Future of Chemical Education
Online Symposium
April 14, 2021

Three Years of Experience with Large Moodle-based Organic Chemistry Exams Using a SMILES Generator for Molecular Structure Input

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Outline

- **MOSFECCS**, a new tool for drawing structural formulae and generating SMILES-codes
- The use of MOSFECCS in online quizzes and **exams** within Moodle, and **some conclusions** after 7 exam sessions

Acknowledgements

Prof. em. Dr. Bernhard Jaun

B. Jaun, C. Thilgen, *Chimia* 2018, *72*, 48.

ETH zürich *Educational Development and Technology* Team

Portrait of the Two 1st-Year Courses OC I and II

- **500-600 students**, 3 different B.Sc. programs:
  - *Biology*
  - *Pharmaceutical Sciences*
  - *Health Sciences and Technology*

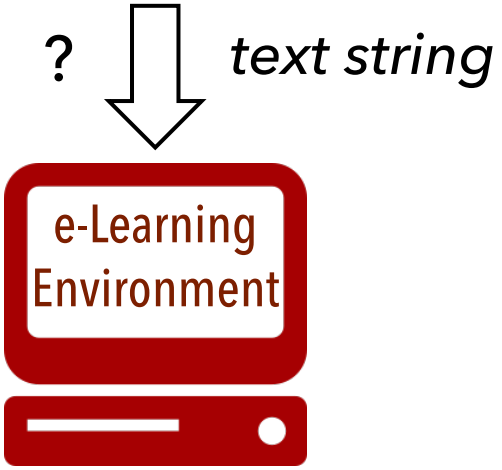
- **OC I** (1st semester) and **OC II** (2nd semester) courses include:
  - **Lecture**
  - Traditional **weekly assignments** + problem-solving session with TA's
  - **Study Center**
  - Optional **online exercises** (e-learning platform Moodle)

Moodle-based activities in OC I/II

- **Start-of-semester orientational self-assessment** (state of knowledge in Chemistry at start of studies)
- **Online exercises** (quizzes complementing the weekly assignments, can be done *ad libitum*)
- **Midterm self-assessment**
- **End-of-semester self-assessment**
- **Exam**

Is Moodle a Suitable Environment for Exercises and Exams in Organic Chemistry?

- **Input of molecular structure** is essential in (organic) chemistry
- Most e-learning environments (incl. Moodle) are **text-based** and do not allow it
- Computer must **check input for correctness**
- Solution: Translate molecular structure into an **alphanumeric string**



InChI and SMILES

Systems for **encoding chemical structure** into an **alpha-numeric string**:

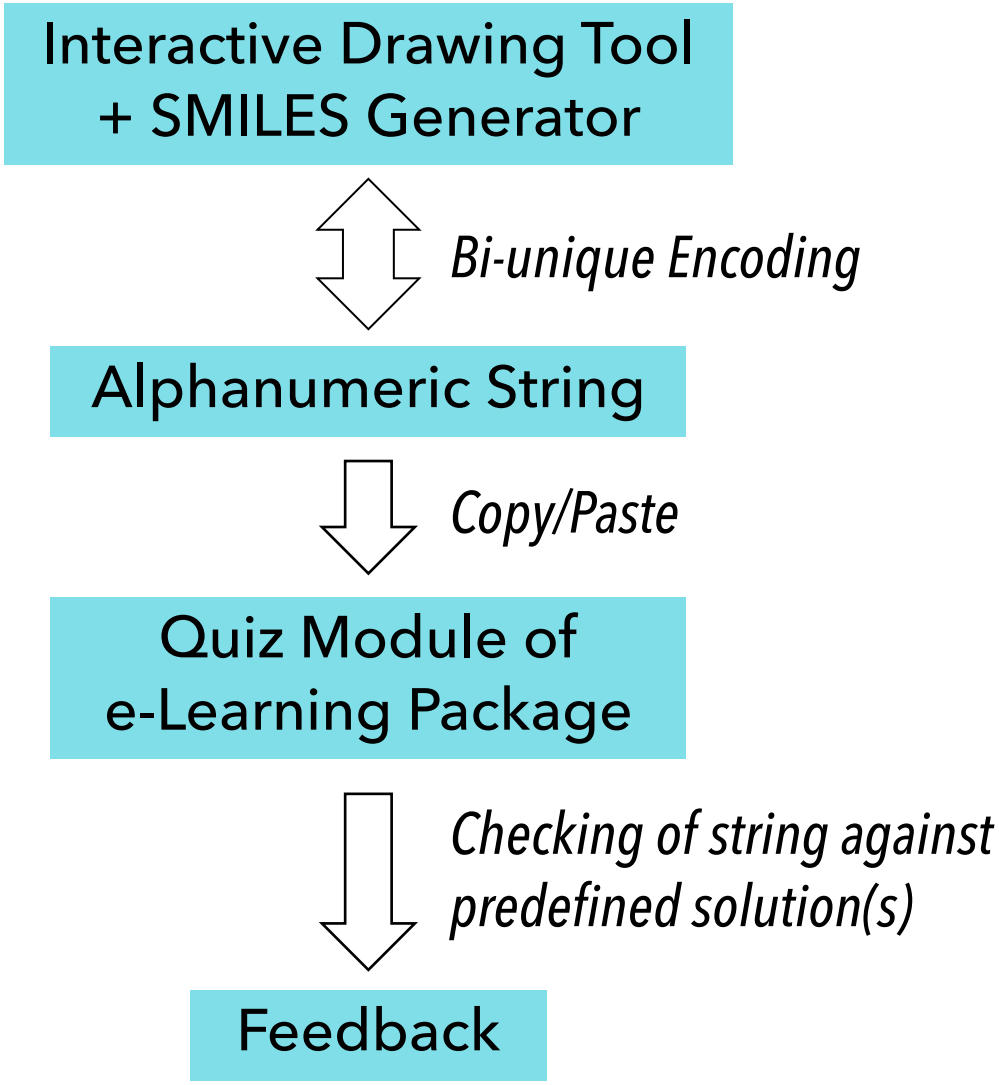
- **InChI** = IUPAC International Chemical Identifier generated by an open-source algorithm: www.inchi-trust.org
- **SMILES** = Simplified Molecular Input Line Entry System SMILES™: daylight.com; openSMILES: opensmiles.org

Sulfanilamide

InChI=1S/C6H8N2O2S/c7-5-1-3-6(4-2-5)11(8,9)10/h1-4H,7H2,(H2,8,9,10)

SMILES: Nc1ccc(cc1)[S](N)(=O)=O

Modular Concept Combining SMILES Generator with Standard e-Learning Package



Why Develop a New SMILES Generator ?

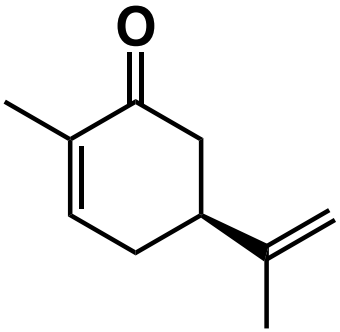
Existing SMILES Generators: JSME (https://jsme-editor.github.io), Marvin JS (ChemAxon, https://chemaxon.com), ChemDraw, …

- Use in exams without knowing source code?
- SMILES generation often not bi-unique
- Didactic reasons:
  - Undesired auto-correction features
  - Undesired ready-made functional groups
- Issues with existing SMILES generators ➜

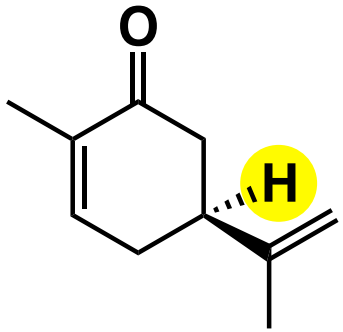
Issues with Existing SMILES Generators

SMILES codes may depend on whether H-atoms are drawn explicitly or not.

(+)-(*S*)-Carvone



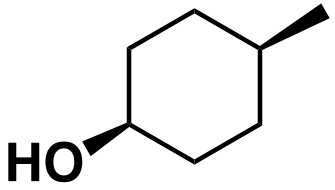
vs.



Marvin JS:	CC(=C)[C@H]1CC=C(C)C(=O)C1
Marvin JS (expl. H):	[H][C@@]1(CC=C(C)C(=O)C1)C(C)=C
ChemDraw:	C=C(C)[C@H]1CC=C(C(C1)=O)C
ChemDraw (expl. H):	C=C(C)[C@@]1([H])CC=C(C(C1)=O)C
JSME:	C=C(C)[C@H]1CC=C(C)C(=O)C1
MOSFECCS:	CC(=C)[C@H]1CC=C(C)C(=O)C1

Issues with Existing SMILES Generators

SMILES codes may depend on the order in which atoms and bonds are drawn

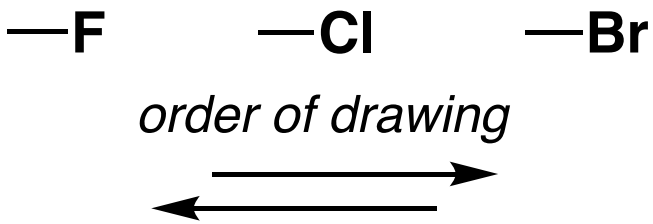


cis-4-Methylcyclohexanol

JSME (Me first):	C[C@H]1CC[C@@H](O)CC1
JSME (OH first):	C[C@@H]1CC[C@H](O)CC1
ChemDraw (Me first):	C[C@H]1CC[C@@H](O)CC1
ChemDraw (OH first):	O[C@H]1CC[C@@H](C)CC1
Marvin JS:	C[C@H]1CC[C@@H](O)CC1
MOSFECCS:	C[C@H]1CC[C@@H](O)CC1

Issues with Existing SMILES Generators

Multi-molecule SMILES may depend on the order in which the molecules are drawn



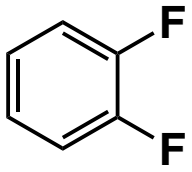
JSME (→): CF.CCl.CBr
JSME (←): CBr.CCl.CF
ChemDraw (→): CF.CCl.CBr
ChemDraw (←): CBr.CCl.CF

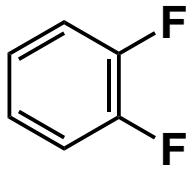
Marvin JS (⇄): CF.CCl.CBr

MOSFECCS (⇄): CCl.CBr.CF

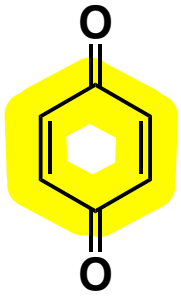
SMILES and "Aromaticity"

Trying to reduce the number of "trivial" resonance structures …

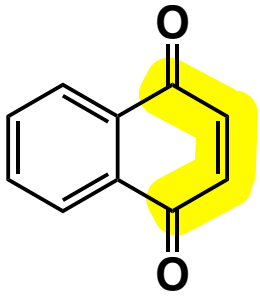




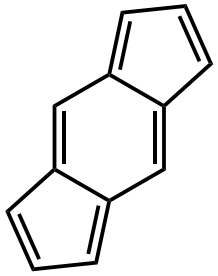
Fc1ccccc1F



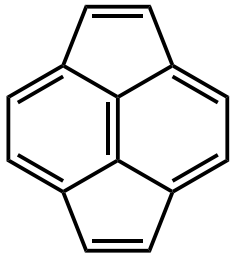
O=C1C=CC(=O)C=C1



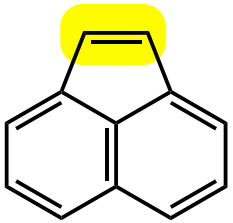
O=C1C=CC(=O)c2ccccc12



c1cc2cc3cccc3cc2c1



c1cc2ccc3ccc4ccc1c4c23



c1cc2cccc3C=Cc(c1)c23

Features of MOSFECCS

(Molecular Structural Formula Editor and Calculator of Canonical SMILES)

Written in **JavaScript** (ECMAScript 5.1), uses ***canvas elements*** as defined in HTML5 for drawing.

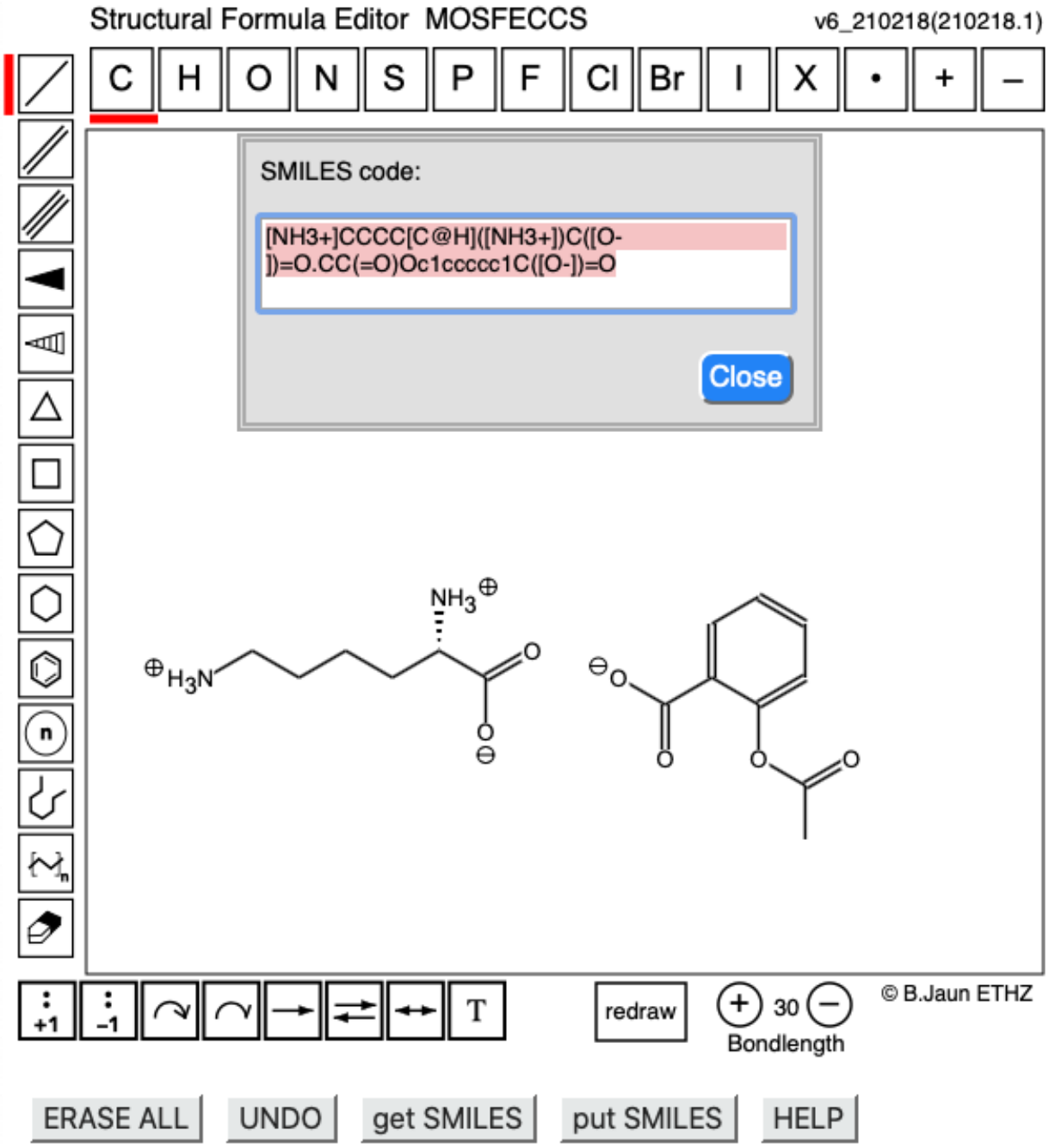
- **Bi-unique** SMILES generation
- **Explicit H-atoms** do not affect SMILES
- Treats *non-trivial* resonance structures and tautomers as **distinctive species**
- **Sorts multi-SMILES** unambiguoulsy

MOSFECCS

MOSFECCS includes

SMILES **generator** +
SMILES **parser**:

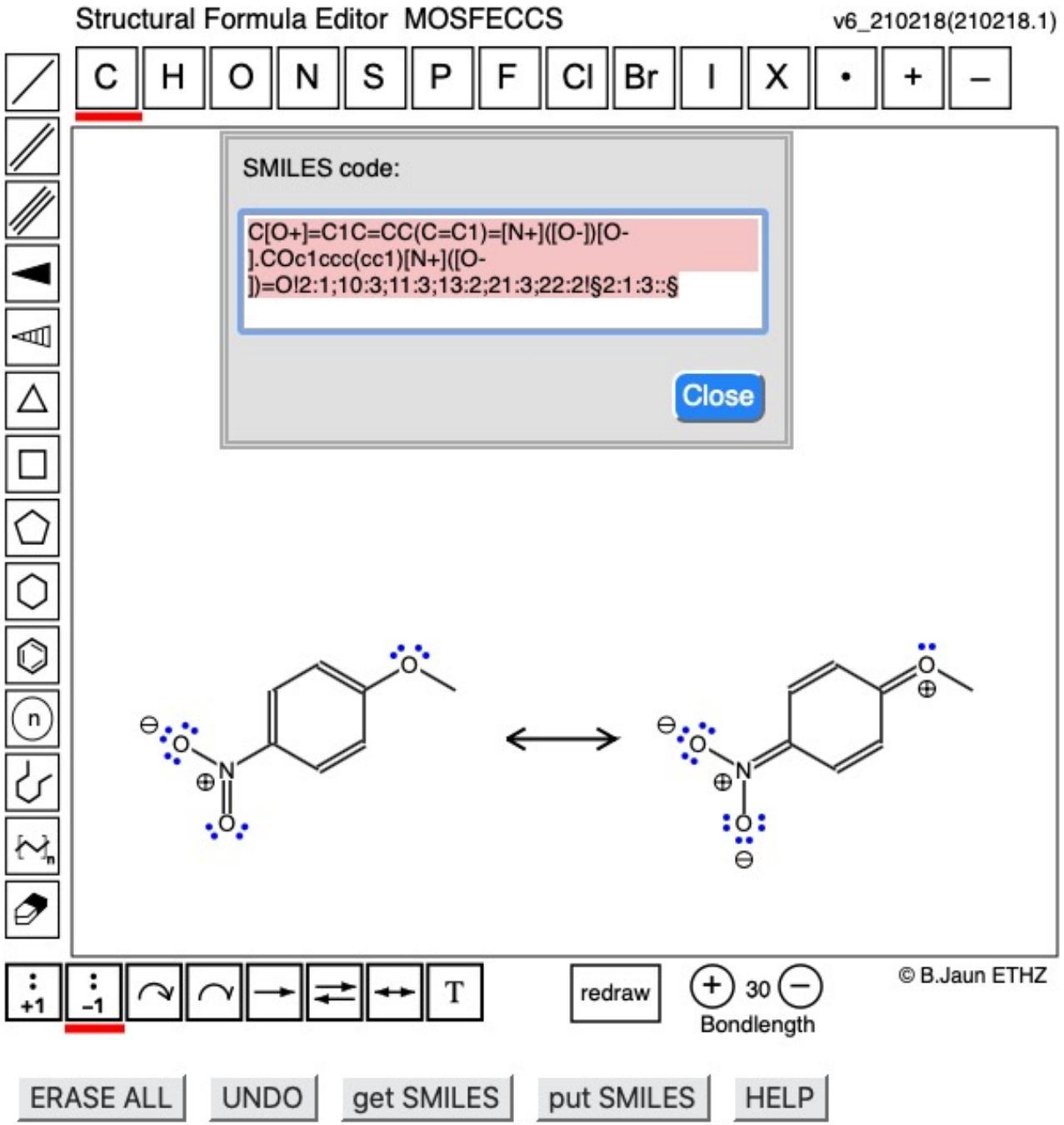
SMILES ⇄ structural drawing



MOSFECCS: *Lewis* and Resonance Structures

Lone pairs

Resonance arrows

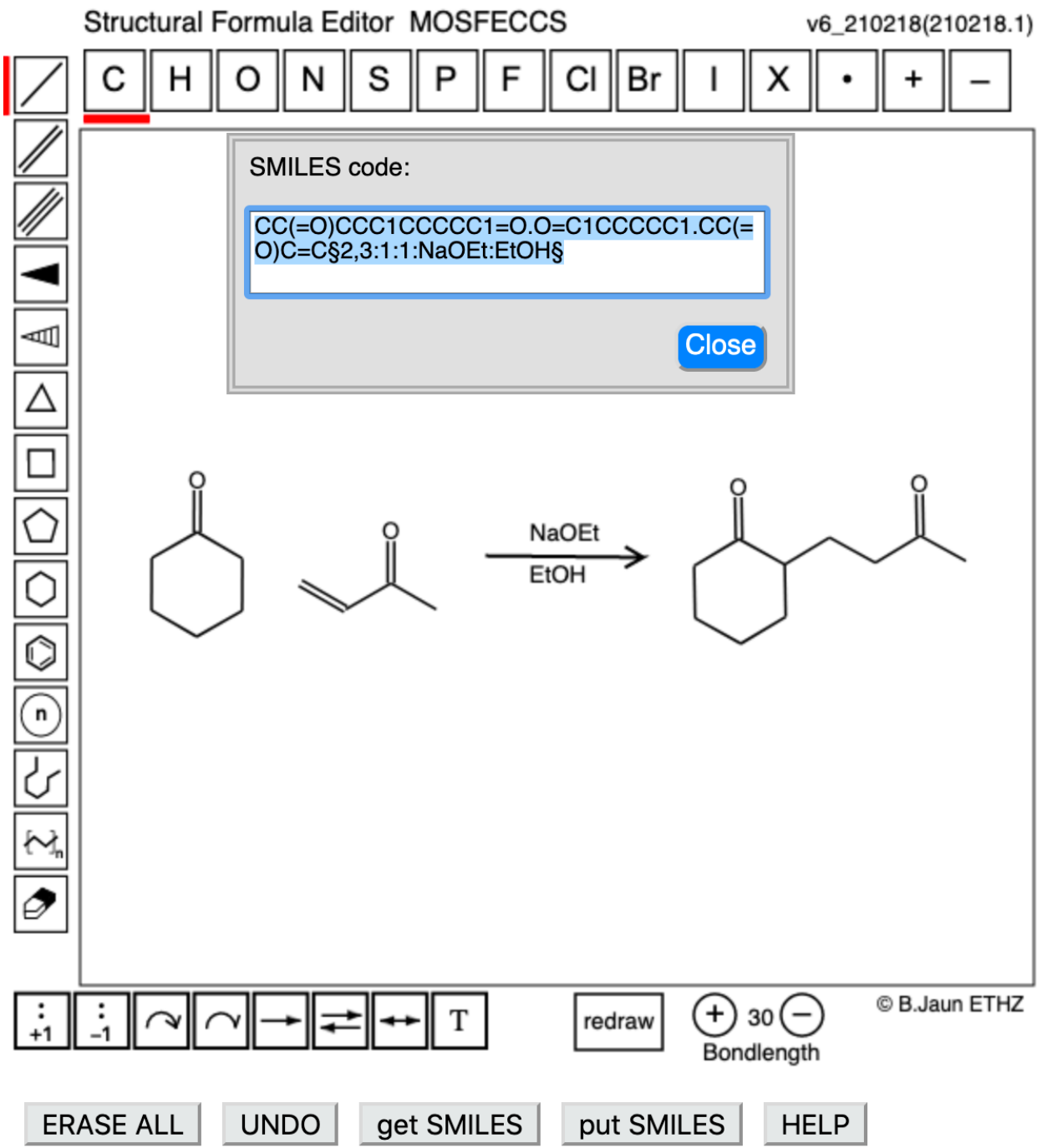


MOSFECCS: Reaction Schemes

Reactions:

Definition of reactants and products

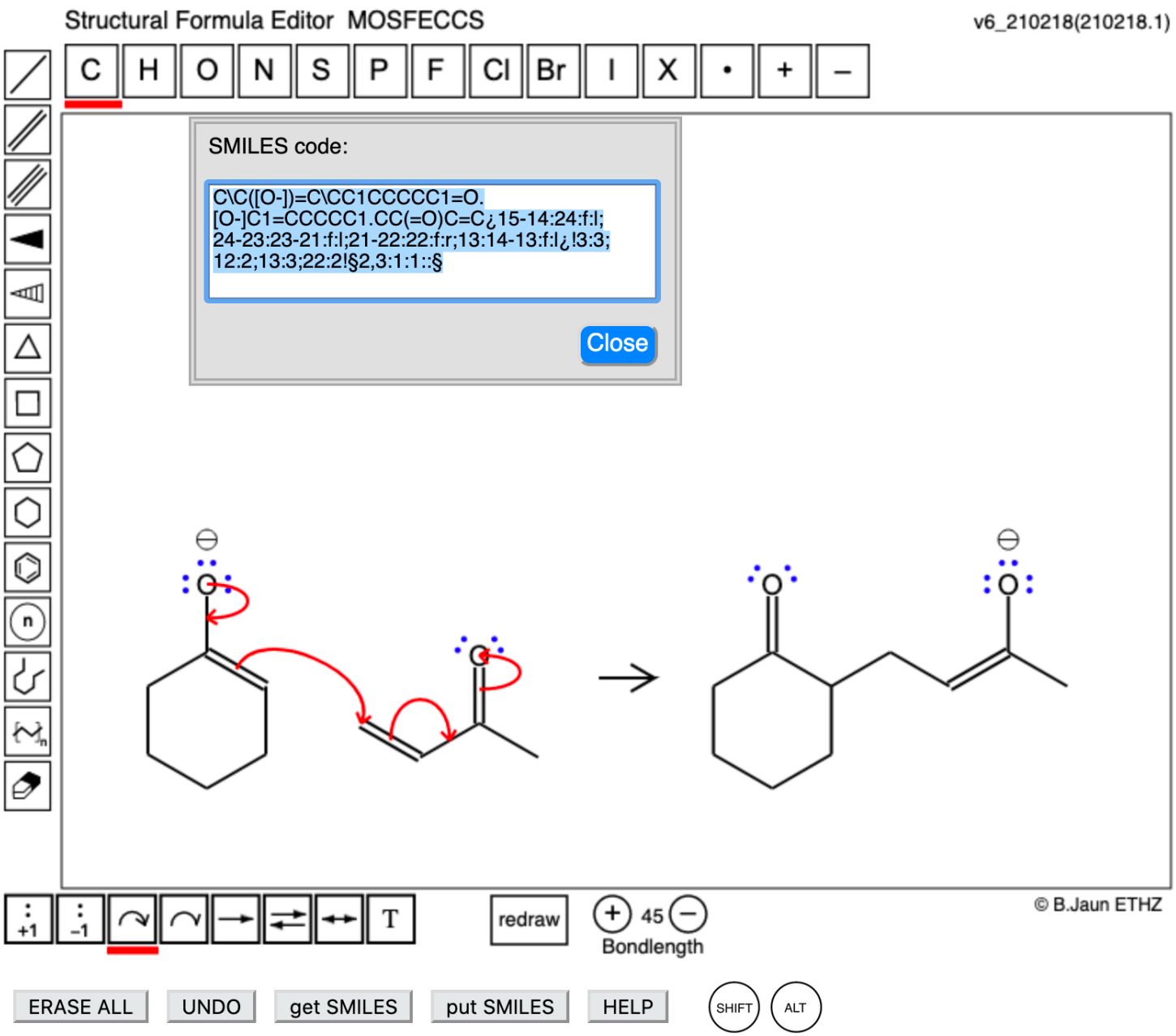
Arrows, reagents



MOSFECCS: Reaction Mechanisms

Mechanisms:

Electron displacement arrows

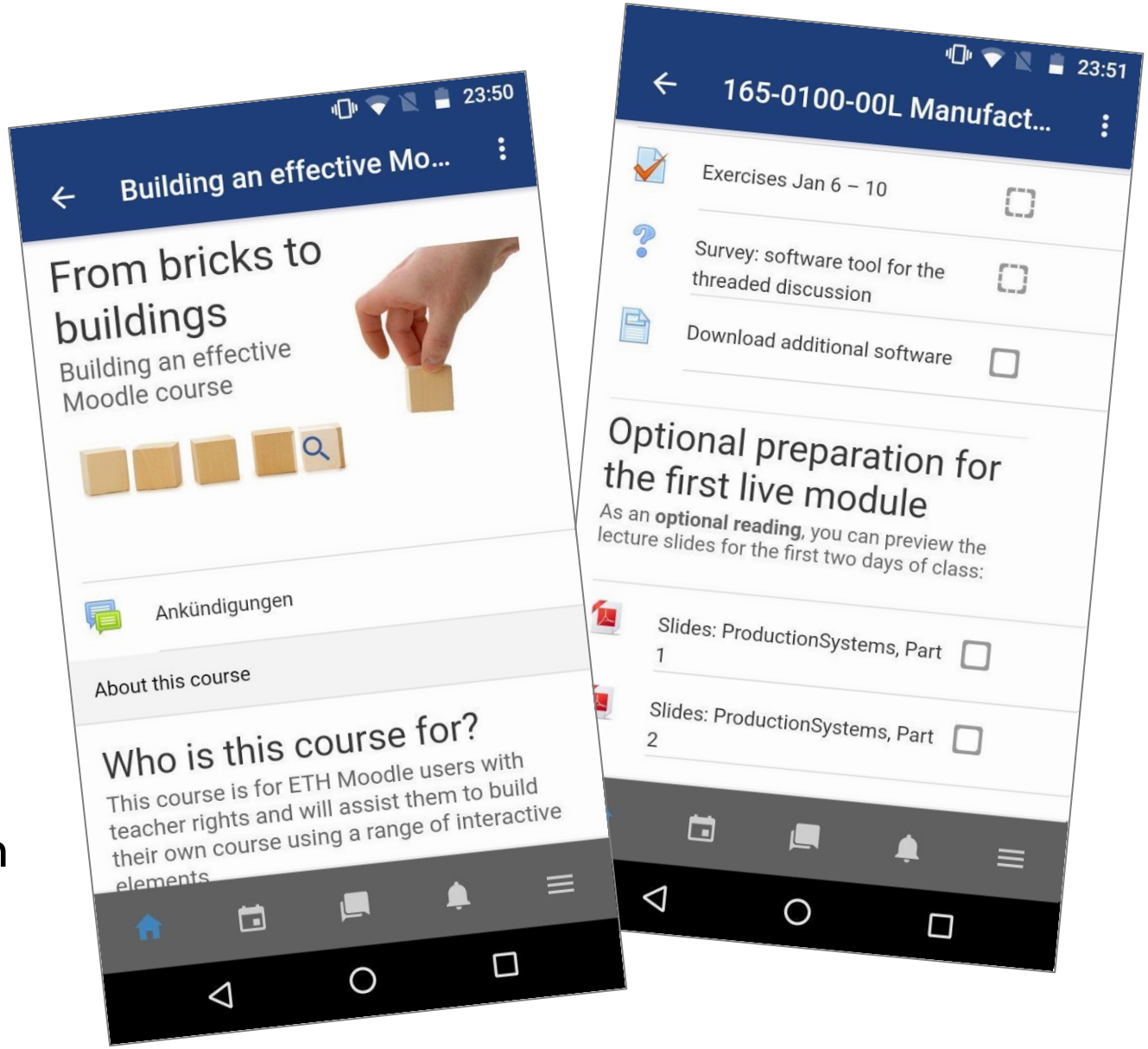


MOSFECCS: Tablet and Smartphone Versions

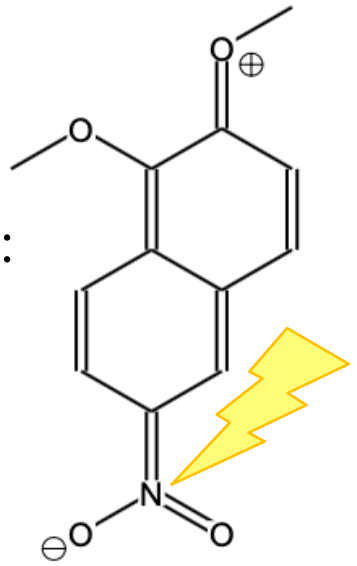
Tablet version:
see
previous slide

ETH Moodle App
for Android & iOS

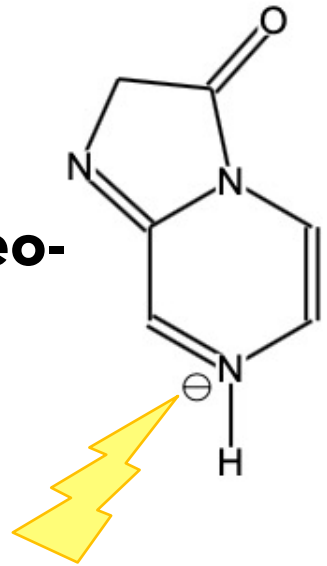
(branded version
of the official
Moodle App)

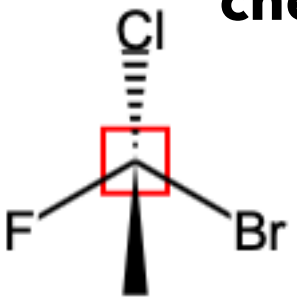


Didactic Aspects of MOSFECCS



- **Tolerates many mistakes** that students may do:
  - Exceeding of valencies
  - Wrong charges
- **No ready-made functional groups**
- Treats tautomers and “non-trivial” resonance structures as **distictive species**
- Returns a warning in case of **conflict with stereo-chemical conventions** (no auto-correction)





MOSFECCS To Do's ...

- **Publish source code**
- Implementation of bond types such as **coordinative bonds**, **π-coordination**
- Handling of stereogenic centers with **square planar**, **trigonal bipyramidal**, and **octahedral** bonding geometries

Exam Question Samples

Online Exams

- OC I and II exams have been given online **since 2018**:
  3 summer sessions (large) and 4 winter sessions (small).
- Taken so far by **1563 candidates** total
- Carried out under «**controlled**» **conditions**:
  On-campus, dedicated ETH computers
- Platform: **Moodle**

Exam Preparation and Exam Procedure

- Exam needs to be **prepared** and **tested carefully**.
- **3 Exams** offered in parallel: OC I, OC II, and OC I+II
- **No exam papers** to be brought/distributed/collected.
- Candidates choose "their" exam **regardless of seating**.
- **Technical problems** with ...
  - Workstations: rare (≤ 1%)
  - MOSFECCS (freeze): rare (≤ 1%)

Exam Correction

- **No paper copies** to take home and to decontaminate 
- Questions with **fully automated** correction: 😊
- However: Moodle is **cumbersome for manual corrections** in the context of large exams 😕
  - Too many clicks
  - Browser loading times add up …
  - Display options limited
- In any case: you see the SMILES, but **not the structure** …

  [O-]C1=[N+]2C=CNC=C2N=C1 😕

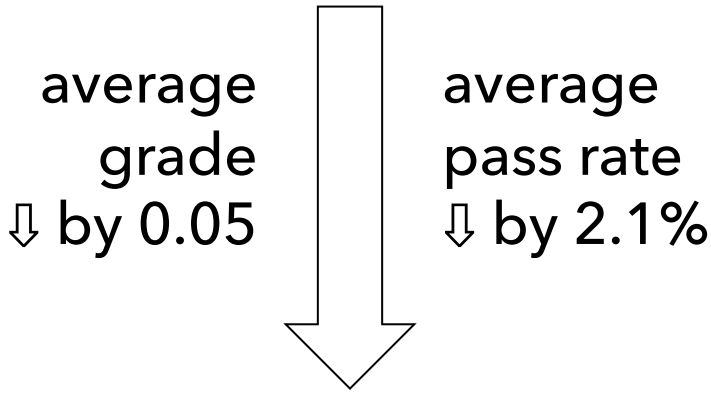
Exam Correction

- Home-made solution: **work on raw data extracted** from Moodle …
  - Data work-up **automatized** with scripts → spreadsheet
  - Use MOSFECCS parsing capability to **re-generate structural drawings**
  - **Distinct answers only** require manual correction 😁
  - Define new partially correct answers in Moodle and **re-grade**
- Raw data handling has to be done **with great care !!!**
- *Exam Moodle* and *ETH grading data app* are **well inter-faced.**

Exam Correction Sample

Switch from "Paper" to "Online": Impact on Exam Results?

Paper Exams
Summer Sessions **2015-2017**
1130 Candidates



Online Exams
Summer Sessions **2018-2020**
1185 Candidates

Conclusions

- **Total amount of work similar** in both cases (paper vs. online). Online: work is **more interesting** and **varied**.
- **Cross-fertilization** between online exam and e-Learning Course.
- **No** handling and archiving of kilograms of **paper copies**.
  - **Post-exam review** particularly **easy**.
- Online exam requires **good IT background infrastructure** (equipment & administration).
- Your own **tools** and **scripts** need **maintenance**.
- **Costs** for online exams are **higher**.
- Embarking for online exams should be considered as a **long-term investment**.
- **The more** candidates, **the better** the return.

Acknowledgements

Prof. em. Dr. Bernhard Jaun

B. Jaun, C. Thilgen, *Chimia* 2018, *72*, 48.

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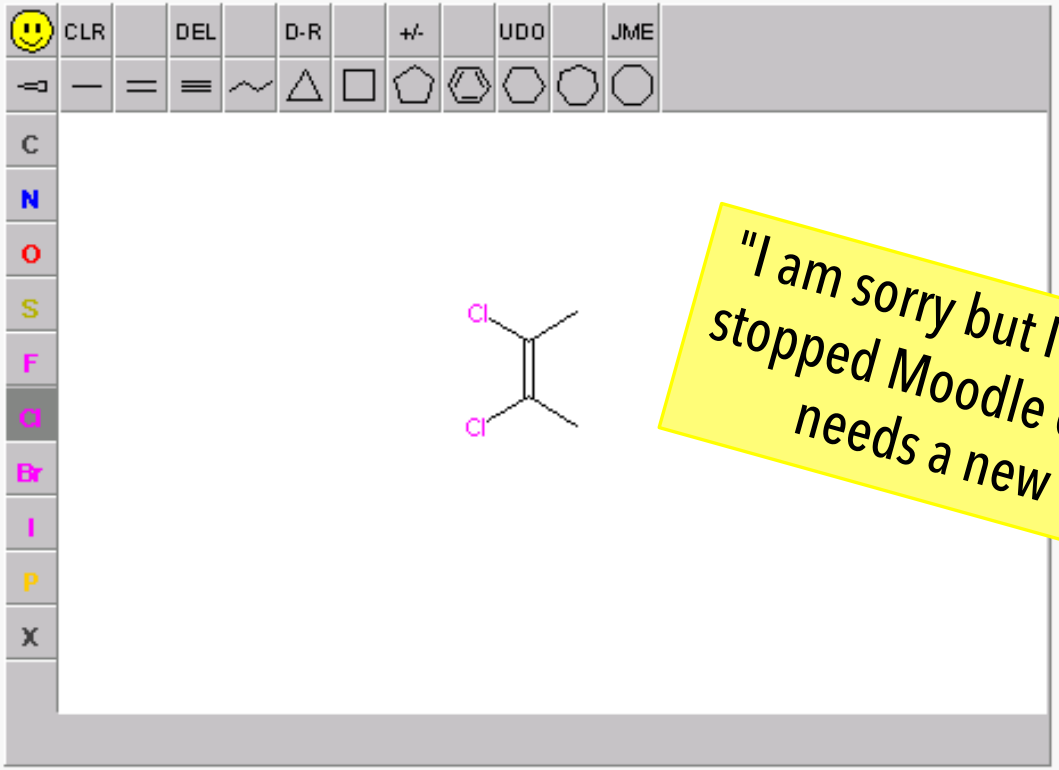
Solution ? Moodle Question Type JME

Please draw the structure of 2,3-dichloro-but-2-ene.

Answer:

Answers must be written in the SMILES chemical markup language. You can use the JME editor to create a structure interactively, and then use the "Insert from editor" buttons to insert the code into the answer boxes.



JME Editor courtesy of Peter Ertl, Novartis

"I am sorry but I am now retired and I stopped Moodle coding ... this plugin needs a new maintainer ..."

Answer:

Insert from editor

Dan Stowell (original author), Jean-Michel Védrine (lead maintainer)
https://docs.moodle.org/310/en/question/type/jme