R/exams: A One-for-All Exams Generator
Online Tests, Live Quizzes, and Written Exams with R

Achim Zeileis

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

Additionally: In spring 2020.

• Conversion to distance learning.
• Leveraging available e-learning tools and learning management systems.
Motivation and challenges

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

Additionally: In spring 2020.
• Exploit flexibility of the implemented strategy.
• Replace in-class materials by e-learning materials based on the same pool of exercises.
## Motivation and challenges

<table>
<thead>
<tr>
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### Learning:

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

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<tr>
<td>Screencast</td>
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</tbody>
</table>

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 Canvas or OpenOLAT.
- Blackboard (partially based on QTI 1.2)
- ARSnova, TCExam, LOPS, …

Infrastructure: Standing on the shoulders of lots of open-source software…
## R package `exams`

<table>
<thead>
<tr>
<th>Type</th>
<th>Software</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Statistical computing</td>
<td>R</td>
<td>Random data generation, computations</td>
</tr>
<tr>
<td>Writing/reporting</td>
<td>\LaTeX, Markdown</td>
<td>Text formatting, mathematical notation</td>
</tr>
<tr>
<td>Reproducible research</td>
<td>knitr, rmarkdown, Sweave</td>
<td>Dynamically tie everything together</td>
</tr>
<tr>
<td>Document conversion</td>
<td>TtH/TtM, pandoc</td>
<td>Conversion to HTML and beyond</td>
</tr>
<tr>
<td>Image manipulation</td>
<td>ImageMagick, magick, png</td>
<td>Embedding graphics</td>
</tr>
<tr>
<td>Web technologies</td>
<td>base64enc, RCurl, …</td>
<td>Embedding supplementary files</td>
</tr>
<tr>
<td>Learning management</td>
<td>Moodle, OpenOLAT, Canvas, ARSnova, …</td>
<td>E-learning infrastructure</td>
</tr>
</tbody>
</table>
Exam 1

1. Question

What is the derivative of \( f(x) = x^6 \cdot e^{x^2} \), evaluated at \( x = 0.356 \)?

a. 44.03  

b. 88.76

c. 135.61

d. 59.34

e. 38.24

2. Question

Using the product rule for \( f(x) = g(x) \cdot h(x) \), where \( g(x) = x^2 \) and \( h(x) = e^{x^2} \), we obtain

\[
\frac{d}{dx} [f(x)] = \frac{d}{dx} [g(x) \cdot h(x)] = g'(x) \cdot h(x) + g(x) \cdot h'(x)
\]

\[
g'(x) = 2x \quad \text{and} \quad h'(x) = 2x \cdot e^{x^2}
\]

Thus, we have

\[
\frac{d}{dx} [f(x)] = \frac{d}{dx} [x^2 \cdot e^{x^2}] = 2x \cdot e^{x^2} + x^2 \cdot 2x \cdot e^{x^2} = x^2 \cdot 2x \cdot e^{x^2}
\]

Evaluating at \( x = 0.356 \), we get

\[
f'(0.356) = 0.32 \cdot 0.356 \cdot e^{0.356^2} 
\]

Thus, rounded to two digits we have \( f'(0.356) \approx 44.03 \).
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 the following cities are the capital of the corresponding country?

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 the following cities are the capital of the corresponding country?
Dynamic exercises: .Rmd

Example: Which of the following cities are the capital of the corresponding country?

Question
========
Which of the following cities are the capital of the corresponding country?

Answerlist
-----------
* Lagos (Nigeria)
* São Paulo (Brazil)
* Toronto (Canada)
* Auckland (New Zealand)
* Istanbul (Turkey)
* Zürich (Switzerland)
* Tokyo (Japan)
* New Delhi (India)
* Astana (Kazakhstan)
* Warsaw (Poland)
* Riyadh (Saudi Arabia)
**Dynamic exercises**: .Rmd

**Example**: Which of the following cities are the capital of the corresponding country?

**Solution**

**Answerlist**

- False. The capital of Nigeria is Abuja.
- False. The capital of Brazil is Brasilia.
- False. The capital of Canada is Ottawa.
- False. The capital of New Zealand is Wellington.
- False. The capital of Turkey is Ankara.
- False. The de facto capital of Switzerland is Bern.
- True. Tokyo is the capital of Japan.
- True. New Delhi is the capital of India.
- True. Astana is the capital of Kazakhstan.
- True. Warsaw is the capital of Poland.
- True. Riyadh is the capital of Saudi Arabia.
Example: Which of the following cities are the capital of the corresponding country?

Meta-information
===============
exname: Capitals
extype: mchoice
exsolution: 00000011111
exshuffle: 5
Dynamic exercises: \texttt{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: \texttt{Rnw}

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

\begin{verbatim}
<<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 \( f(x) = x^{\texttt{a}} e^{\texttt{b}\cdot x} \), evaluated at \( x = \texttt{c} \)?
\end{question}
\end{verbatim}
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 $g(x) := x^{\text{\Sexpr{a}}} \cdot h(x) := e^{\text{\Sexpr{b} \cdot x}}$, we obtain
\begin{eqnarray*}
f'(x) &=& [g(x) \cdot h(x)]' = g'(x) \cdot h(x) + g(x) \cdot h'(x) \\
&=& g'(x) \cdot h(x) + g(x) \cdot h'(x) \\
&=& a \cdot x^{a-1} \cdot e^{b \cdot x} + \ldots
\end{eqnarray*}
Evaluated at $x = \text{\Sexpr{c}}$, the answer is
\[
\text{\Sexpr{a}} \cdot c^{a-1} \cdot e^{b \cdot c} \cdot (a + b \cdot c) = \text{\Sexpr{fmt(res, 6)}}.
\]
Thus, rounded to two digits we have $f'(\text{\Sexpr{c}}) = \text{\Sexpr{fmt(res)}}$.
\end{solution}
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 $g(x) := x^a$ and $h(x) := e^{b \cdot x}$, we obtain
\begin{eqnarray*}
f'(x) & = & [g(x) \cdot h(x)]' = g'(x) \cdot h(x) + g(x) \cdot h'(x) \\
& = & a x^{a - 1} \cdot e^{b \cdot x} + \ldots
\end{eqnarray*}
Evaluated at $x = c$, the answer is
\[
\left[ e^{b \cdot c} \cdot c^{a - 1} \cdot (a + b \cdot c) \right] = \text{fmt}(\text{res}, 6).
\]
Thus, rounded to two digits we have $f'(c) = \text{fmt}(\text{res})$.
\end{solution}

\extype{num} \exsolution{\text{fmt}(\text{res})} \exname{derivative exp} \extol{0.01}
Dynamic exercises: Single choice

extype: schoice
exsolution: 010
Dynamic exercises: Single choice

**Question**
What is the seat of the federal authorities in Switzerland (i.e., the de facto capital)?
(a) Vaduz
(b) Bern
(c) St. Gallen
(d) Basel
(e) Zurich

*Knowledge quiz: Shuffled distractors.*
Dynamic exercises: Single choice

**Question**
What is the derivative of $f(x) = x^7 e^{3.2x}$, evaluated at $x = 0.85$?

(a) 40.08  
(b) 55.65  
(c) 44.94  
(d) 45.32  
(e) 31.56

**Numeric exercises**: Distractors are random numbers and/or typical arithmetic mistakes.
Dynamic exercises: Multiple choice

extype: mchoice
exsolution: 011
Dynamic exercises: Multiple choice

Question
Which of the following cities are the capital of the corresponding country?

(a) Riyadh (Saudi Arabia)
(b) Astana (Kazakhstan)
(c) Warsaw (Poland)
(d) Lagos (Nigeria)
(e) Istanbul (Turkey)

Knowledge quiz: Shuffled true/false statements.
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.
(c) The spread in sample A is clearly bigger than in B.
(d) The skewness of both samples is similar.
(e) Distribution A is left-skewed.

**Interpretations:** Statements that are approximately correct or clearly wrong.
Dynamic exercises: Numeric

extype: num
exsolution: 123.45
Dynamic exercises: Numeric

Numeric exercises: Solving arithmetic problems.

Question
Given the following information:

\[
\begin{align*}
\text{orange} + \text{pineapple} + \text{pineapple} &= 486 \\
\text{orange} + \text{banana} + \text{banana} &= 194 \\
\text{pineapple} + \text{orange} + \text{orange} &= 339
\end{align*}
\]

Compute:

\[
\begin{align*}
\text{banana} + \text{orange} + \text{pineapple} &= ?
\end{align*}
\]
Dynamic exercises: String

exetype: string
exsolution: ANSWER
Dynamic exercises: String

**Question**
What is the name of the R function for extracting the estimated coefficients from a fitted (generalized) linear model object?

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

extype: string
exsolution: ANSWER
Dynamic exercises: Cloze

extype: cloze
exclozetype: mchoice|num
exsolution: 10|123.45
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.
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(
+   "capitals.Rmd",
+   "deriv2.Rmd",
+   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, …).
Online test:
R> exams2moodle(myexam, n = 10, dir = odir)

Live quiz:
R> exams2arsnova(myexam, n = 1, dir = odir)

Written exam:
R> exams2nops(myexam, n = 3, dir = odir,
+ language = "hu", institution = "WhyR?")

Other: exams2pdf(), exams2html(), exams2canvas(), exams2openolat(),...
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, …

Scenarios:

- Short quizzes conducted in-class.
- Online tests conducted over several days.
- E-exams conducted in-class or remotely.
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

---

**Preview question: R01 Q1 : deriv**

**Question 1**

Incorrect

Mark 0.00 out of 1.00

What is the derivative of \( f(x) = x^3 \cdot 3^x \), evaluated at \( x = 0.75 \)?

Answer: 51.83594

Check

---

Using the product rule for \( f(x) = g(x) \cdot h(x) \), where \( g(x) = x^3 \) and \( h(x) = 3^x \), we obtain

\[
\begin{align*}
   f'(x) &= [g(x) \cdot h(x)]' \\
   &= g'(x) \cdot h(x) + g(x) \cdot h'(x) \\
   &= 3x^2 \cdot 3^x + x^3 \cdot 3^x \cdot 3x \\
   &= 3x^2 \cdot 3^x + 3x^3 \\
   &= 3x^2 \cdot (3^x + x^3).
\end{align*}
\]

Evaluated at \( x = 0.75 \), the answer is

\[3^x \cdot 0.75, 0.75^3, (3 + 3 \cdot 0.75) = 36.501945.\]

Thus, rounded to two digits we have \( f'(0.75) = 36.59 \).

The correct answer is: 36.59

---

**Preview question: R01 Q6 : Im**

**Question 1**

Correct

Mark 2.00 out of 2.00

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

b. Estimated slope with respect to \( x \): -0.08

Check
E-Learning: Online test

**eRum-2018**

**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
k = -0.99168, df = 132, p-value = 0.3084
alternative hypothesis: true difference in means is less than 0
95 percent confidence interval:
Inf 0.5862572
sample estimates:
mean in group Sparag mean in group Consumo
7.608268 7.862992

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

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

Using the data provided in **regression.csv** estimate a linear regression of \( y \) on \( x \) and answer the following questions.

- [x] a.1. \( x \) and \( y \) are not significantly correlated
- [ ] a.2. \( y \) increases significantly with \( x \)
- [ ] a.3. \( y \) decreases significantly with \( x \)

b. Estimated slope with respect to \( x \) = 0.08
E-Learning: Live quiz

Which of these institutions already hosted a useR! or eRum conference?

- Universitäts Wien
- ETH Zürich
- Københavns Universitet

What is the derivative of \( f(x) = x^9 e^{2x} \), evaluated at \( x = 0.7 \)?

- 2.43
- 3.70
- 2.10

Given the following information:

<table>
<thead>
<tr>
<th>+</th>
<th>+</th>
<th>+</th>
<th>= 470</th>
</tr>
</thead>
<tbody>
<tr>
<td>+</td>
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<td>+</td>
<td>= 502</td>
</tr>
<tr>
<td>+</td>
<td>+</td>
<td>+</td>
<td>= 166</td>
</tr>
</tbody>
</table>

Compute:

| + | + | + | = ? |
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.
1. Which of the following cities are the capital of the corresponding country?
(a) Riyadh (Saudi Arabia)
(b) Astana (Kazakhstan)
(c) Warsaw (Poland)
(d) Lagos (Nigeria)
(e) Istanbul (Turkey)

2. What is the derivative of \( f(x) = x^8e^{2.8x} \), evaluated at \( x = 0.84 \)?
(a) 22.91
(b) 27.41
(c) 24.80
(d) 18.93
(e) 32.10

3. 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.
(c) The spread in sample A is clearly bigger than in B.
(d) The skewness of both samples is similar.
(e) Distribution A is left-skewed.

(a) The location of both distributions is about the same.
(b) Both distributions contain no outliers.
(i) The spread in sample A is clearly bigger than in B.
(d) The skewness of both samples is similar.
(e) Distribution A is left-skewed.
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: 3.1666666666667

Értékelés

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<tr>
<th>Kérdés</th>
<th>Pontok</th>
<th>Adott válasz</th>
<th>Helyes válasz</th>
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</tr>
</tbody>
</table>

Vizsgalap

R University
Exam 2015-07-29

Universität Innsbruck
Klausur 2015-07-29
Getting Started
Getting started

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.
Getting started

Installation:

1. R (including Rtools on Windows and OS X). RStudio recommended for beginners.

2. R package exams (including dependencies).
   ```r
   install.packages("exams", dependencies = TRUE)
   ```

3. \LaTeX{} for producing PDF output.
   New: tinytex integration.
   ```r
   install.packages("tinytex")
   tinytex::install_tinytex()
   ```

4. Pandoc (e.g., provided along with RStudio).

Getting started

First steps: Create exams skeleton.

- demo-*.R scripts.
- exercises/ folder with all .Rmd/.Rnw exercises.
- templates/ folder with various customizable templates.
- nops/ folder (empty) for exams2nops() output.

R> exams_skeleton()

Getting started

**First steps:** Compile built-in exercises to both HTML and PDF.


R> exams2html("swisscapital.Rmd")
R> exams2pdf("swisscapital.Rmd")


R> exams2html("deriv.Rmd")
R> exams2html("deriv.Rmd", converter = "pandoc-mathjax")
R> exams2pdf("deriv.Rmd")
Getting started

**First steps:** Extract the meta-information to check whether it is processed correctly.

```r
R> exm <- exams2html(c("swisscapital.Rmd", "tstat.Rmd"))
R> exams_metainfo(exm)

exam1
   1. Swiss Capital: 2
   2. t statistic: 27.783 (27.773--27.793)
```
Getting started

Quality control: Stress testing.

- Generate a large number of random versions of an exercise.
- Check for errors, warnings, long computation times, …
- Especially for numeric exercises: Check solution distribution, outliers, dependency on randomized parameters.
- Especially for multiple-choice exercises: Check shuffling of correct answers.

Getting started

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

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

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/r-exams
Twitter  @AchimZeileis

References: