

# Classroom learning dynamics using a cellular automata spatiotemporal model comparing peer instruction and traditional instruction

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Peer instruction (PI) has recently become one of the popular means of classroom instruction in Physics Education. Such instruction method is vastly different from how classes are traditionally handled where the instructor conducts a lecture for the entire duration of the class. In this study, we model the transfer of knowledge within the class as a probabilistic cellular automata model and investigate the effects of different factors such as seating arrangements, size, learning rate, and heterogeneity on the classes' overall learning efficiency in peer instruction. We compared the learning efficiency between the traditional learning model and the PI model. We found that larger class sizes sway the advantage towards traditional instruction, while increased learning rate heterogeneity favors PI. Additionally, an increase in the students' effective learning rate benefits both traditional instruction and PI but in different ways. Classes under traditional instruction were found to have two stages of learning when heterogeneity was introduced: a fast initial stage and a slow final stage. On the other hand, learning trends in PI were generally unaffected by heterogeneity, having similar effects with the other factors we considered. Among the seating arrangements (SAs) we considered for PI, the inner corner SA performed the best in terms of both the time it takes for all the students to learn and the classroom's learning rate. This result differs from previous studies where they found that the outer corner SA performed the best. The difference stems from the simplifications made in this model. We did not consider the orientation factor of each student, resulting in an isotropic system. Our model also uses binary values and does not consider the effect of aptitude similarity that have been described in previous studies. Despite these simplifications, our findings generally agree with previous studies and existing practices that PI performs similarly or better than traditional instruction and that a mix of traditional instruction and PI would be the optimal method of instruction. We offer insights based on the qualitative results of the model.

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## I. INTRODUCTION

Articles published in American Physical Society journals are converted to an XML file during final journal production. Other formats such as PDF are derived directly from the XML, which constitutes the version of record. Even before journal production, the APS editorial process can make use of the information in a properly prepared manuscript. Information such as title, authors, affiliations, etc., can be automatically extracted and used to populate our manuscript database. References can also be culled, cross-checked for accuracy, and used to create a linked version for referees and editors. Moreover,

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time can be saved as referrals can be made electronically rather than by conventional mail. Thus, a well-prepared electronic manuscript can enhance the entire peer review process from author to reader while making the whole process less expensive. To this end, authors should follow the guidelines in this document when preparing their submissions to *Physical Review Letters*, *Reviews of Modern Physics*, *Physical Review A-E*, *Physical Review X*, *Physical Review Applied*, *Physical Review Fluids*, *Physical Review Materials*, *Physical Review Accelerators and Beams*, and *Physical Review Physics Education Research*.

Updated versions of this document will be made available at <https://journals.aps.org/revtex/>. For more complete descriptions of how to use the REVTeX 4.2 macros, please see the *REVTeX 4.2 Author's Guide* included with the REVTeX 4.2 distribution. Questions about REVTeX 4.2 and using it to submit to APS journals may be emailed to [revtex@aps.org](mailto:revtex@aps.org).

## II. FORMATTING

### II.1. Preprint, reprint, and twocolumn options

REVTeX 4.2 offers a `reprint` class option to typeset a manuscript in a format that is a close approximation to the actual journal's appearance. It should be emphasized that this is only an *approximation*; a manuscript may be substantially different in length or appearance after it goes through our production process. This is mostly due to the choice of fonts and the scaling of figures.

REVTeX 4.2 is designed to make it straightforward to switch between two-column and single-column formatting just by changing the class option. Authors may submit with either the `reprint` or the `twocolumn` class options. The `preprint` primarily does three things: It increases the font size to 12pt, increases the line spacing, and changes the formatting to single column.

### II.2. Paper size

Manuscripts should be submitted to APS formatted for letter size paper. Papers are sent electronically to referees who may want to print them out. Letter size formatting ensures that this will be trouble free for all referees.

## III. MARKING UP FRONT MATTER

Perhaps the most important macros are those pertaining to the markup of the front matter (title, authors, affiliations, abstract, etc.). Note that proper use of the REVTeX 4.2 macros means that explicit centering environments in the front matter are not needed and should not be used.

### III.1. Title

The title of the manuscript should be specified using the `\title` macro. A double backslash `\\` may be used to force a line break in a long title.

### III.2. Authors, affiliations, and collaborations

REVTeX 4.2 makes it straightforward to input author names and link them up properly with affiliations. Authors should let REVTeX 4.2 do the work of grouping authors and affiliations and, if using the superscript style, numbering affiliations. Please follow these guidelines:

- Use a single `\author` macro for each author's name. REVTeX 4.2 automatically puts in all commas and the word 'and.'
- Use the `\surname` macro to explicitly indicate if an author's family name consists of more than one name or if the family name is not the author's last name.
- The `\email` macro may be used to specify an author's e-mail address. The `\thanks` macro must not be used for this. Only the e-mail address itself may appear in the macro's required argument.
- The `\homepage` macro may be used to specify a URL associated with an author. The `\thanks` macro must not be used for this. Only the URL may appear in the macro's required argument.
- The `\altaffiliation` macro may be used to specify an alternate affiliation or temporary address for an author. The `\thanks` macro must not be used for this. Only the affiliation may appear in the macro's required argument.
- The `\thanks` macro may be used only if one of the more specific macros list above does not apply.
- Use a single `\affiliation` for each affiliation.
- Superscripts linking authors to affiliations must be accomplished using the `superscriptaddress` class option rather than putting in explicit superscripts by hand.
- A collaboration may be specified by using the `\collaboration` macro. The `\author` macro must not be used for collaborations.

### III.3. Abstract

The abstract must be specified using the `abstract` environment. Note that in REVTeX 4.2, the abstract must come before the `\maketitle` command. REVTeX 4.2 now allows the use of the `description` environment within the abstract to provide *structured abstracts*.

For instance, *Physical Review C* would like authors to provide abstracts with sections summarizing the paper’s **Background**, **Purpose**, **Method**, **Results**, and **Conclusions**. This can be accomplished in the following manner:

```
\begin{abstract}
\begin{description}
\item[Background] This part would describe the
context needed to understand what the paper
is about.
\item[Purpose] This part would state the purpose
of the present paper.
\item[Method] This part describe the methods
used in the paper.
\item[Results] This part would summarize the
results.
\item[Conclusions] This part would state the
conclusions of the paper.
\end{description}
\end{abstract}
```

#### IV. REFERENCES AND FOOTNOTES

Authors are strongly encouraged to use BibTeX when preparing their bibliographies. If BibTeX is used, current production processes require that the .bbl file be included directly into the manuscript’s main .tex file. REVTeX 4.2 comes with two BibTeX style files for formatting references, one for the *Physical Review* journals and one for *Review of Modern Physics*. In 4.2, the BibTeX styles have been modified to display journal article titles in the bibliography.

The following apply whether BibTeX is used or not.

- Authors should use the `\cite` and `\bibitem` commands to create bibliographies and to refer to items in the bibliography. “By hand” numbering of references should be avoided.
- REVTeX 4.2 provides new syntax for combining multiple citations into a single entry in the bibliography and for putting extra text before and after a reference. Please refer to *REVTeX 4.2 Author’s Guide* included with the REVTeX 4.2 distribution for full details.
- Footnotes must be specified using the `\footnote` macro. REVTeX 4.2 will place the footnotes in the bibliography for the *Physical Review* journals. Please note that even if you don’t use BibTeX, you may have to run BibTeX to get the footnotes to appear. Footnotes giving additional information about authors (such as e-mail addresses) must not be specified using the `\footnote` macro (see Section III.2).
- Avoid custom footnotes using `\footnotemark` and `\footnotetext` [except in the context of tables (see Section VIII.5)].

- References should be formatted and specified according to the *Physical Review Style Guide*. Note that using BibTeX automatically ensures this.
- URLs should be specified using the `\url` macro. BibTeX will automatically take care of this if the `url` field is used.
- E-print identifiers should be included using the `\eprint` macro. BibTeX will automatically take care of this if the `eprint` field is used.

Please see the REVTeX 4.2 Author’s Guide for new features in REVTeX 4.2’s APS BibTeX styles, including support for citing data sets, journals that use DOIs in place of page numbers, and journals that use year and issue instead of volume to uniquely identify articles.

#### V. BODY OF THE PAPER

##### V.1. Sectioning and cross-referencing

For sectioning a manuscript, the basic rule is to use the appropriate sectioning commands (`\section`, `\subsection`, `\subsubsection`, *etc.*). Cross-referencing a section must be done by using the proper `\label` and `\ref` commands. Cross-referencing by hand is not allowed. `\part`, `\chapter`, and `\subparagraph` should not be used.

##### V.2. Appendices

Appendices should be specified using the `\appendix` command which specifies that all following sections create with the `\section` commands are appendices. If there is only one appendix, then the `\appendix*` command should be used instead.

##### V.3. Acknowledgments

Any acknowledgments should be included by using the `acknowledgments` environment. Note that in REVTeX 4.2, this is an environment and not a command.

##### V.4. Counters

No counters may be created and the standard ones may not be altered. If an exceptional label is needed for an equation, the `\tag` command (requires the `amsmath` class option) should be used. Please note that the use of the `\tag` command may conflict with the use of the `hyperref` package due an incompatibility between `amsmath` and `hyperref`.

TABLE I.  $\text{\LaTeX} 2_{\epsilon}$  and AMS- $\text{\LaTeX}$  font summary.

<code>\textit</code>	Italics. Replaces <code>\it</code>
<code>\textbf</code>	Bold face. Replaces <code>\bf</code>
<code>\textrm</code>	Roman. Replaces <code>\rm</code>
<code>\textsl</code>	Slanted. Replaces <code>\sl</code>
<code>\textsc</code>	Small caps. Replaces <code>\sc</code>
<code>\textsf</code>	Sans serif. Replaces <code>\sf</code>
<code>\texttt</code>	Typewriter. Replaces <code>\tt</code>
<code>\textmd</code>	Medium series
<code>\textnormal</code>	Normal
<code>\textup</code>	Upright
<code>\mathbf</code>	Bold face
<code>\mathcal</code>	Replaces <code>\cal</code>
<code>\mathit</code>	Italics
<code>\mathnormal</code>	Replaces <code>\mit</code>
<code>\mathsf</code>	Sans serif
<code>\mathtt</code>	Typewriter
<code>\mathfrak</code>	Fraktur: Requires <code>amsfonts</code> or <code>amssymb</code> class option
<code>\mathbb</code>	Bold blackboard: Requires <code>amsfonts</code> or <code>amssymb</code> class option
<code>\bm</code>	Bold Greek and other math symbols: Requires <code>\usepackage{bm}</code> and may require the <code>amsfonts</code> class option

## V.5. Fonts

It is preferable to avoid the older  $\text{\TeX}$  and  $\text{\LaTeX}$  2.09 macros for controlling fonts such as `\rm`, `\it`, *etc.* Rather, it is better to use the macros introduced in  $\text{\LaTeX} 2_{\epsilon}$ . If the older font commands are used (they really should be avoided!), be sure to use curly braces to properly limit the extent of the font change. `{\bf ...}` is the correct method. Commands for controlling text and math font changes are summarized in Table I.

Bold Greek letters and other bold math symbols should be accomplished with the use of `\bm.sty` which is distributed as a required tool with the latest versions of  $\text{\LaTeX} 2_{\epsilon}$  and should be loaded via `\usepackage{bm}`. This package introduces the `\bm` macro. Some bold characters may require using the `amsfonts` class option.

New fonts may not be declared with `\newfont`. Font attribute commands for selecting a font family, shape, and series are all disallowed; the standard  $\text{\LaTeX} 2_{\epsilon}$  font selection macros list above should be used instead.

Finally, the `\symbol` macro is also not allowed.

## V.6. Environments

### V.6.1. Lists

The standard list environments `itemize`, `enumerate`, and `description` are allowed. The `\item` macro with or without the optional argument is also allowed. Customization of the list environments (with macros such as `\labelstyle`, `\labelitemi`, `\labelenumi`, `\itemsep`, *etc.*) is allowed but may be ignored in production. Generalized lists (`\begin{list}`) and trivial lists (`\begin{trivlist}`) are not allowed.

### V.6.2. Other Environments

Creating generalized new environments with `\newenvironment` is not allowed. Creating a new theorem environment with `\newtheorem` is allowed though.

The tabbing environment and the macros `\=`, `\>`, `\'`, and `\'` are allowed but may be ignored in production. Conversion programs used in production should recognize the escapes `\a=`, `\a'`, and `\a'` for using the corresponding accents within a tabbing environment though.

The `verbatim` environment is allowed.

## V.7. Boxes

Most boxes and macros to manipulate them are not allowed. These include `\raisebox`, `\parbox`, `\minipage`, `\rulebox`, `\framebox`, `\mbox`, `\fbox`, `\savebox`, `\newsavebox`, `\sbox`, `\usebox`, and the environment `\begin{lrbox}`. Rules produced with `\rule` are not allowed.

### V.7.1. Margin Notes

Margin notes created with `\marginpar` are not allowed, as are the associated style parameters `\marginparwidth`, `\marginparsep`, and `\marginparpush`.

## VI. MATH MARKUP

In general, all math markup and the standard math environments from  $\text{\LaTeX} 2_{\epsilon}$  are allowed. These include `\begin{math}`, `\begin{displaymath}`, `\begin{equation}`, `\begin{eqnarray}`, and `\begin{eqnarray*}`. The shortcuts `$`, `$$`, `\[`, and `\]` are allowed. In addition, authors may use almost all of the additional markup introduced by AMS- $\text{\LaTeX}$  by using the `amsmath` class option. The explicit exceptions are `\genfrac`, `\boxed`, and `\smash`. The markup contained in `amsextra` and `amsthm` may not be used though. Commutative diagrams created with the `amscd` package are acceptable.

## VII. FIGURES

### VII.1. Figure inclusions

Figures should be included into a REVTeX 4.2 manuscript by using the standard L<sup>A</sup>T<sub>E</sub>X 2<sub>ε</sub> macros. L<sup>A</sup>T<sub>E</sub>X 2<sub>ε</sub> includes several powerful packages for including the files in various formats. The two main packages are `graphics` and `graphicx`. Both offer a macro called `\includegraphics`; they mainly differ in how arguments for controlling figure placement (*e.g.*, scaling and rotation) are passed to the `\includegraphics`.

The `figure` environment should be used to add a caption to the figure and to allow L<sup>A</sup>T<sub>E</sub>X to number and place the figures where they fit best. If a figure needs to be referred to in the text, rather than manually numbering the figures a `\label` should be added to the figure environment (best practice is to put the label within the argument of the `\caption` command) and the `\ref` macro should be used to reference this label. Figures that span the page should use the `figure*` environment. The `picture` environment must not be used directly (one can include an Encapsulated PostScript figure that was produced using the `picture` environment of course).

### VII.2. Figure placement

Figures should be placed as close as possible to the point where they are first referenced. There is no need to place all figures separately at the end of the manuscript and it is preferred that authors leave the figures in their natural locations. Authors may also find useful the REVTeX 4.2 `floatfix` class option which adds emergency float placement processing to avoid “stuck” floats which would otherwise be deferred to the end of the job (and can lead to the fatal “Too many unprocessed floats” message).

## VIII. TABLES

The standard L<sup>A</sup>T<sub>E</sub>X 2<sub>ε</sub> table formatting environments are supported as is the use of the `longtable` package. Tables may be reformatted during production to meet APS style guidelines. Here are some helpful hints for trying to get tables formatted correctly:

- Use the `longtable` package to get tables to break across pages.
- The macro `\squeezetable` will reduce the font size of the table. This macro must occur within a group outside the table environment. The proper markup is:

```
\begingroup
\squeezetable
\begin{table}
...
```

```
\end{table}
\endgroup
```

- Try using the float placement option `H` which will enable L<sup>A</sup>T<sub>E</sub>X to break a float across pages. Long tables are more attractively set with `longtable` however.

```
\begin{table}[H]
\begin{ruledtabular}
\begin{tabular}
...
\end{tabular}
\end{ruledtabular}
\end{table}
```

### VIII.1. Doubled rules and table formatting

REVTeX 4.2 provides the `ruledtabular` environment which automatically puts the scotch rules (double lines) around tables and formats all enclosed `tabular` environments to the full width of the tables and improves inter-column spacing. This environment should be used whenever possible.

### VIII.2. Wide tables

When typesetting using `twocolumn`, tables can either span a single column or both columns. Using the `*`-ed version of the `table` or `longtable` environments produces wide tables that span the columns.

Tables that are very wide and that may be better typeset in a landscape orientation (rotated 90 degrees) should be enclosed in a `turnpage` environment. This will place the rotated table on its own page. Note that some dvi previewers may not be able to show the table properly, but `dvips` and `pdflatex` work correctly.

### VIII.3. Table placement

Tables should be placed as close as possible to the point where they are first referenced. There is no need to place all tables separately at the end of the manuscript and this is not desirable for APS purposes. The class option `floatfix` may be helpful for table placement as well as figure placement (see Section VII.2).

### VIII.4. Aligning columns on a decimal point

The standard L<sup>A</sup>T<sub>E</sub>X 2<sub>ε</sub> macro package `dcolumn` should be used to accomplish this.

### VIII.5. Tablenotes

Footnotes in tables (tablenotes) should use the `\footnote` macro. However, if more than one reference to the same footnote is needed, authors may use `\footnotetext` and `\footnotemark`. This will produce notes (labeled by lower-case roman letters) inserted below the table rather than in the reference section or at the bottom of the page.

## IX. AUTHOR-DEFINED MACROS

Authors may define convenience macros to save keystrokes. This means that the macros may not invoke T<sub>E</sub>X macros such as `\if` or other context dependent com-

mands. Also, L<sup>A</sup>T<sub>E</sub>X 2<sub>ε</sub> provides three macros for declaring new commands: `\providecommand`, `\newcommand`, and `\renewcommand` (as well as their ‘\*’-ed versions). These should be used. Authors may not use T<sub>E</sub>X’s low-level commands `\def`, `\edef`, and `\gdef`.

## X. SUMMARY

To ensure the best use of T<sub>E</sub>X manuscripts, authors need to follow the guidelines specified here. Use of low-level formatting commands to finely control horizontal and vertical spacing may be ignored during production, or even worse, make it impossible to convert the manuscript to XML. Authors should keep things as simple as possible and correctly use the proper REV<sub>T</sub><sub>E</sub>X 4.2 or L<sup>A</sup>T<sub>E</sub>X 2<sub>ε</sub> macros. Any questions about usage may be directed to [revtex@aps.org](mailto:revtex@aps.org).