Universität Innsbruck

# Flexible Generation of E-Learning Exams and Beyond

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# Overview

- Motivation and challenges
- R package **exams**
- Exercises
- Exams
  - Combination of exercises
  - PDF output
  - HTML output
  - **Moodle**, **OLAT**, **ARSnova**, . . .
- Discussion

# Motivation and challenges

**Motivation:**

- Introductory statistics and mathematics courses for business and economics students at WU Wien and Universität Innsbruck.
- Courses are attended by more than 1,000 students per semester.
- Several lecturers teach lectures and tutorials in parallel.
- Need for integrated teaching materials: Presentation slides, collections of exercises, exams, etc.
- Different types assessments from the same pool of exercises: Written exams, online tests, live quizzes, etc.

# Motivation and challenges

**Challenges:** Based on the same pool of exercises. . .

- *Scalable exams:* Automatic generation of a large number of different exams.
- *Flexible rendering:* Output for written exams or online learning management systems, etc.
- *Associated self-study materials:* Collections of exercises along with solutions.
- *Joint development:* Development and maintenance in a multi-author and cross-platform setting.

# R package exams

**Tools chosen:**

- R for random data generation and computations.
- LaTeX for mathematical notation.
- LaTeX or Markdown for text formatting
- `Sweave` or **knitr**/**rmarkdown** for tying everything together.

**Exercises:**

- Dynamic templates if R code is used for randomization.
- Each exercise is a single file (either `.Rnw` or `.Rmd`).
- Contains question and (optionally) the corresponding solution.

# R package exams

**Answer types:**

- Single choice and multiple choice.
- Numeric values.
- Text strings (typically short).
- Combinations of the above (cloze).

**Output:**

- PDF – either fully customizable or standardized with automatic scanning/evaluation.
- HTML – either fully customizable or embedded into any of the standard formats below.
- **Moodle** XML.
- QTI XML standard (version 1.2 or 2.1), e.g., for **OLAT**/**OpenOLAT**.
- **ARSnova**, **TCExam**, **LOPS**, . . . (**Blackboard** under development).

# Exercises

**Exercise templates:** `.Rnw` or `.Rmd` files composed of

- R code chunks for random data generation.
  - `.Rnw`: Within `<<>>=` and `@`.
  - `.Rmd`: Within ```` ```{r} ```` and ```` ``` ````.
- Question and solution descriptions contained in sections with corresponding names.
  - `.Rnw`: `\begin`/`\end` pairs for `{question}`/`{solution}`.
  - `.Rmd`: `Question`/`Solution` sections with `#######` markup.
- Metainformation about `extype` (numeric, multiple choice, ...), correct `exsolution`, a short `exname`, etc.
  - `.Rnw`: `\extype{mchoice}`, `\exsolution{01001}`, ...
  - `.Rmd`: `extype: mchoice`, `exsolution: 01001`, ....
- Question and basic metainformation is mandatory – everything else optional. All parts can contain R code chunks or data.
  - `.Rnw`: `\Sexpr{...}`.
  - `.Rmd`: `` `r ...` ``.

# Exercises

**Simple geometric example:**

- Computation of the distance between two points $p$ and $q$ in a Cartesian coordinate system (via the Pythagorean formula).
- Template `dist.Rnw` and `dist.Rmd` contained in **exams** package.

**Illustration:**

```
R> library("exams")
R> exams2pdf("dist.Rnw")
```

# Exercises: dist.Rnw

```
<<echo=FALSE, results=hide>>=
p <- c(sample(1:3, 1), sample(1:5, 1))
q <- c(sample(4:5, 1), sample(1:5, 1))
sol <- sqrt(sum((p - q)^2))
@

\begin{question}
What is the distance between the two points
$p = (\Sexpr{p[1]}, \Sexpr{p[2]})$ and $q = (\Sexpr{q[1]}, \Sexpr{q[2]})$
in a Cartesian coordinate system?
\end{question}

\begin{solution}
The distance $d$ of $p$ and $q$ is given by
$d^2 = (p_1 - q_1)^2 + (p_2 - q_2)^2$ (Pythagorean formula).

Hence $d = \sqrt{(p_1 - q_1)^2 + (p_2 - q_2)^2} =
  \sqrt{(\Sexpr{p[1]} - \Sexpr{q[1]})^2 + (\Sexpr{p[2]} - \Sexpr{q[2]})^2}
   = \Sexpr{round(sol, digits = 3)}$.
[...]
\end{solution}

%% \extype{num}
%% \exsolution{\Sexpr{round(sol, digits = 3)}}
%% \exname{Euclidean distance}
%% \extol{0.01}
```

# Exercises: dist.Rnw

```
<<echo=FALSE, results=hide>>=
p <- c(sample(1:3, 1), sample(1:5, 1))
q <- c(sample(4:5, 1), sample(1:5, 1))
sol <- sqrt(sum((p - q)^2))
@

\begin{question}
What is the distance between the two points
$p = (\Sexpr{p[1]}, \Sexpr{p[2]})$ and $q = (\Sexpr{q[1]}, \Sexpr{q[2]})$
in a Cartesian coordinate system?
\end{question}

\begin{solution}
The distance $d$ of $p$ and $q$ is given by
$d^2 = (p_1 - q_1)^2 + (p_2 - q_2)^2$ (Pythagorean formula).

Hence $d = \sqrt{(p_1 - q_1)^2 + (p_2 - q_2)^2} =
  \sqrt{(\Sexpr{p[1]} - \Sexpr{q[1]})^2 + (\Sexpr{p[2]} - \Sexpr{q[2]})^2}
   = \Sexpr{round(sol, digits = 3)}$.
[...]
\end{solution}

%% \extype{num}
%% \exsolution{\Sexpr{round(sol, digits = 3)}}
%% \exname{Euclidean distance}
%% \extol{0.01}
```

# Exercises: dist.Rnw

```
<<echo=FALSE, results=hide>>=
p <- c(sample(1:3, 1), sample(1:5, 1))
q <- c(sample(4:5, 1), sample(1:5, 1))
sol <- sqrt(sum((p - q)^2))
@

\begin{question}
What is the distance between the two points
$p = (\Sexpr{p[1]}, \Sexpr{p[2]})$ and $q = (\Sexpr{q[1]}, \Sexpr{q[2]})$
in a Cartesian coordinate system?
\end{question}

\begin{solution}
The distance $d$ of $p$ and $q$ is given by
$d^2 = (p_1 - q_1)^2 + (p_2 - q_2)^2$ (Pythagorean formula).

Hence $d = \sqrt{(p_1 - q_1)^2 + (p_2 - q_2)^2} =
  \sqrt{(\Sexpr{p[1]} - \Sexpr{q[1]})^2 + (\Sexpr{p[2]} - \Sexpr{q[2]})^2}
   = \Sexpr{round(sol, digits = 3)}$.
[...]
\end{solution}

%% \extype{num}
%% \exsolution{\Sexpr{round(sol, digits = 3)}}
%% \exname{Euclidean distance}
%% \extol{0.01}
```

# Exercises: dist.Rnw

```
<<echo=FALSE, results=hide>>=
p <- c(sample(1:3, 1), sample(1:5, 1))
q <- c(sample(4:5, 1), sample(1:5, 1))
sol <- sqrt(sum((p - q)^2))
@

\begin{question}
What is the distance between the two points
$p = (\Sexpr{p[1]}, \Sexpr{p[2]})$ and $q = (\Sexpr{q[1]}, \Sexpr{q[2]})$
in a Cartesian coordinate system?
\end{question}

\begin{solution}
The distance $d$ of $p$ and $q$ is given by
$d^2 = (p_1 - q_1)^2 + (p_2 - q_2)^2$ (Pythagorean formula).

Hence $d = \sqrt{(p_1 - q_1)^2 + (p_2 - q_2)^2} =
  \sqrt{(\Sexpr{p[1]} - \Sexpr{q[1]})^2 + (\Sexpr{p[2]} - \Sexpr{q[2]})^2}
   = \Sexpr{round(sol, digits = 3)}$.
[...]
\end{solution}

%% \extype{num}
%% \exsolution{\Sexpr{round(sol, digits = 3)}}
%% \exname{Euclidean distance}
%% \extol{0.01}
```

# Exercises: dist.Rnw

```
<<echo=FALSE, results=hide>>=
p <- c(sample(1:3, 1), sample(1:5, 1))
q <- c(sample(4:5, 1), sample(1:5, 1))
sol <- sqrt(sum((p - q)^2))
@

\begin{question}
What is the distance between the two points
$p = (\Sexpr{p[1]}, \Sexpr{p[2]})$ and $q = (\Sexpr{q[1]}, \Sexpr{q[2]})$
in a Cartesian coordinate system?
\end{question}

\begin{solution}
The distance $d$ of $p$ and $q$ is given by
$d^2 = (p_1 - q_1)^2 + (p_2 - q_2)^2$ (Pythagorean formula).

Hence $d = \sqrt{(p_1 - q_1)^2 + (p_2 - q_2)^2} =
  \sqrt{(\Sexpr{p[1]} - \Sexpr{q[1]})^2 + (\Sexpr{p[2]} - \Sexpr{q[2]})^2}
   = \Sexpr{round(sol, digits = 3)}$.
[...]
\end{solution}

%% \extype{num}
%% \exsolution{\Sexpr{round(sol, digits = 3)}}
%% \exname{Euclidean distance}
%% \extol{0.01}
```

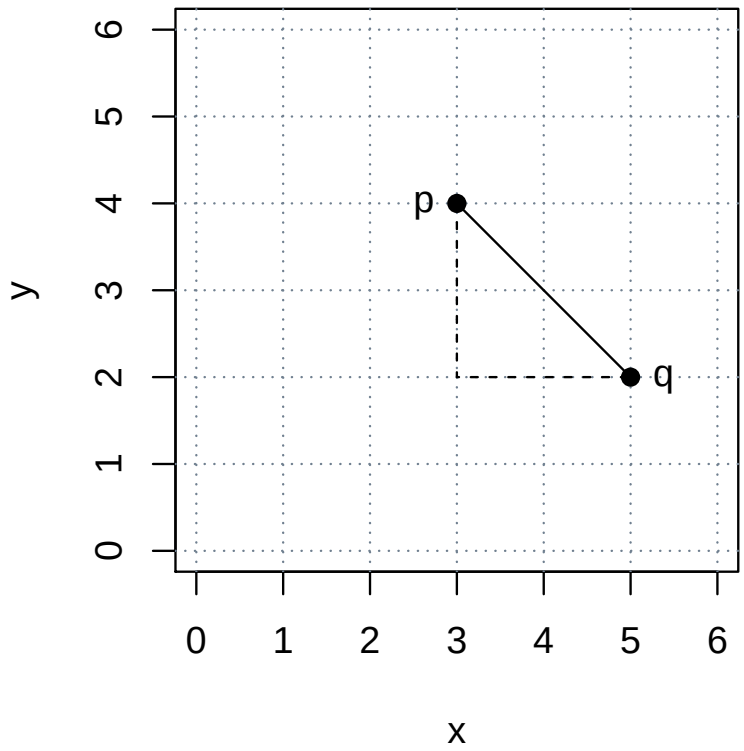
# Exercises: LaTeX output of `Sweave("dist.Rnw")`

```
\begin{question}
What is the distance between the two points
$p = (3, 4)$ and $q = (5, 2)$
in a Cartesian coordinate system?
\end{question}

\begin{solution}
The distance $d$ of $p$ and $q$ is given by
$d^2 = (p_1 - q_1)^2 + (p_2 - q_2)^2$ (Pythagorean formula).

Hence $d = \sqrt{(p_1 - q_1)^2 + (p_2 - q_2)^2} =
  \sqrt{(3 - 5)^2 + (4 - 2)^2}
   = 2.828$.

\includegraphics{dist-002}
\end{solution}

%% \extype{num}
%% \exsolution{2.828}
%% \exname{Euclidean distance}
%% \extol{0.01}
```

# Exercises: PDF output of `exams2pdf("dist.Rnw")`

- **Problem**
  What is the distance between the two points $p = (3, 4)$ and $q = (5, 2)$ in a Cartesian coordinate system?

  **Solution**
  The distance $d$ of $p$ and $q$ is given by $d^2 = (p_1 - q_1)^2 + (p_2 - q_2)^2$ (Pythagorean formula).
  Hence $d = \sqrt{(p_1 - q_1)^2 + (p_2 - q_2)^2} = \sqrt{(3 - 5)^2 + (4 - 2)^2} = 2.828$.



# Exams: Combination of exercises

**Idea:** An exam is simply a list of exercise templates. For example, using statistics exercise templates contained in **exams**.

```
R> myexam <- list(
+    "boxplots.Rnw",
+    c("confint.Rnw", "ttest.Rnw", "tstat.Rnw"),
+    c("anova.Rnw", "regression.Rnw"),
+    "scatterplot.Rnw",
+    "relfreq.Rnw"
+  )
```

**Draw random exams:**

- First randomly select one exercise from each list element.
- Generate random numbers/input for each selected exercise.
- Combine all exercises in output file(s) (PDF, HTML, . . . ).

# Exams: Combination of exercises

**Interfaces:** `exams2pdf()`, `exams2html()`, `exams2moodle()`, `exams2qti12()`, `exams2nops()`, `exams2arsnova()`, ...

**Workhorse function:** Internally, all interfaces call `xexams()` that handles (temporary) files/directories and carries out four steps.

1. *Weave:* Each `.Rnw`/`.Rmd` exercise is weaved into a `.tex`/`.md` file. Default: `xweave()` which calls `Sweave()` or `knit()`.
2. *Read:* Each resulting `.tex`/`.md` file is read into an R list with question, solution, metainformation. Default: `read_exercise()`.
3. *Transform:* Each of these exercise-wise list objects can be transformed, e.g., by converting LaTeX text to HTML or Markdown to LaTeX etc. Default: No transformation.
4. *Write:* The (possibly transformed) lists of exercises can be written out to one ore more files per exam in an output directory. Default: No files are written.

# Exams: Transformers

**Transformer functions:**

- For LaTeX to HTML: Ian H. Hutchinson's **TtH** (TeX to HTML) package (**tth** in R). Mathematical notation is either represented using MathML (`ttm`), requiring a suitable browser (e.g., Firefox or Safari), or plain HTML (`tth`).
- Alternatively: John MacFarlane's **pandoc** package (**rmarkdown** in R) with various options for rendering mathematical notation (including MathML).
- For Markdown to HTML or LaTeX: **pandoc** only.
- In either case: No LaTeX installation needed, but also limited to LaTeX commands supported by **TtH** or **pandoc**, respectively.
- Links to dynamically generated data can be easily included, e.g., `\url{mydata.rda}` (`.Rnw`) or `[mydata.rda](mydata.rda)` (`.Rmd`).

# Exams: PDF output

`exams2pdf()`:

- The *write* step embeds all questions/solutions into (one or more) master LaTeX template(s).
- LaTeX templates control whether solutions are shown, what the title page looks like, etc.
- Compilation of each exam via pdfLaTeX (called from within R).

A single exam is popped up in a PDF viewer:

```
R> exams2pdf(myexam, template = "exam")
```

Multiple exams are written to an output directory:

```
R> odir <- tempfile()
R> set.seed(1090)
R> exams2pdf(myexam, n = 3, dir = odir,
+    template = c("exam", "solution"))
```

# Exams: PDF output

**R University**
**Statistics Exam 2015-12-02** **Exam ID 00001**

**Name:** _____

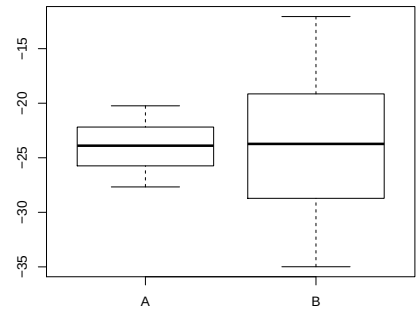
**Student ID:** _____

**Signature:** _____

1. (a) ☐ (b) ☐ (c) ☐ (d) ☐ (e) ☐
2. ☐☐☐☐☐☐ . ☐☐☐
3. ☐☐☐☐☐☐ . ☐☐☐
4. (a) ☐ (b) ☐ (c) ☐ (d) ☐ (e) ☐
5. (a) ☐ (b) ☐ (c) ☐ (d) ☐ (e) ☐



1. In the following figure the distributions of a variable given by two samples (A und B) are represented by parallel boxplots. Which of the following statements are correct? *(Comment: The statements are either about correct or clearly wrong.)*




   (a) The location of both distributions is about the same.
   (b) Both distributions contain no outliers.
   (c) The spread in sample A is clearly bigger than in B.
   (d) The skewness of both samples is similar.
   (e) Distribution A is about symmetric.

2. A machine fills milk into 500ml packages. It is suspected that the machine is not working correctly and that the amount of milk filled differs from the setpoint $\mu_0 = 500$. A sample of 226 packages filled by the machine are collected. The sample mean $\bar{y}$ is equal to 499.7 and the sample variance $s^2_{n-1}$ is equal to 576.1.

   Test the hypothesis that the amount filled corresponds on average to the setpoint. What is the absolute value of the $t$ test statistic?

3. For 49 firms the number of employees $X$ and the amount of expenses for continuing education $Y$ (in EUR) were recorded. The statistical summary of the data set is given by:

| | Variable $X$ | Variable $Y$ |
|---|---|---|
| Mean | 58 | 232 |
| Variance | 124 | 1606 |

   The correlation between $X$ and $Y$ is equal to 0.65.

   Estimate the expected amount of money spent for continuing education by a firm with 60 employees using least squares regression.

4. The following figure shows a scatterplot. Which of the following statements are correct?

# Exams: PDF output (NOPS)

`exams2nops()`:

- Calls `exams2pdf()` internally.
- Standardized and internationalized LaTeX template is generated on the fly.
- Intended for single-choice and multiple-choice questions.
- Can be scanned and evaluated automatically within R.
- Limited support for open-ended questions that have to be marked by a person.

A single exam is popped up in a PDF viewer, multiple exams are written to an output directory:

```
R> set.seed(1090)
R> exams2nops(myexam[-(2:3)], n = 3, dir = odir)
```

# Exams: PDF output (NOPS)

**R University**

**Exam 2015-12-02**

Personal Data

Family Name:

Given Name:

Signature:

checked

Registration Number

0 1 2 3 4 5 6 7 8 9

In this section **no** changes or modifications must be made!

**Scrambling** 0 0

Type: 005

Exam ID: 15120200001

Please mark the boxes carefully: ☒ Not marked: ☐ or ■

This document is scanned automatically. Please keep clean and do not bend or fold. For filling in the document please use a **blue or black pen**.

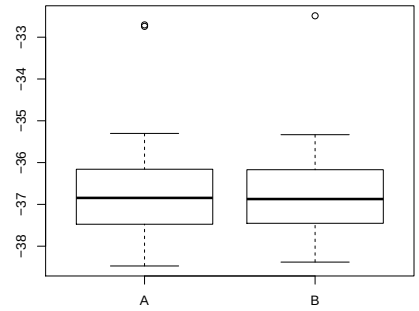
**Only clearly marked and positionally accurate crosses will be processed!**

Answers 1 - 3

| | a | b | c | d | e |
|---|---|---|---|---|---|
| 1 | ☐ | ☐ | ☐ | ☐ | ☐ |
| 2 | ☐ | ☐ | ☐ | ☐ | ☐ |
| 3 | ☐ | ☐ | ☐ | ☐ | ☐ |

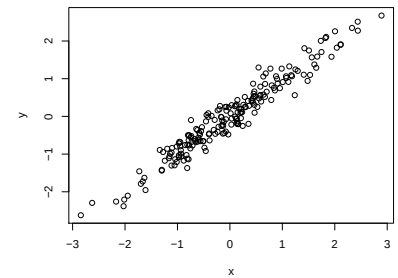


1. In the following figure the distributions of a variable given by two samples (A und B) are represented by parallel boxplots. Which of the following statements are correct? *(Comment: The statements are either about correct or clearly wrong.)*




(a) The location of both distributions is about the same.
(b) Both distributions contain no outliers.
(c) The spread in sample A is clearly bigger than in B.
(d) The skewness of both samples is similar.
(e) Distribution A is about symmetric.

2. The following figure shows a scatterplot. Which of the following statements are correct?




(a) The slope of the regression line is about 1.
(b) The standard deviation of $Y$ is at least 6.

# Exams: HTML output

`exams2html()`:

- In the *transform* step, LaTeX/Markdown text is converted to HTML using either **TtH** or **pandoc**.
- The *write* step embeds everything into HTML templates and writes out one HTML file per exam.
- Also useful for quickly checking whether an exercises is processed correctly.

A single exam is popped up in a browser, multiple exams are written to an output directory:

```
R> set.seed(1090)
R> exams2html(myexam, n = 3, dir = odir)
```

# Exams: HTML output

File Edit View History Bookmarks Tools Help

Exam 1

file:///tmp/RtmpjjlbQz/file2c8d10dbc901/plain1.html

DuckDuckGo

## Exam 1

1. **Question**

   In Figure  the distributions of a variable given by two samples (A und B) are represented by parallel boxplots. Which of the following statements are correct? *(Comment: The statements are either about correct or clearly wrong.)*

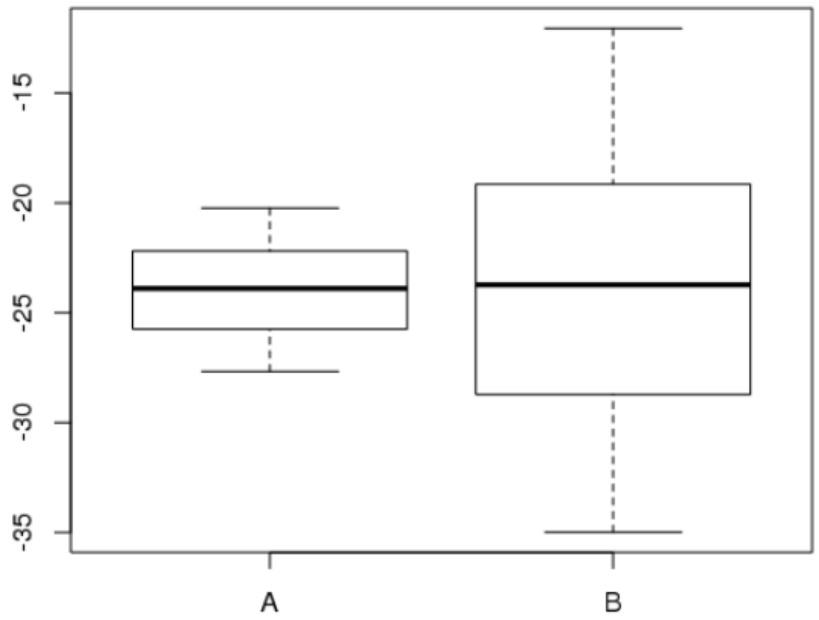



Figure 1: Parallel boxplots.

a. The location of both distributions is about the same.
b. Both distributions contain no outliers.
c. The spread in sample A is clearly bigger than in B.
d. The skewness of both samples is similar.
e. Distribution A is about symmetric.

# Exams: Moodle XML

`exams2moodle()`:

- All LaTeX/Markdown text is *transformed* to HTML.
- Rather than writing out one file per exam, a single **Moodle** XML file encompassing all exams is produced.
- All supplementary materials (graphics, data, etc.) are embedded into the HTML code directly using Base64 encoding.
- The resulting `.xml` file can be easily imported into a question bank in **Moodle** and then be used within a **Moodle** quiz.

Multiple replications are written to a single XML file in the output directory:

```
R> set.seed(1090)
R> exams2moodle(myexam, n = 3, dir = odir)
```

# Exams: Moodle XML

File Edit View History Bookmarks Tools Help

JSS Quiz

138.232.202.120/mod/quiz/attempt.php?attempt=2

DuckDuckGo

**R exams course**

You are logged in as Nikolaus Umlauf (Logout)

Home ► Rexams ► 20 November - 26 November ► JSS Quiz ► Preview

**Quiz navigation**

1 2 3 4 5

Finish attempt ...

Start a new preview

**Navigation**

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      - 4 December - 10 December
      - 11 December - 17 December
      - 18 December - 24 December
      - 25 December - 31

Question 1

Not yet answered

Marked out of 1.00

Flag question

Edit question

In Figure  the distributions of a variable given by two samples (A und B) are represented by parallel boxplots. Which of the following statements are correct? *(Comment: The statements are either about correct or clearly wrong.)*

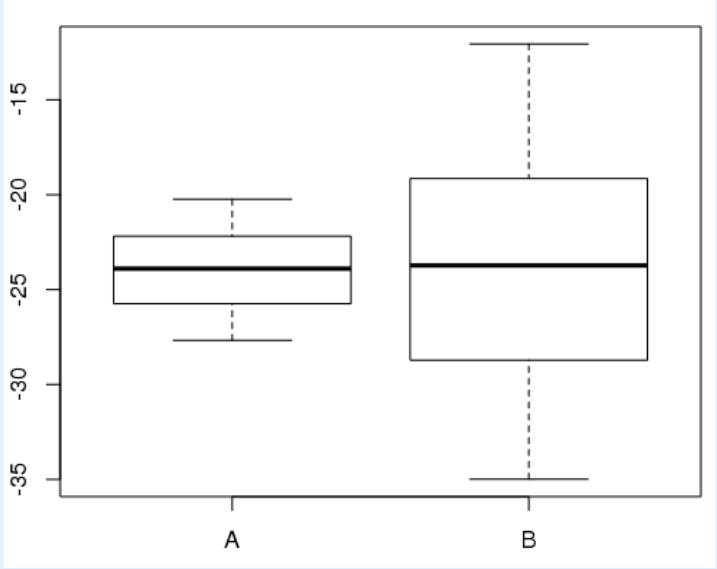



Figure 1: Parallel boxplots.

Select one or more:

- a. The location of both distributions is about the same.
- b. Both distributions contain no outliers.
- c. The spread in sample A is clearly bigger than in B.
- d. The skewness of both samples is similar.
- e. Distribution A is about symmetric.

# Exams: QTI

`exams2qti12()`/`exams2qti21()`:

- All LaTeX/Markdown text is *transformed* to HTML.
- Rather than writing out one file per exam, a single `.zip` archive is produced, containing the QTI XML specification (version 1.2 or 2.1) plus supplementary materials (graphics, data, etc.) if any.
- Base64 encoding is used for graphics by default, but not for other supplements.
- QTI (question and test interoperability) is an international standard for e-learning exams.
- The `.zip` files can be easily imported into various learning management systems, e.g., **OLAT**/**OpenOLAT**.

Multiple replications are written to a single zipped XML file in the output directory:

```
R> set.seed(1090)
R> exams2qti12(myexam, n = 3, dir = odir)
```

# Exams: QTI

File Edit View History Bookmarks Tools Help

OLAT - OLAT: Course templat...

138.232.202.96:8080/OLAT-LMS-7.6.0.0/auth/1%3A6%3A1000020776%3A1%3

DuckDuckGo

Print Help Log out

Home | Groups | Learning resources | Group administration | User management | Administration | gui_demo | OLAT: Course...

qti12

Finish test

Actual score: 0 / 5

qti12

1. Exercise
1.1. Question 0
2. Exercise
2.1. Question 0
3. Exercise
3.1. Question 0
4. Exercise
4.1. Question 0
5. Exercise
5.1. Question 0

Still 1 attempt(s).

## Question

In Figure the distributions of a variable given by two samples (A und B) are represented by parallel boxplots. Which of the following statements are correct? *(Comment: The statements are either about correct or clearly wrong.)*

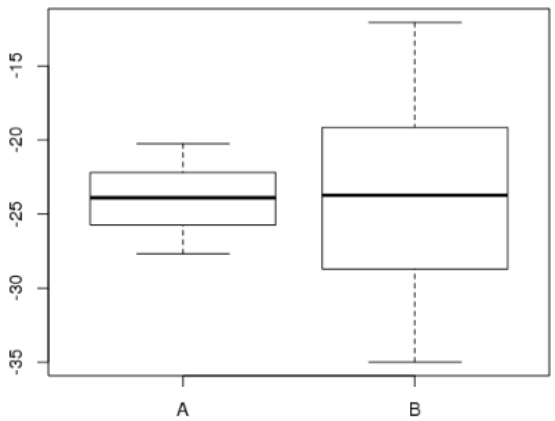



Figure 1: Parallel boxplots.

- [ ] a. The location of both distributions is about the same.
- [ ] b. Both distributions contain no outliers.
- [ ] c. The spread in sample A is clearly bigger than in B.
- [ ] d. The skewness of both samples is similar.
- [ ] e. Distribution A is about symmetric.

Save answer

# Exams: ARSnova

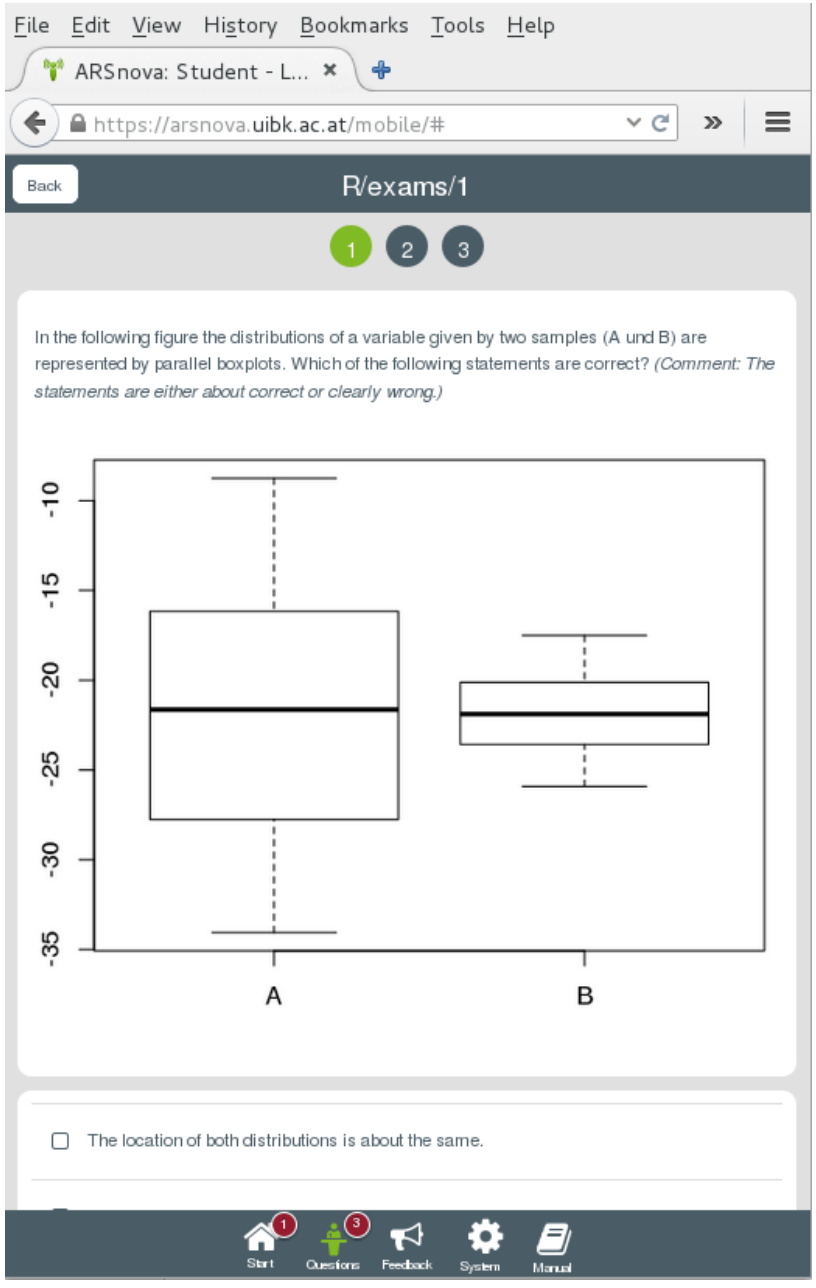
`exams2html()`:

- In the *transform* step, LaTeX text is converted to Markdown using **pandoc**.
- The *write* step embeds everything into a JSON format and writes out one JSON file per exam.
- The JSON file can be imported in **ARSnova** to create a new session.
- Alternatively, questions can be imported into an existing **ARSnova** session via **RCurl**.
- No proper support for numeric exercises, yet (but under development by **ARSnova** team).

Multiple exams are written to an output directory:

```
R> set.seed(1090)
R> exams2arsnova(myexam[-(2:3)], n = 3, dir = odir)
```

# Exams: ARSnova



# Discussion

**Package exams:**

- Framework for automatic generation of simple (mathematical or statistical) exams and associated self-study materials.
- Based on independent exercises in `.Rnw`/`.Rmd` format which can be compiled into exams (or other collections of exercises).
- Version 1 (Grün and Zeileis 2009) only supported PDF output, version 2 (Zeileis *et al.* 2014) added a toolbox for various output formats, recent versions add support for Markdown and **pandoc**.
- Contributing to the pool of exercises only requires knowledge of `Sweave`/**knitr** and minimal markup for metainformation.
- For a first session employ `exams_skeleton()` which copies demo scripts, exercises, and templates into a working directory.
- Hosted on R-Forge, providing a support forum: `http://R-Forge.R-project.org/projects/exams/`

# Discussion

**At Universität Innsbruck:**

- Large-scale courses with **OpenOLAT** support.
- Team of about 5–10 persons (professors, lecturers, student assistants) contribute to the pool of exercises.
- During the semester, several online tests (and self tests) are carried out in **OpenOLAT** (via `exams2qti12`) using numerical and multiple-choice exercises.
- Written exams (via `exams2nops`) are carried out using single-choice exercises. Results are scanned (via `nops_scan`) and automatically evaluated (via `nops_eval`). Individual HTML reports are uploaded for each student into **OpenOLAT**.

# References


Zeileis A, Grün B, Leisch F, Umlauf N (2015). ***exams**: Automatic Generation of Exams in R.* R package version 2.1-0.
URL `http://CRAN.R-project.org/package=exams`

Zeileis A, Umlauf N, Leisch F (2014). "Flexible Generation of E-Learning Exams in R: Moodle Quizzes, OLAT Assessments, and Beyond." *Journal of Statistical Software*, **58**(1), 1–36. `doi:10.18637/jss.v058.i01`

Grün B, Zeileis A (2009). "Automatic Generation of Exams in R." *Journal of Statistical Software*, **29**(10), 1–14. `doi:10.18637/jss.v029.i10`