R/exams

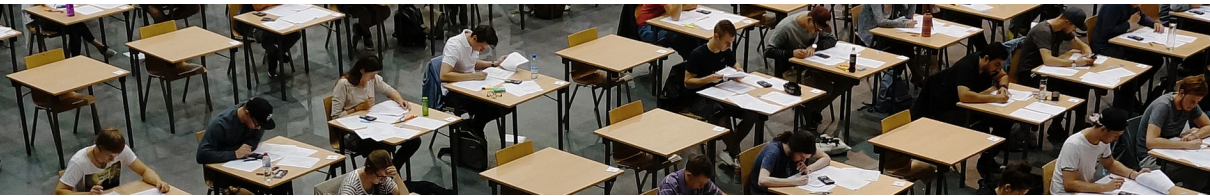
R/exams: A One-for-All Exams Generator

Written Exams, Online Tests, and Live Quizzes with R

Achim Zeileis

`http://www.R-exams.org/`

R/exams



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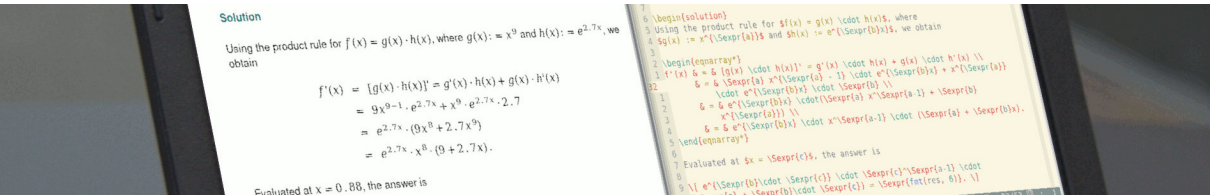

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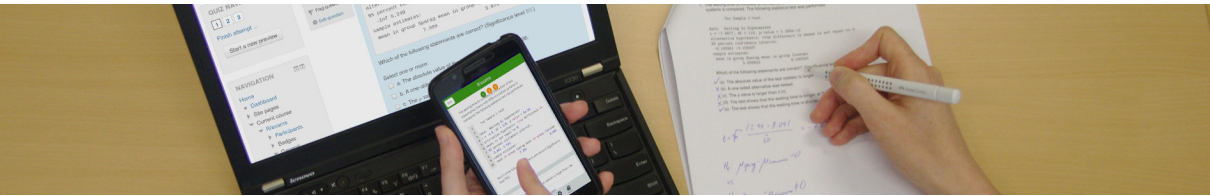

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Motivation and challenges

Motivation:

- Many of us teach large lecture courses, also as support for other fields.
- For example, statistics, probability, or mathematics in curricula such as business and economics, social sciences, psychology, etc.
- At WU Wien and Universität Innsbruck: Some courses are attended by more than 1,000 students per semester.
- Several lecturers teach lectures and tutorials in parallel.

Strategy:

- Individualized organization of learning, feedback, and assessment.
- The same pool of exercises at the core of all parts of the course.

Motivation and challenges

	Learning	Feedback	Assessment
Synchronous	Lecture	Live quiz	Written exam
	Live stream	(+ Tutorial)	
Asynchronous	Textbook	Self test	Online test
	Screencast	(+ Forum)	

Motivation and challenges

	Learning	Feedback	Assessment
Synchronous	Lecture	Live quiz	Written exam
	Live stream	(+ Tutorial)	
Asynchronous	Textbook	Self test	Online test
	Screencast	(+ Forum)	

Learning:

- *Standard:* Textbook along with presentation slides.
- *Streaming:* Videos streamed simultaneously or (pre-)recorded.

Motivation and challenges

	Learning	Feedback	Assessment
Synchronous	Lecture	Live quiz	Written exam
	Live stream	(+ Tutorial)	
Asynchronous	Textbook	Self test	Online test
	Screencast	(+ Forum)	

Feedback & assessment:

- *Scalability:* Randomized dynamic exercises required.
- *Feedback:* Support for complete correct solutions.
- *Flexibility:* Automatic rendering into different assessment formats.

R package *exams*

Exercises:

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

Answer types:

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

R package *exams*

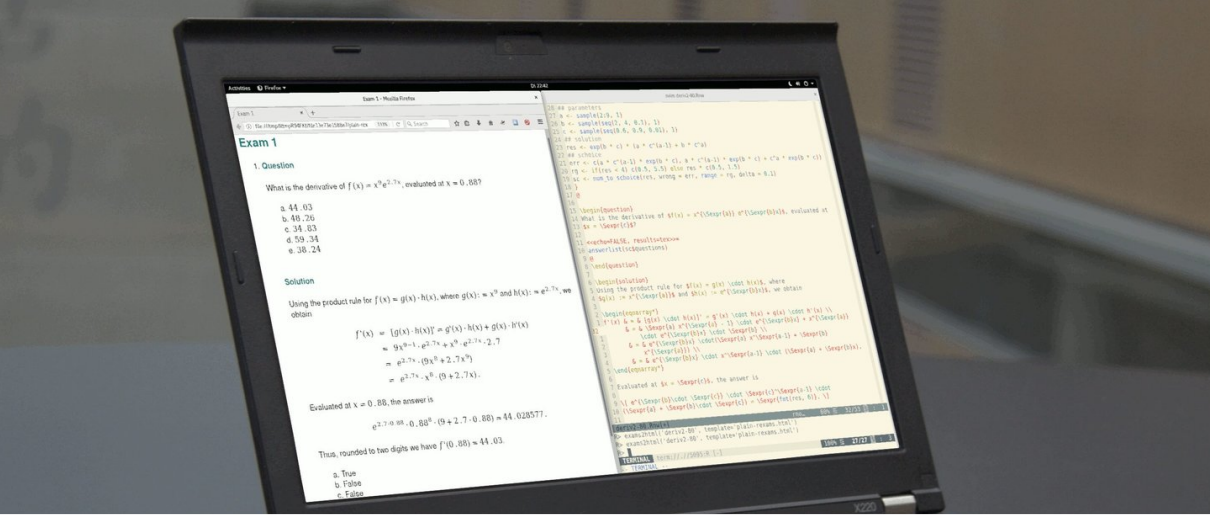
Output:

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

Infrastructure: Standing on the shoulders of lots of open-source software...

R package *exams*

Type	Software	Purpose
Statistical computing	R	Random data generation, computations
Writing/reporting	LaTeX, *Markdown*	Text formatting, mathematical notation
Reproducible research	*knitr*, *rmarkdown*, `Sweave`	Dynamically tie everything together
Document conversion	*TtH*/*TtM*, *pandoc*	Conversion to HTML and beyond
Image manipulation	*ImageMagick*, *magick*, *png*	Embedding graphics
Web technologies	*base64enc*, *RCurl*, …	Embedding supplementary files
Learning management	*Moodle*, *OpenOLAT*, *ARSnova*, …	E-learning infrastructure



Dynamic Exercises

Dynamic exercises

Text file:

1. Random data generation (optional).
2. Question.
3. Solution (optional).
4. Metainformation.

Examples:

Multiple-choice knowledge quiz with shuffled answer alternatives.
Which of these are open-source learning management systems?

Dynamic numeric arithmetic exercise.
What is the derivative of $f(x) = x^a e^{b \cdot x}$, evaluated at $x = c$?

Dynamic exercises: `.Rmd`

Example: Which of these are open-source learning management systems?

Dynamic exercises: `.Rmd`

Example: Which of these are open-source learning management systems?

```
Question
========
Which of these are open-source learning management systems?

Answerlist
----------
* Canvas
* Ilias
* Moodle
* OLAT
* Blackboard
* Desire2Learn
```

Dynamic exercises: `.Rmd`

Example: Which of these are open-source learning management systems?

```
Solution
========
An overview of learning management systems can be found in Wikipedia at
<https://en.wikipedia.org/wiki/List_of_learning_management_systems>.

Answerlist
----------
* True. Canvas is developed by Instructure Inc. under the Affero General Public License Version 3.
* True. Ilias is an open-source system released under the General Public License.Version 3.
* True. Moodle is an open-source system released under the General Public License Version 3.
* True. OLAT is developed by the University of Zurich under the Apache License 2.0 License.
* False. Blackboard Learn is a commercial system developed by Blackboard Inc.
* False. Brightspace is a commercial system developed by Desire2Learn.
```

Dynamic exercises: `.Rmd`

Example: Which of these are open-source learning management systems?

```
Solution
========
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* False. Blackboard Learn is a commercial system developed by Blackboard Inc.
* False. Brightspace is a commercial system developed by Desire2Learn.

Meta-information
================
exname: Learning management systems
extype: mchoice
exsolution: 111100
exshuffle: 5
```

Dynamic exercises: `.Rnw`

Example: What is the derivative of $f(x) = x^a e^{b \cdot x}$, evaluated at $x = c$?

Dynamic exercises: `.Rnw`

Example: What is the derivative of $f(x) = x^a e^{b \cdot x}$, evaluated at $x = c$?

```
<<echo=FALSE, results=hide>>=
## parameters
a <- sample(2:9, 1)
b <- sample(seq(2, 4, 0.1), 1)
c <- sample(seq(0.5, 0.8, 0.01), 1)
## solution
res <- exp(b * c) * (a * c^(a-1) + b * c^a)
@
```

Dynamic exercises: `.Rnw`

Example: What is the derivative of $f(x) = x^a e^{b \cdot x}$, evaluated at $x = c$?

```
<<echo=FALSE, results=hide>>=
## parameters
a <- sample(2:9, 1)
b <- sample(seq(2, 4, 0.1), 1)
c <- sample(seq(0.5, 0.8, 0.01), 1)
## solution
res <- exp(b * c) * (a * c^(a-1) + b * c^a)
@

\begin{question}
What is the derivative of $f(x) = x^{\Sexpr{a}} e^{\Sexpr{b}x}$,
evaluated at $x = \Sexpr{c}$?
\end{question}
```

Dynamic exercises: `.Rnw`

Example: What is the derivative of $f(x) = x^a e^{b \cdot x}$, evaluated at $x = c$?

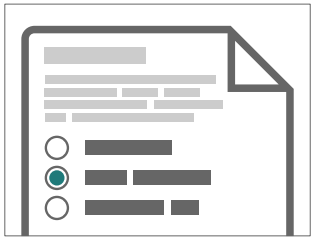
```
\begin{solution}
Using the product rule for $f(x) = g(x) \cdot h(x)$, where
$g(x) := x^{\Sexpr{a}}$ and $h(x) := e^{\Sexpr{b}x}$, we obtain
\begin{eqnarray*}
f'(x) & = & [g(x) \cdot h(x)]' = g'(x) \cdot h(x) + g(x) \cdot h'(x) \\
      & = & \Sexpr{a} x^{\Sexpr{a} - 1} \cdot e^{\Sexpr{b}x} +
            ...
\end{eqnarray*}
Evaluated at $x = \Sexpr{c}$, the answer is
\[ e^{\Sexpr{b}\cdot \Sexpr{c}} \cdot \Sexpr{c}^\Sexpr{a-1} \cdot
   (\Sexpr{a} + \Sexpr{b}\cdot \Sexpr{c}) = \Sexpr{fmt(res, 6)}. \]
Thus, rounded to two digits we have $f'(\Sexpr{c}) = \Sexpr{fmt(res)}$.
\end{solution}
```

Dynamic exercises: `.Rnw`

Example: What is the derivative of $f(x) = x^a e^{b \cdot x}$, evaluated at $x = c$?

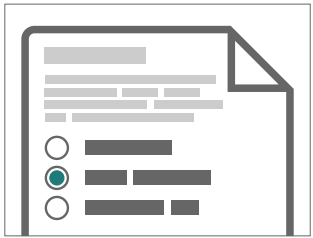
```
\begin{solution}
Using the product rule for $f(x) = g(x) \cdot h(x)$, where
$g(x) := x^{\Sexpr{a}}$ and $h(x) := e^{\Sexpr{b}x}$, we obtain
\begin{eqnarray*}
f'(x) & = & [g(x) \cdot h(x)]' = g'(x) \cdot h(x) + g(x) \cdot h'(x) \\
      & = & \Sexpr{a} x^{\Sexpr{a} - 1} \cdot e^{\Sexpr{b}x} +
            ...
\end{eqnarray*}
Evaluated at $x = \Sexpr{c}$, the answer is
\[ e^{\Sexpr{b}\cdot \Sexpr{c}} \cdot \Sexpr{c}^\Sexpr{a-1} \cdot
   (\Sexpr{a} + \Sexpr{b}\cdot \Sexpr{c}) = \Sexpr{fmt(res, 6)}. \]
Thus, rounded to two digits we have $f'(\Sexpr{c}) = \Sexpr{fmt(res)}$.
\end{solution}

\extype{num}
\exsolution{\Sexpr{fmt(res)}}
\exname{derivative exp}
\extol{0.01}
```

Dynamic exercises: Single choice



```
extype: schoice
exsolution: 010
```

Dynamic exercises: Single choice



```
extype: schoice
exsolution: 010
```

Question
What is the seat of the federal authorities in Switzerland (i.e., the de facto capital)?

(a) Bern

(b) Lausanne

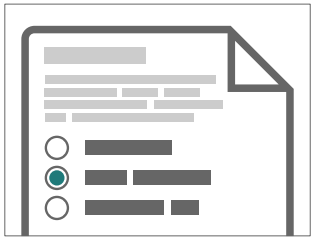
(c) Zurich

(d) St. Gallen

(e) Basel

Knowledge quiz: Shuffled distractors.

Dynamic exercises: Single choice



```
extype: schoice
exsolution: 010
```

Question
What is the derivative of $f(x) = x^3 e^{3.3x}$, evaluated at $x = 0.85$?

(a) 45.97

(b) 35.82

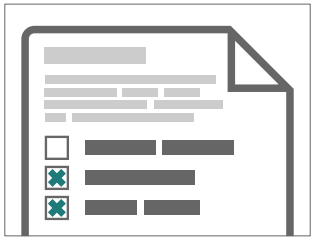
(c) 56.45

(d) 69.32

(e) 39.31

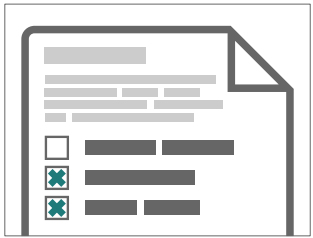
Numeric exercises: Distractors are random numbers and/or typical arithmetic mistakes.

Dynamic exercises: Multiple choice



```
extype: mchoice
exsolution: 011
```

Dynamic exercises: Multiple choice



```
extype: mchoice
exsolution: 011
```

Question
Which of these are open-source learning management systems?

(a) Ilias

(b) OLAT

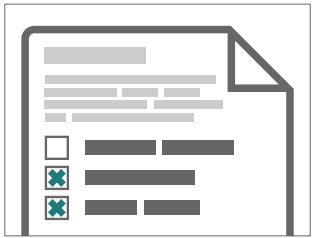
(c) Blackboard

(d) Moodle

(e) Canvas

Knowledge quiz: Shuffled true/false statements.

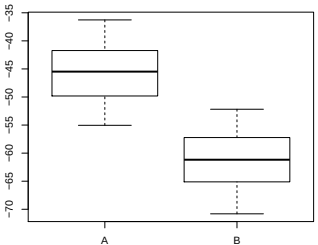
Dynamic exercises: Multiple choice



```
extype: mchoice
exsolution: 011
```

Question

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

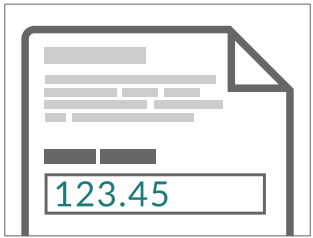


(a) The location of both distributions is about the same.

(b) Both distributions contain no outliers

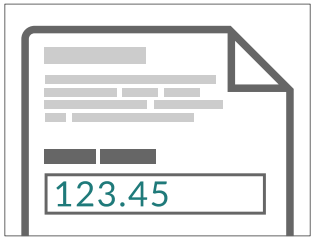
Interpretations: Statements that are approximately correct or clearly wrong.

Dynamic exercises: Numeric

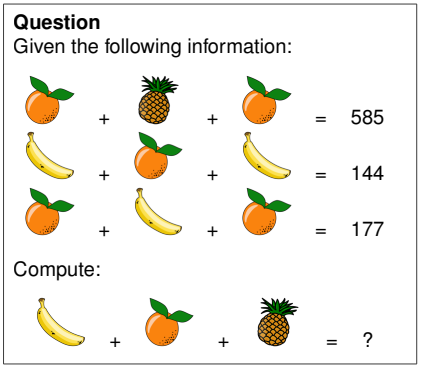



```
extype: num
exsolution: 123.45
```

Dynamic exercises: Numeric




```
extype: num
exsolution: 123.45
```



Numeric exercises: Solving arithmetic problems.

Dynamic exercises: String


```
extype: string
exsolution: ANSWER
```

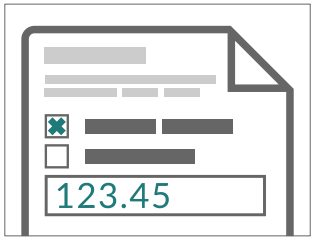
Dynamic exercises: String


```
extype: string
exsolution: ANSWER
```

Question
What is the name of the R function for Poisson regression?

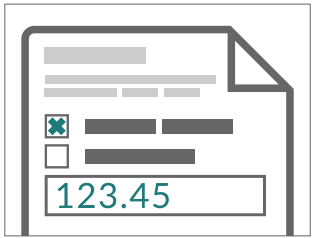
Knowledge quiz: Sample a word/phrase from a given vocabulary or list of question/answer pairs.

Dynamic exercises: Cloze




```
extype: cloze
exclozetype: mchoice|num
exsolution: 10|123.45
```

Dynamic exercises: Cloze



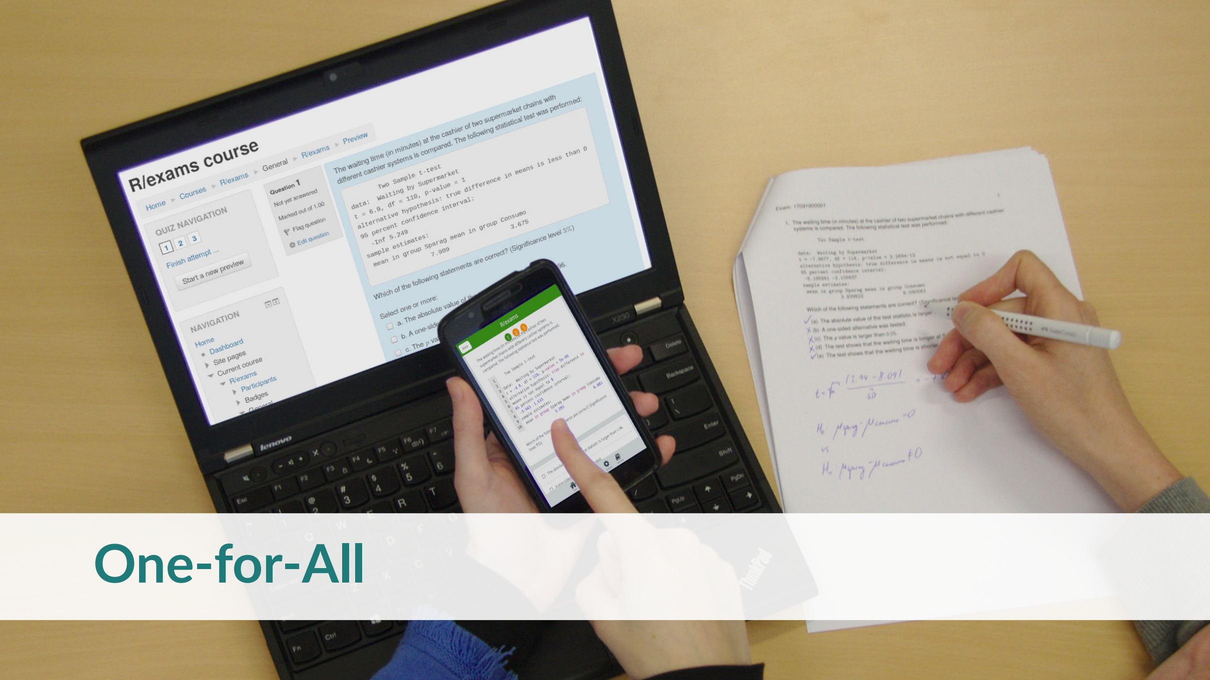

```
extype: cloze
exclozetype: mchoice|num
exsolution: 10|123.45
```

Question
Using the data provided in `regression.csv` estimate a linear regression of `y` on `x` and answer the following questions.

(a) `x` and `y` are not significantly correlated / `y` increases significantly with `x` / `y` decreases significantly with `x`

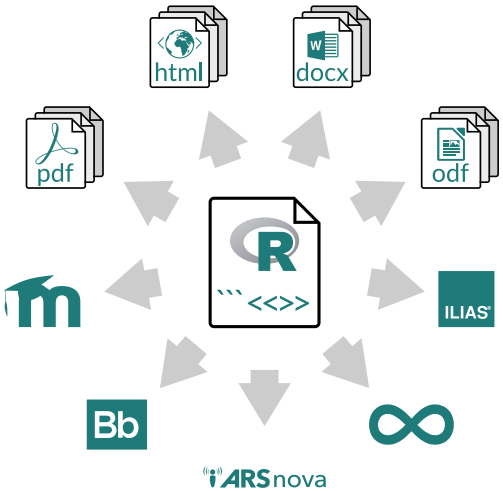
(b) Estimated slope with respect to `x`:

Exercises with sub-tasks: Several questions based on same problem setting.


R/exams course
Home
Courses
R/exams
General
R/exams
Preview
QUIZ NAVIGATION
1 2 3
Finish attempt ...
Start a new preview
NAVIGATION
Home
Dashboard
Site pages
Current course
R/exams
Participants
Badges
Question 1
Not yet answered
Marked out of 1.00
Flag question
Edit question
The waiting time (in minutes) at the cashier of two supermarket chains with different cashier systems is compared. The following statistical test was performed:
Two Sample t-test
data: Waiting by Supermarket
t = 6.9, df = 118, p-value = 1
alternative hypothesis: true difference in means is less than 0
95 percent confidence interval:
-Inf 5.249
sample estimates:
mean in group Sparag mean in group Consumo
7.989 3.675
Which of the following statements are correct? (Significance level 5%)
Select one or more:
lenovo

One-for-All

One-for-all



- The *same* exercise can be exported into different formats.
- Multiple standalone documents vs. combined exercise pool.
- Multiple-choice and single-choice supported in all output formats.

One-for-All

Idea: An exam is simply a list of exercise templates.

```
R> myexam <- list(
+    "deriv2.Rnw",
+    "fruit2.Rnw",
+    c("ttest.Rnw", "boxplots.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, ...).

One-for-All

Written exam:

```
R> exams2nops(myexam, n = 3, dir = odir,
+    language = "nl", institution = "TEA 2018")
```

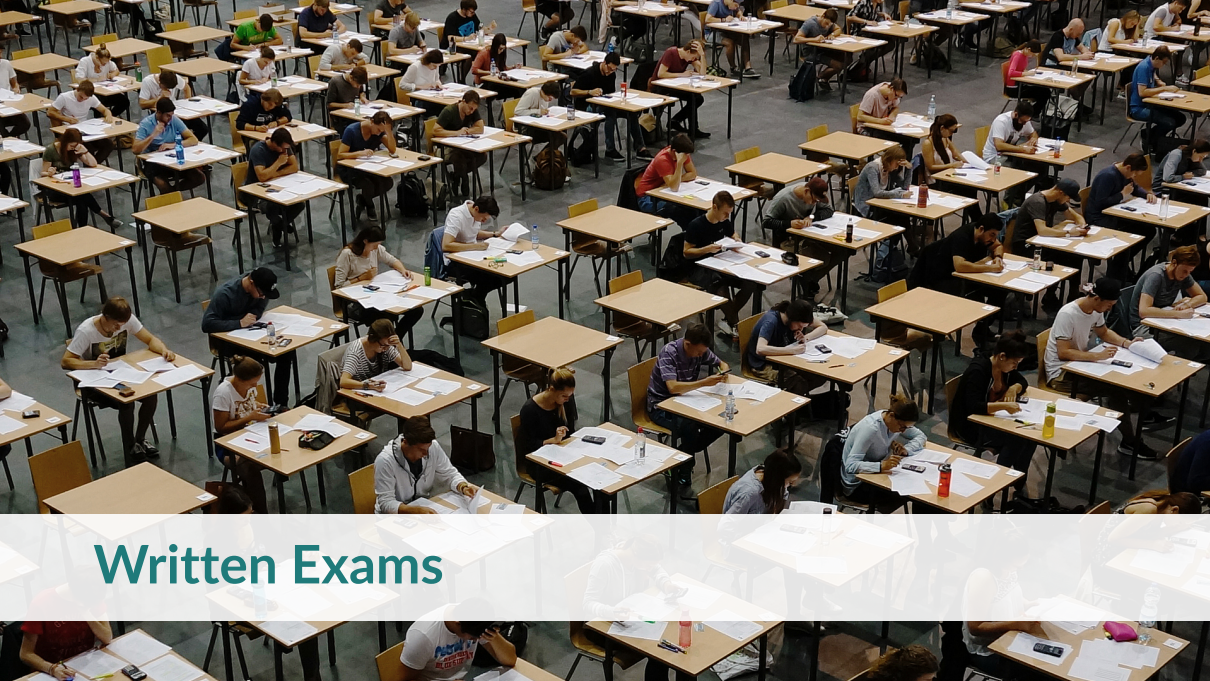
Online test:

```
R> exams2moodle(myexam, n = 10, dir = odir)
```

Live quiz:

```
R> exams2arsnova(myexam, n = 1, dir = odir)
```

Other: `exams2pdf()`, `exams2html()`, `exams2qti12()`, `exams2qti21()`, ...



Written Exams

Written Exams

Flexible: Roll your own.

- Combination with user-specified template in `exams2pdf()` and `exams2pandoc()`.
- Customizable but typically has to be evaluated “by hand”.

Standardized: “NOPS” format.

- `exams2nops()` intended for single- 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.

Written exams

TEA 2018

Exam 2018-12-09

Persoonlijke Gegevens

Achternaam:

Voornaam:

Handtekening:

Gecontroleerd

Studentnummer

0 1 2 3 4 5 6 7 8 9

Scrambling

0 , 0

In dit veld mag **niets** worden aangepast!

Type: 005

Examen-ID: 1812090001

Graag zorgvuldig aankruisen: ☒ Niet aangekruist: ☐ ↺ ■

Dit document wordt automatisch gescand. Zorg ervoor dat het schoon blijft; niet kreukelen of vouwen. Vul de vragen in met een **blauwe of zwarte** pen.

Alleen duidelijk en correct geplaatste kruisjes worden verwerkt!

Antwoorden 1 - 3

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

Exam: 1812090001 1

1. What is the derivative of $f(x) = x^3 e^{0.7x}$, evaluated at $x = 0.83$?

   (a) 49.35
   (b) 87.17
   (c) 71.00
   (d) 72.46
   (e) 55.20

2. Given the following information:

   Compute:

   (a) 106
   (b) 313
   (c) 161
   (d) 232
   (e) 454

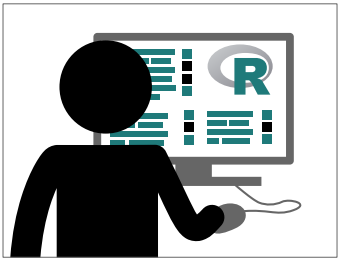
3. The waiting time (in minutes) at the cashier of two supermarket chains with different cashier systems is compared. The following statistical test was performed:

```
        Two Sample t-test

data:  Waiting by Supermarket
t = -3.3, df = 90, p-value = 1
alternative hypothesis: true difference in means is greater than 0
95 percent confidence interval:
 -3.227     Inf
sample estimates:
mean in group Sparag mean in group Consumo
               4.045                6.192
```

   Which of the following statements are correct? (Significance level 5%)

   (a) The absolute value of the test statistic is larger than 1.96.
   (b) A one-sided alternative was tested.
   (c) The *p* value is larger than 0.05.
   (d) The test shows that the waiting time is longer at Sparag than at Consumo.
   (e) The test shows that the waiting time is shorter at Sparag than at Consumo.

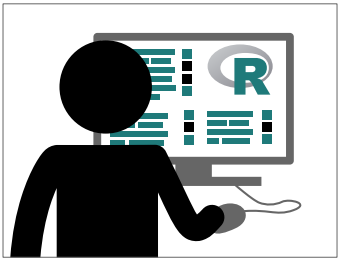
Written exams

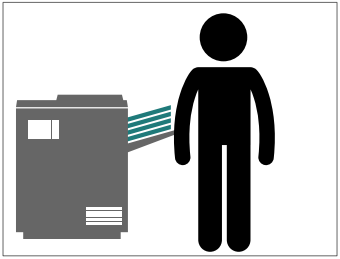


1. Create

- As illustrated above.
- Using `exams2nops()`, create (individual) PDF files for each examinee.

Written exams





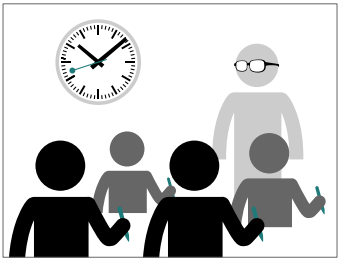
1. Create

- As illustrated above.
- Using `exams2nops()`, create (individual) PDF files for each examinee.

2. Print

- Print the PDF exams, e.g., on a standard printer.
- …or for large exams at a print shop.

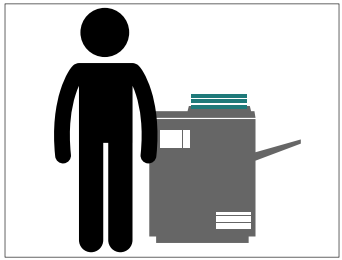
Written exams



3. Exam

- Conduct the exam as usual.
- Collect the completed exams sheets.

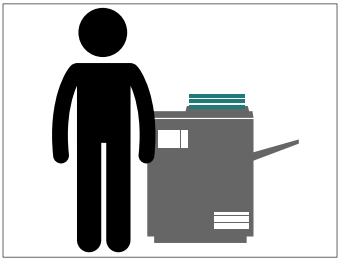
Written exams

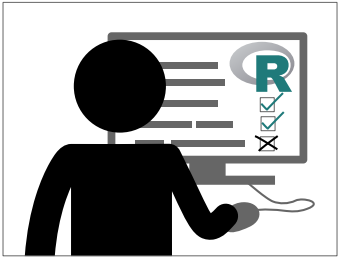


4. Scan

- Scan exam sheets, e.g., on a photocopier.
- Using `nops_scan()`, process the scanned exam sheets to machine-readable content.

Written exams





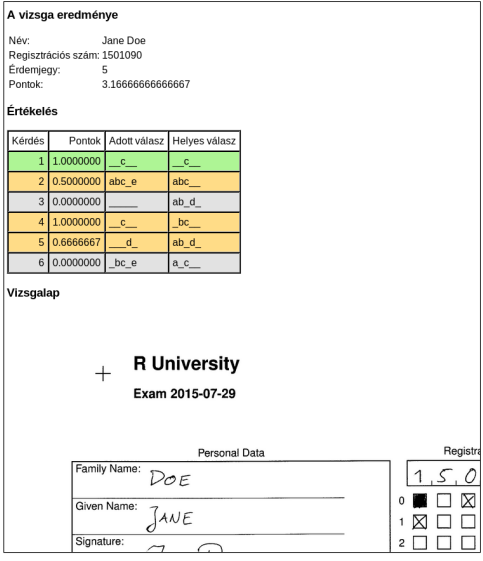
4. Scan

- Scan exam sheets, e.g., on a photocopier.
- Using `nops_scan()`, process the scanned exam sheets to machine-readable content.

5. Evaluate

- Using `nops_eval()`, evaluate the exam to obtain marks, points, etc. and individual HTML reports for each examinee.
- Required files: Correct answers (1.), scans (4.), and a participant list in CSV format.

Written exams



A vizsga eredménye

Név: Jane Doe
Regisztrációs szám: 1501090
Érdemjegy: 5
Pontok: 3.16666666666667

Értékelés

Kérdés	Pontok	Adott válasz	Helyes válasz
1	1.0000000	__c__	__c__
2	0.5000000	abc_e	abc__
3	0.0000000	_____	ab_d_
4	1.0000000	__c__	_bc__
5	0.6666667	___d_	ab_d_
6	0.0000000	_bc_e	a_c__

Vizsgalap

R University

Exam 2015-07-29

Personal Data

Family Name: DOE

Given Name: JANE

Signature:

Registra

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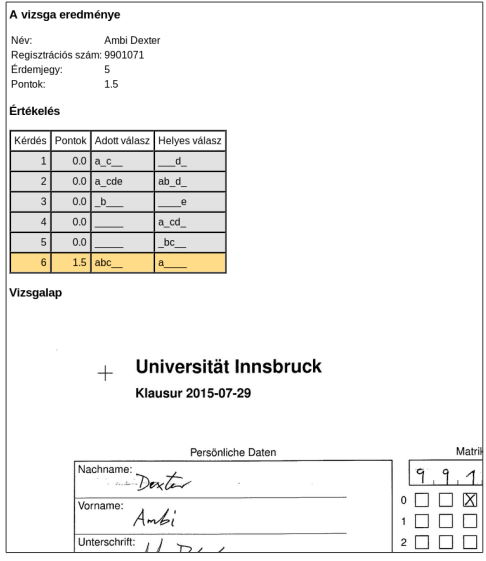

A vizsga eredménye

Név: Ambi Dexter
Regisztrációs szám: 9901071
Érdemjegy: 5
Pontok: 1.5

Értékelés

Kérdés	Pontok	Adott válasz	Helyes válasz
1	0.0	a_c__	___d_
2	0.0	a_cde	ab_d_
3	0.0	_b___	___e
4	0.0	_____	a_cd_
5	0.0	_____	_bc__
6	1.5	abc__	a____

Vizsgalap

Universität Innsbruck

Klausur 2015-07-29

Persönliche Daten

Nachname: Dexter

Vorname: Ambi

Unterschrift:

Matrik

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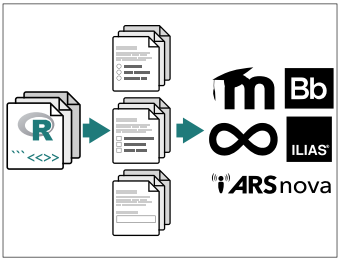
E-Learning

E-Learning

1. Goal

- Online tests with flexible exercise types.
- Possibly: Dynamic supplements and/or complete correct solution.
- Random variations of similar exercises to reduce the risk of cheating.
- Use university's learning management system, e.g., Moodle, …

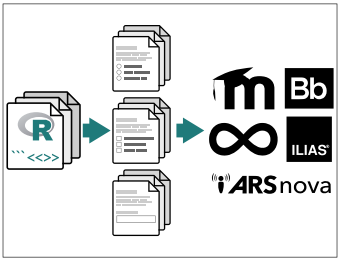
E-Learning



2. Create

- Draw random replications from exercise templates, e.g., via `exams2moodle()`, ...
- Automatically embed these into exchange file format (typically via HTML/XML).

E-Learning



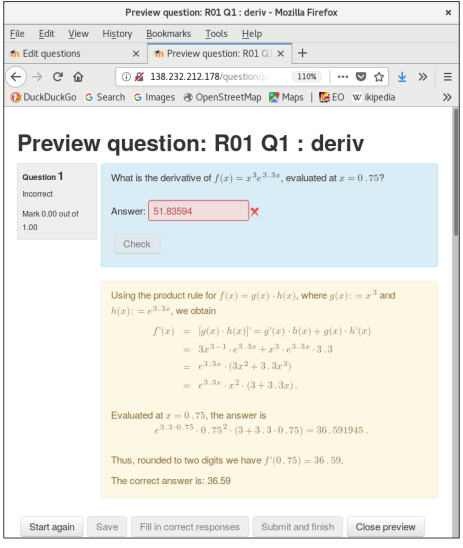
2. Create

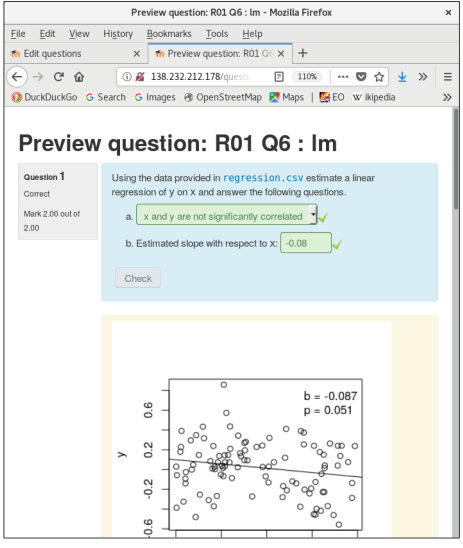
- Draw random replications from exercise templates, e.g., via `exams2moodle()`, ...
- Automatically embed these into exchange file format (typically via HTML/XML).

3. Import

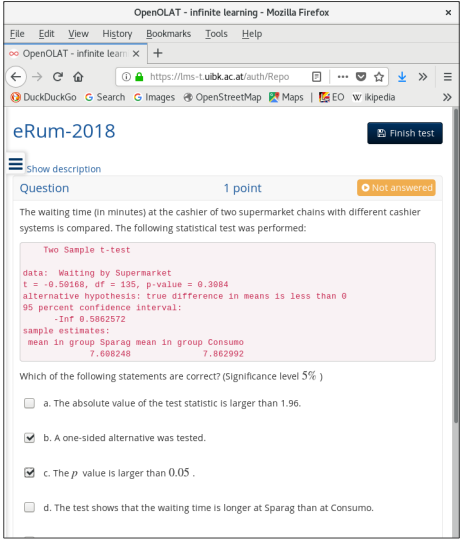
- Import in learning management system.
- From there handling “as usual” in the system.

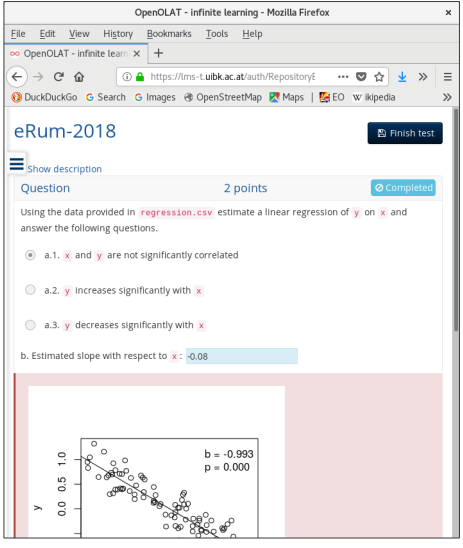
E-Learning: Online test



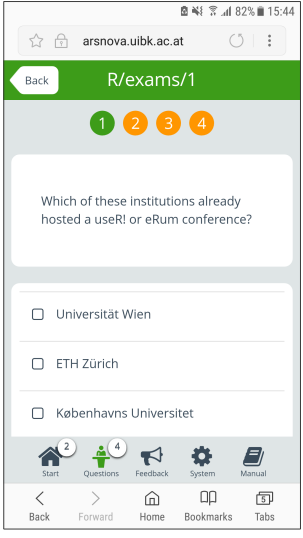


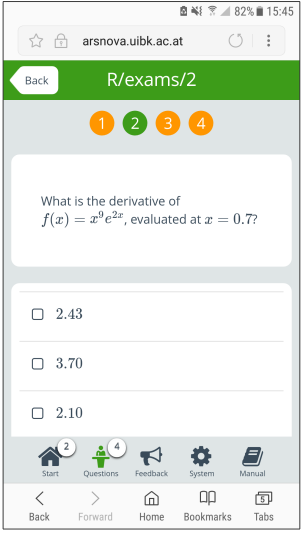
E-Learning: Online test

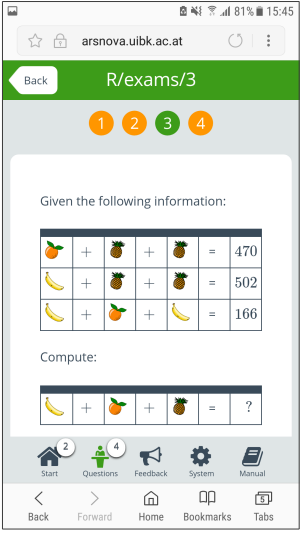




E-Learning: Live quiz





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quad
payflow
hesse
deriv
PCA screeplot

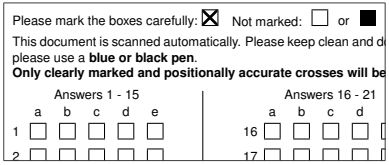
What Else?

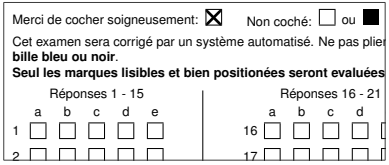
What else?

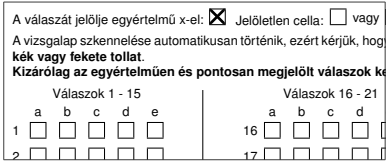
Under development:

- *Many volunteers:* Internationalization for “NOPS” exams.
- *Nikolaus Umlauf:* Exercise “stress tester”.
- *Nikolaus Umlauf:* Graphical exams manager based on *shiny* that can be used on a local machine or on a server.
- *Achim Zeileis:* Reports for lecturers based on IRT models.
- *Niels Smits:* Better management of exercise categories.
- *Niels Smits*, *Claus Ekstrøm*, *Nikolaus Umlauf: Canvas* interface based on QTI 1.2.
- *Mirko Birbaumer*, *Andreas Melillo*, *Achim Zeileis: Ilias* interface based on QTI 1.2.

NOPS internationalization





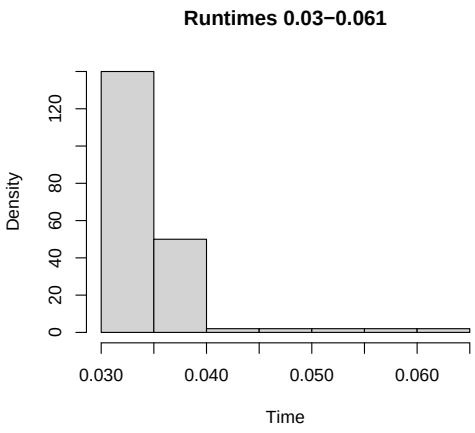


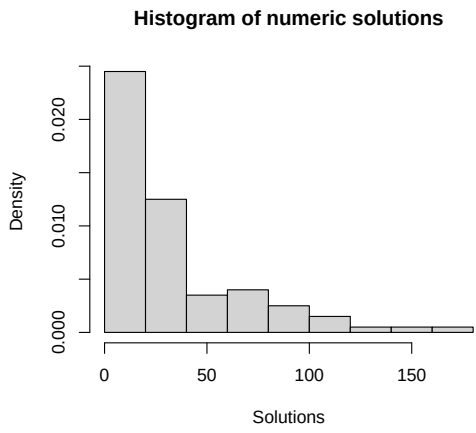
da	Jensen, Messner
de	Zeileis
en	Zeileis
es	Kogelnik
fi	Nordhausen
fr	Allignol
gsw	Stauffer
hr	Juraić, Kecojevic
hu	Daróczi, Tóth
it	Zambella
nl	Smits
pt	Calvão, Dellinger, Petutschnig (pt-PT/pt-BR)
ro	Gatu
ru	Demeshev
sk	Fabsic
sr	Kecojevic
tr	Er

More contributions welcome …

Stress tester

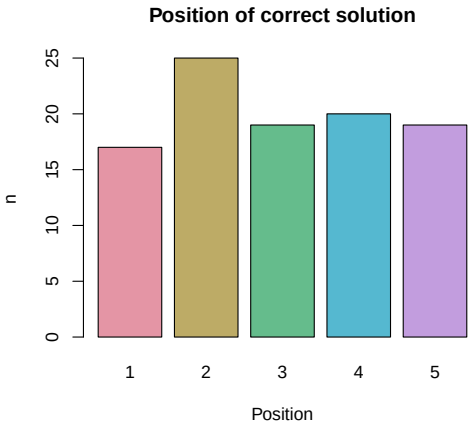
```
R> s <- stresstest_exercise("deriv2.Rnw")
R> plot(s)
```

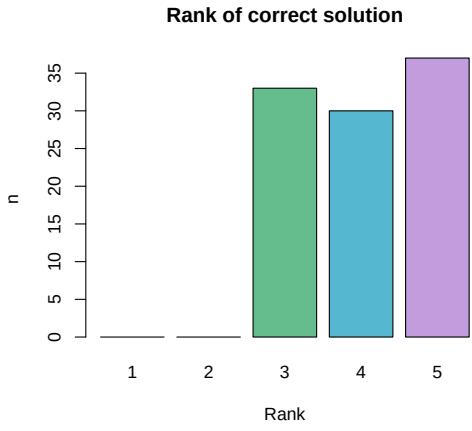




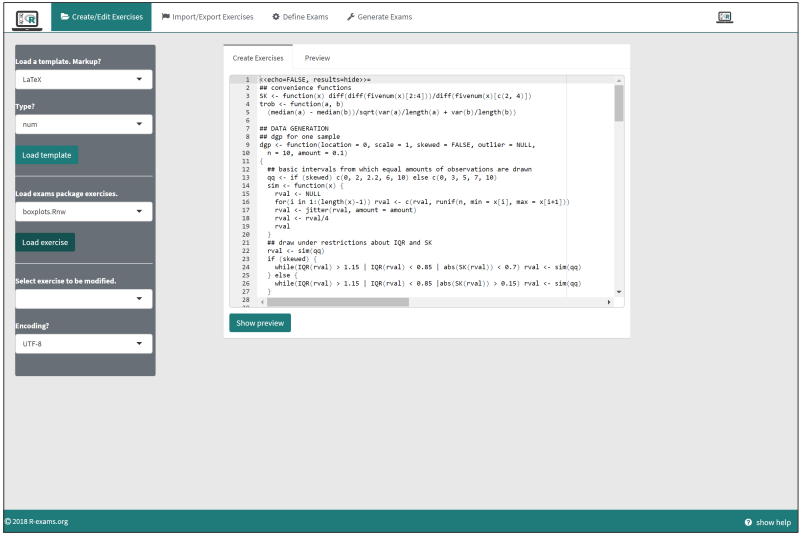
Stress tester

```
R> s <- stresstest_exercise("deriv2.Rnw")
R> plot(s)
```

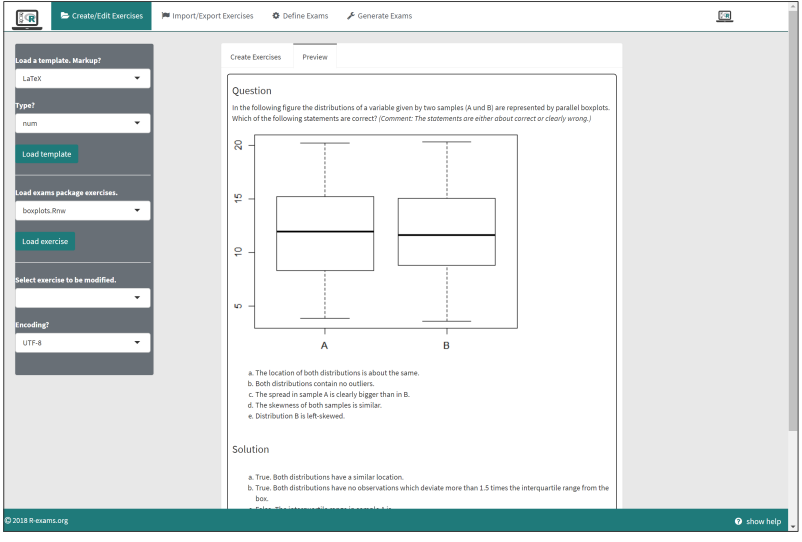




Graphical exams manager



Graphical exams manager



Examining exams

Report: Exercise difficulty, student performance, unidimensionality, fairness.

Methods: Psychometrics, especially item response theory.

Example: End-term exam from first-year mathematics course for business and economics students at Universität Innsbruck.

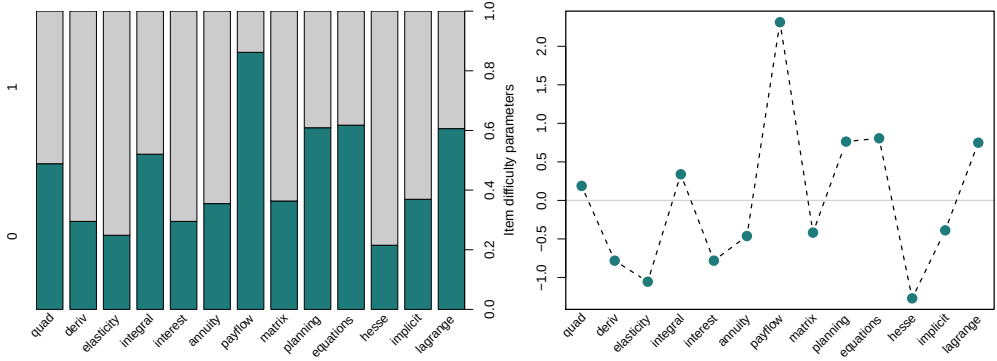
- 729 students (out of 941 registered).
- 13 single-choice exercises on the basics of analysis, linear algebra, financial mathematics.
- Two groups with partially different pools of exercise templates.

```
R> library("psychotools")
R> data("MathExam14W", package = "psychotools")
R> mex <- subset(MathExam14W, nsolved > 0 & nsolved < 13)
```

Examining exams

Item difficulty: Raw proportions vs. Rasch model.

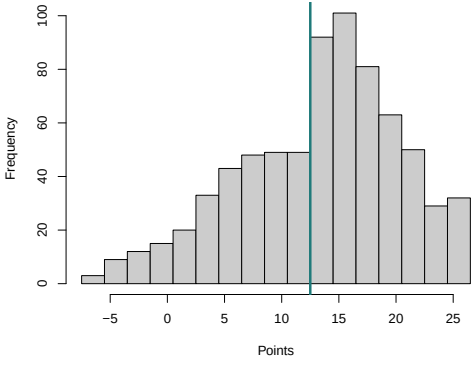
```
R> plot(mex$solved, ...)
R> mr <- raschmodel(mex$solved)
R> plot(mr, ...)
```

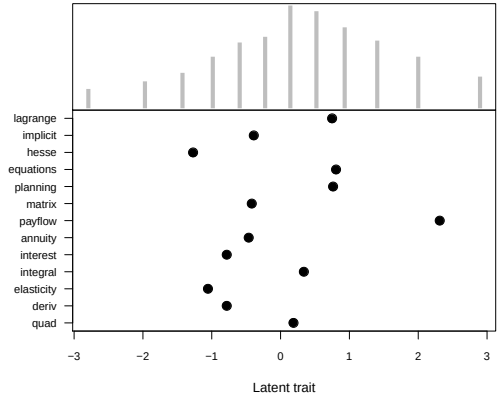


Examining exams

Student performance: Points and person-item map.

```
R> hist(MathExam14W$points, ...)
R> piplot(mr)
```

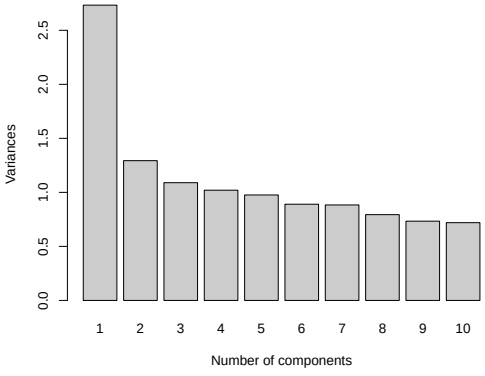


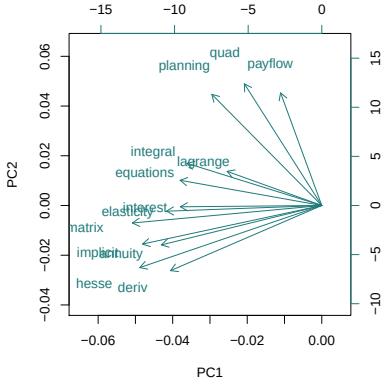


Examining exams

Unidimensionality: Principal component analysis.

```
R> pr <- prcomp(mex$solved, scale = TRUE)
R> plot(pr, ...)
R> biplot(pr, ...)
```

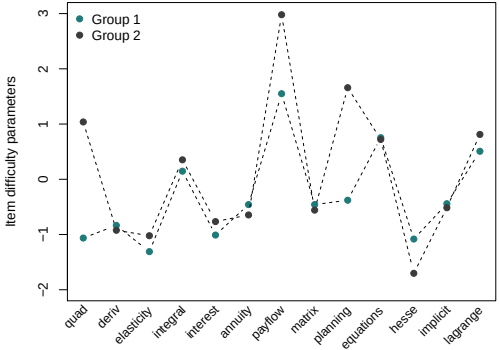


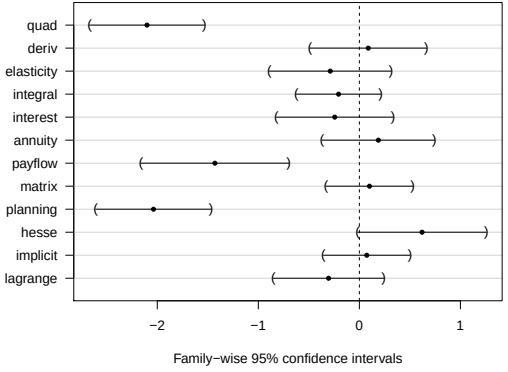


Examining exams

Fairness: Differential item functioning.

```
R> ma <- anchortest(solved ~ group, data = mex, adjust = "single-step")
R> plot(ma$final_tests, ...)
```





Recommendations

If you want to try  R/exams:

- Start with simple exercises before moving to more complex tasks.
- Focus on content of exercises.
- Don’t worry about layout/formatting too much.
- Try to build a team (with lecturers, assistants, etc.).
- Use exercise types creatively.
- Don’t be afraid to try stuff, especially in formative assessments.
- Thorough quality control for dynamic exercises before summative assessments.

Resources

Contributors: Zeileis, Grün, Leisch, Umlauf, Smits, Birbaumer, Ernst, Keller, Krimm, Stauffer.

Links:

Web	`http://www.R-exams.org/`
CRAN	`https://CRAN.R-project.org/package=exams`
Forum	`http://R-Forge.R-project.org/forum/?group_id=1337`
StackOverflow	`https://stackoverflow.com/questions/tagged/exams`
Twitter	@AchimZeileis

References:

- 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`