "Str3" "Str3" "Str3" "Str3" "Str3" "Str3" "Str3" "Str3" "Str3" "Str3" NA
#> E NA NA   NA   NA   NA   NA   NA   NA   NA   NA   NA   NA
#> F NA "Str5" "Str5" "Str5" "Str5" "Str5" "Str5" "Str5" "Str5" "Str5" "Str5" "Str5" NA
#> G NA "Str6" "Str6" "Str6" "Str6" "Str6" "Str6" "Str6" "Str6" "Str6" "Str6" "Str6" NA
#> H NA NA   NA   NA   NA   NA   NA   NA   NA   NA   NA   NA
#>
#> [[1]]$metadata
#> block_name
#> "Bacteria"
#>
#>
#> [[2]]
#> [[2]]$data
#>   1  2    3    4    5    6    7  8    9    10   11   12
#> A NA NA   NA   NA   NA   NA   NA NA   NA   NA   NA   NA
#> B NA "Med1" "Med2" "Med3" "Med4" "Med5" NA "Med7" "Med8" "Med9" "Med10" NA
#> C NA "Med1" "Med2" "Med3" "Med4" "Med5" NA "Med7" "Med8" "Med9" "Med10" NA
#> D NA "Med1" "Med2" "Med3" "Med4" "Med5" NA "Med7" "Med8" "Med9" "Med10" NA
#> E NA "Med1" "Med2" "Med3" "Med4" "Med5" NA "Med7" "Med8" "Med9" "Med10" NA
#> F NA "Med1" "Med2" "Med3" "Med4" "Med5" NA "Med7" "Med8" "Med9" "Med10" NA
#> G NA "Med1" "Med2" "Med3" "Med4" "Med5" NA "Med7" "Med8" "Med9" "Med10" NA
#> H NA NA   NA   NA   NA   NA   NA NA   NA   NA   NA   NA
#>
#> [[2]]$metadata
#> block_name
#> "Media"

```

So far, we've been using the `blocks` option for `output_format`, because it's easy to see that our design matches what we'd intended with that format. However, **for merging our designs with plate reader data, we need it tidy-shaped**. Luckily, there's no need to transform it yourself, simply change the `output_format` argument option to `tidy`.

```

my_design_tdy <- make_design(
  output_format = "tidy",
  nrows = 8, ncols = 12, lookup_tbl_start = "a",
  Bacteria = make_designpattern(
    values = c("Str1", "Str2", "Str3",
               "Str4", "Str5", "Str6"),
    rows = 2:7, cols = 2:11, pattern = "abc0ef",
    byrow = FALSE),
  Media = make_designpattern(
    values = c("Med1", "Med2", "Med3",
               "Med4", "Med5", "Med6",
               "Med7", "Med8", "Med9",
               "Med10", "Med11", "Med12"),
    rows = 2:7, cols = 2:11, pattern = "abcde0ghij"))

```

```
head(my_design_tdy, 20)
#>      Well Bacteria Media
#> 1      A1          NA    NA
#> 2      A2          NA    NA
#> 3      A3          NA    NA
#> 4      A4          NA    NA
#> 5      A5          NA    NA
#> 6      A6          NA    NA
#> 7      A7          NA    NA
#> 8      A8          NA    NA
#> 9      A9          NA    NA
#> 10    A10          NA    NA
#> 11    A11          NA    NA
#> 12    A12          NA    NA
#> 13     B1          NA    NA
#> 14     B2      Str1  Med1
#> 15     B3      Str1  Med2
#> 16     B4      Str1  Med3
#> 17     B5      Str1  Med4
#> 18     B6      Str1  Med5
#> 19     B7      Str1    NA
#> 20     B8      Str1  Med7
```

Saving designs to files

Often after generating designs in R with `make_design`, you'll want to save those designs to files. This might be so that human-readable files documenting your designs are available without opening R. Or perhaps it's because you need to post the design files, for instance to Dryad as part of a manuscript submission.

If you'd like to save your designs to files, you can save them either tidy-shaped or block-shaped. Both formats can easily be read back into R by `gcplyr`.

Saving tidy-shaped designs These design files will be less human-readable, but easier to import and merge. Additionally, tidy-shaped files are often better for data repositories, like Dryad. To save tidy-shaped designs, simply use the built-in `write.csv` function.

```
#See the previous section where we created my_design_tdy
write.csv(x = my_design_tdy, file = "tidy_design.csv",
          row.names = FALSE)
```

Saving block-shaped designs These design files will be more human-readable but require slightly more computational steps to import and merge. For these, use the `gcplyr` function `write_blocks`. Typically, you'll use `write_blocks` to save files in one of two formats:

- **multiple** - each block will be saved to its own `.csv` file
- **single** - all the blocks will be saved to a single `.csv` file, with an empty row in between them

Saving block-shaped designs to multiple files The default setting for `write_blocks` is `output_format = 'multiple'`. This creates one `csv` file for each block, naming the files according to the `block_names` in the metadata for each block.

```

#See the previous section where we created my_design_blk
write_blocks(my_design_blk)

#Let's see what the files look like
print_df(read.csv("Bacteria.csv", header = FALSE, colClasses = "character"))
#>   1     2     3     4     5     6     7     8     9    10    11 12
#> A
#> B   Str1 Str1 Str1 Str1 Str1 Str1 Str1 Str1 Str1 Str1 Str1
#> C   Str2 Str2 Str2 Str2 Str2 Str2 Str2 Str2 Str2 Str2 Str2
#> D   Str3 Str3 Str3 Str3 Str3 Str3 Str3 Str3 Str3 Str3 Str3
#> E
#> F   Str5 Str5 Str5 Str5 Str5 Str5 Str5 Str5 Str5 Str5 Str5
#> G   Str6 Str6 Str6 Str6 Str6 Str6 Str6 Str6 Str6 Str6 Str6
#> H

print_df(read.csv("Media.csv", header = FALSE, colClasses = "character"))
#>   1     2     3     4     5     6 7     8     9    10    11 12
#> A
#> B   Med1 Med2 Med3 Med4 Med5   Med7 Med8 Med9 Med10
#> C   Med1 Med2 Med3 Med4 Med5   Med7 Med8 Med9 Med10
#> D   Med1 Med2 Med3 Med4 Med5   Med7 Med8 Med9 Med10
#> E   Med1 Med2 Med3 Med4 Med5   Med7 Med8 Med9 Med10
#> F   Med1 Med2 Med3 Med4 Med5   Med7 Med8 Med9 Med10
#> G   Med1 Med2 Med3 Med4 Med5   Med7 Med8 Med9 Med10
#> H

```

Saving block-shaped designs to a single file The other setting for `write_blocks` is `output_format = 'single'`. This creates a single csv file that contains all the blocks, putting metadata like `block_names` in rows that precede each block.

Let's take a look what the single output format looks like:

```

#See the previous section where we created my_design_blk
write_blocks(my_design_blk, file = "Design.csv", output_format = "single")

#Let's see what the file looks like
print_df(read.csv("Design.csv", header = FALSE, colClasses = "character"))
#> block_name Bacteria
#>           1     2     3     4     5     6     7     8     9    10    11 12
#>           A
#>           B   Str1 Str1 Str1 Str1 Str1 Str1 Str1 Str1 Str1 Str1 Str1
#>           C   Str2 Str2 Str2 Str2 Str2 Str2 Str2 Str2 Str2 Str2 Str2
#>           D   Str3 Str3 Str3 Str3 Str3 Str3 Str3 Str3 Str3 Str3 Str3
#>           E
#>           F   Str5 Str5 Str5 Str5 Str5 Str5 Str5 Str5 Str5 Str5 Str5
#>           G   Str6 Str6 Str6 Str6 Str6 Str6 Str6 Str6 Str6 Str6 Str6
#>           H
#>
#> block_name   Media
#>           1     2     3     4     5     6     7     8     9    10    11 12
#>           A
#>           B   Med1 Med2 Med3 Med4 Med5   Med7 Med8 Med9 Med10
#>           C   Med1 Med2 Med3 Med4 Med5   Med7 Med8 Med9 Med10

```

```
#>      D      Med1 Med2 Med3 Med4 Med5      Med7 Med8 Med9 Med10
#>      E      Med1 Med2 Med3 Med4 Med5      Med7 Med8 Med9 Med10
#>      F      Med1 Med2 Med3 Med4 Med5      Med7 Med8 Med9 Med10
#>      G      Med1 Med2 Med3 Med4 Med5      Med7 Med8 Med9 Med10
#>      H
```

Here we can see all our design information has been saved to a single file, and the metadata has been added in rows before each block.

Best practices for saving designs to files It's best to leave the `make_design` and `write_blocks` commands in your analysis script, so that every time your analysis is run your design files are kept up to date. Just note that if your `make_design` command has `output_format = blocks`, you'll need to make a version where `output_format = tidy` that you can `merge_dfs` with your plate reader data.

Merging spectrophotometric and design data

Once we have both our design and data in the R environment and tidy-shaped, we can merge them using `merge_dfs`.

For this, we'll use the data in the `example_widedata` dataset that is included with `gcplyr`, and which was the source for our previous examples with `import_blockmeasures` and `read_wides`.

In the `example_widedata` dataset, we have 48 different bacterial strains. The left side of the plate has all 48 strains in a single well each, and the right side of the plate also has all 48 strains in a single well each:

Row names	Column 1	...	Column 6	Column 7	...	Column 12
Row A	Strain #1	...	Strain #6	Strain #1	...	Strain #6
Row B	Strain #7	...	Strain #12	Strain #7	...	Strain #12
...
Row G	Strain #37	...	Strain #42	Strain #37	...	Strain #42
Row H	Strain #43	...	Strain #48	Strain #43	...	Strain #48

Then, on the right hand side of the plate a phage was also inoculated (while the left hand side remained bacteria-only):

Row names	Column 1	...	Column 6	Column 7	...	Column 12
Row A	No Phage	...	No Phage	Phage Added	...	Phage Added
Row B	No Phage	...	No Phage	Phage Added	...	Phage Added
...
Row G	No Phage	...	No Phage	Phage Added	...	Phage Added
Row H	No Phage	...	No Phage	Phage Added	...	Phage Added

Let's generate our design:

```
example_design <- make_design(
  pattern_split = ",", nrows = 8, ncols = 12,
  "Bacteria_strain" = make_designpattern(
    values = paste("Strain", 1:48),
    rows = 1:8, cols = 1:6,
```

```

pattern = 1:48,
byrow = TRUE),
"Bacteria_strain" = make_designpattern(
  values = paste("Strain", 1:48),
  rows = 1:8, cols = 7:12,
  pattern = 1:48,
  byrow = TRUE),
"Phage" = make_designpattern(
  values = c("No Phage"),
  rows = 1:8, cols = 1:6,
  pattern = "1"),
"Phage" = make_designpattern(
  values = c("Phage Added"),
  rows = 1:8, cols = 7:12,
  pattern = "1"))

```

Here's what the resulting data.frame looks like:

```

head(example_design, 20)
#>      Well Bacteria_strain      Phage
#> 1     A1      Strain 1     No Phage
#> 2     A2      Strain 2     No Phage
#> 3     A3      Strain 3     No Phage
#> 4     A4      Strain 4     No Phage
#> 5     A5      Strain 5     No Phage
#> 6     A6      Strain 6     No Phage
#> 7     A7      Strain 1 Phage Added
#> 8     A8      Strain 2 Phage Added
#> 9     A9      Strain 3 Phage Added
#> 10    A10      Strain 4 Phage Added
#> 11    A11      Strain 5 Phage Added
#> 12    A12      Strain 6 Phage Added
#> 13    B1      Strain 7     No Phage
#> 14    B2      Strain 8     No Phage
#> 15    B3      Strain 9     No Phage
#> 16    B4      Strain 10    No Phage
#> 17    B5      Strain 11    No Phage
#> 18    B6      Strain 12    No Phage
#> 19    B7      Strain 7 Phage Added
#> 20    B8      Strain 8 Phage Added

```

Now let's transform the `example_widedata` to tidy-shaped.

```

example_tidydata <- trans_wide_to_tidy(example_widedata,
                                       id_cols = "Time")

```

And finally, we merge the two using `merge_dfs`, saving the result to `ex_dat_mrg`, short for `example_data_merged`:

```

ex_dat_mrg <- merge_dfs(example_tidydata, example_design)
#> Joining, by = "Well"

```



```
head(ex_dat_mrg)
#>   Time Well Measurements Bacteria_strain    Phage
#> 1    0   A1      0.003      Strain 1 No Phage
#> 2    0   B1      0.001      Strain 7 No Phage
#> 3    0   C1      0.002      Strain 13 No Phage
#> 4    0   D1      0.002      Strain 19 No Phage
#> 5    0   E1      0.002      Strain 25 No Phage
#> 6    0   F1      0.001      Strain 31 No Phage
```

What's next?

Now that you've merged your data and designs, you can pre-process and plot your data

1. Introduction
2. Importing & transforming data
3. **Incorporating design information**
4. Pre-processing and plotting your data
5. Processing your data
6. Analyzing your data
7. Statistics, merging other data, and other resources