Automated Analysis of Physics Lesson Plans

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Introduction: lesson plans as learning outcomes of pre-service physics teachers

Session Title:

„Challenges in measuring learning outcomes in STEM fields"

Computer-based classification of lesson phases

Lesson planning

Pre-service physics teachers

Can machines hypothesize about learning processes?

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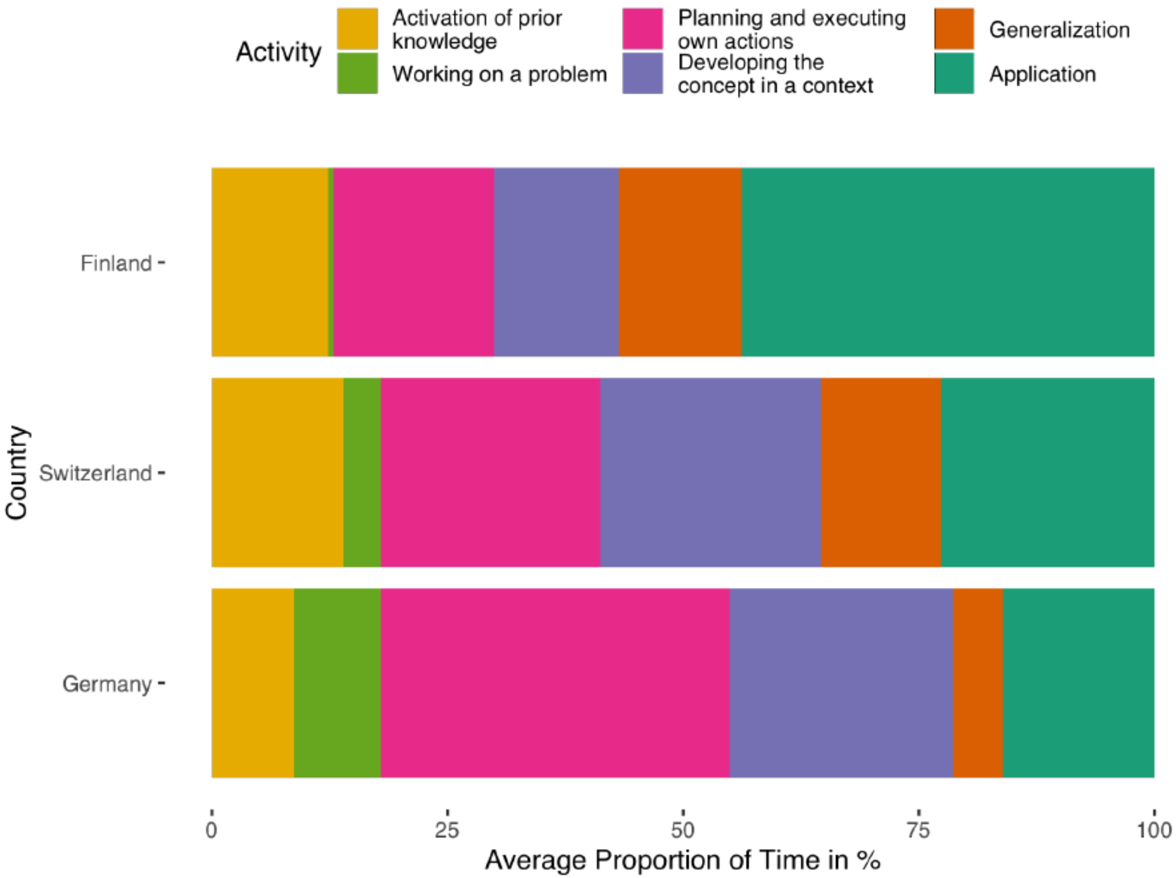
Agenda

» Why automation of classification of phases is beneficial from a practical perspective
  - Problem: Lesson planning in physics
  - Basis models: A theory to solve the problem
  - Machine Learning models as a basis to support automated feedback

» Study: A first step towards feedback

» A perspective for future research

Teachers in Germany tend to use experience to build theory

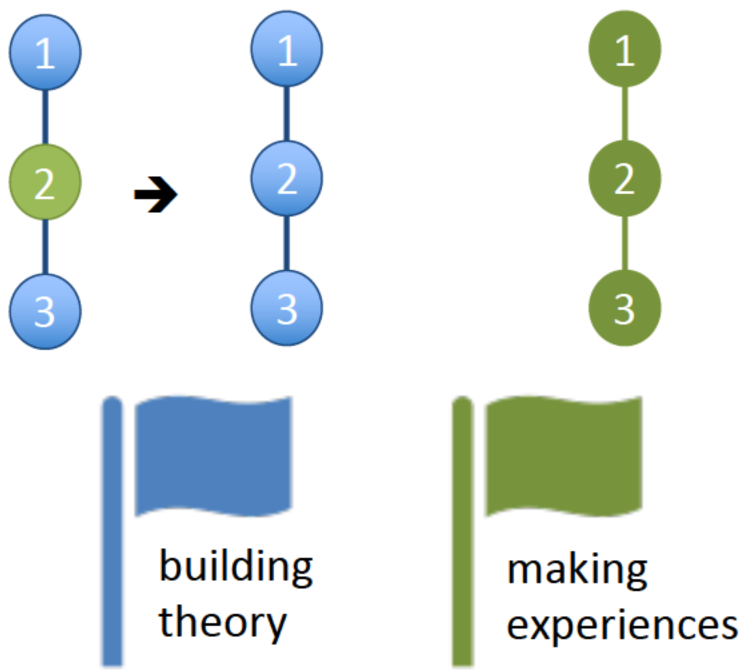


- German teachers provide a mix of both learning by experience and building theory
- German students show less learning gains than Finnish students
- Students can't directly infer a new concept from their experience (Muckenfuß, 1996)

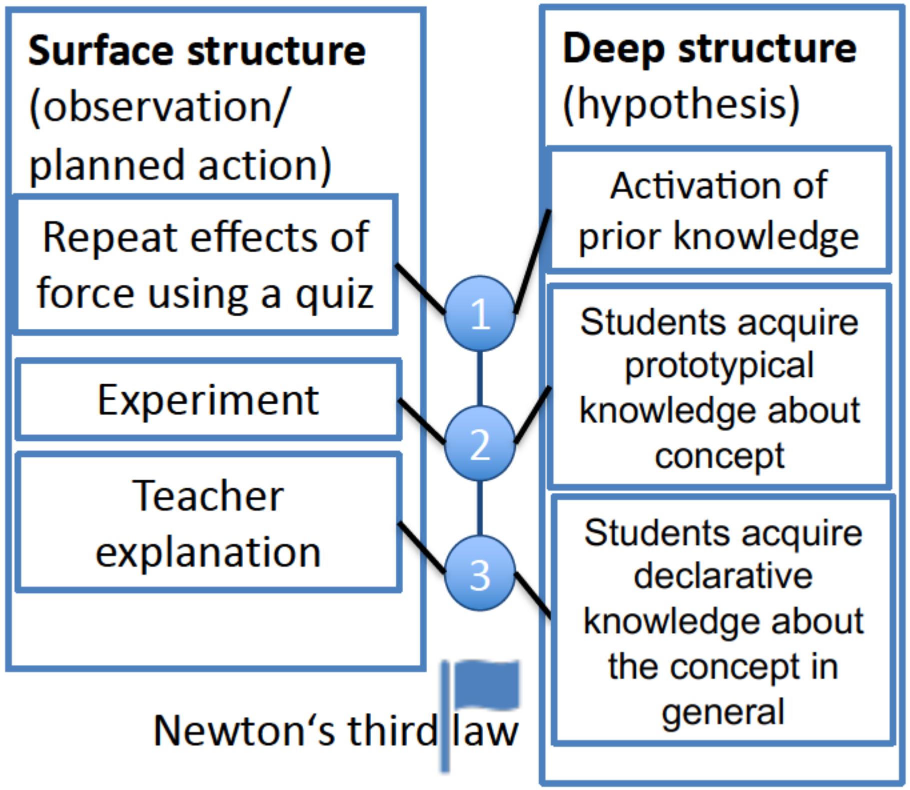
(Geller, 2015, p. 111; graph replotted and translated; values extracted from graph; for exact values see original)

Planning lessons means hypothesizing about learning

Basis Models of Teaching and Learning (e.g. Oser & Baeriswyl, 2001): Different chains of actions (phases) for different teaching goals



+ 12 other basis models



Planning lessons means **hypothesizing about learning**

Providing more feedback would be useful but challenging

» Problem seems insensitive to instruction followed by experience for pre-service physics teachers (Mutschler et al., 2021)

» More frequent feedback would be beneficial (Hattie & Timperley, 2007, Lee et al., 2021) & more research is needed in this field (Mutschler et al., 2021; Geller, 2015)

» Coding related to **deep structures** is resource intensive

- **Experts need extensive experience**
- **Low interrater-agreement**
  - Kappa: 0.39-0.50 (Geller, 2015, p. 85)
  - Kappa: 0.4 median (Reyer, 2004, p. 200)
  - Consensus-validation (Gerber, 2007)
  - Others failed finding agreement and switched research question (Borowski, personal communication)

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A machine learning model would enable us to store the expertise

- **For science education/assessment (Zhai, Shi, & Nehm, 2021; Zhai, Yin et al., 2020) many examples for students:**
  - Extracting student ideas of generality of explanations (Rosenberg & Christ, 2020) unsupervised
  - Computer Assisted Scoring, Biology, Subject Matter Knowledge: (Kappa > 0.8) (Nehm & Härtig, 2012; Nehm, Ha, & Mayfield, 2012)
  - Learning progressions on the concept of flux Kappa > 0.6 (Jescovitch et al., 2021)
- **Less for teacher performance**
  - Teacher Reflection (e.g. Wulff et al., 2020)
  - Araya et al. (2011): Teacher activities and mathematical content (agreement mostly high but scatters by characteristic) from lesson transcripts.
- **Can we also classify deep structural characteristics?**
  - High complexity and high diversity (Zhai, Haudek, et al. 2020; Haudek & Zhai, 2021) and many ways how the same deep structure can be expressed (Zhai, Shi, & Nehm, 2021) makes classification challenging
  - Unclear if even worth trying?
- **The study: Just a step in that direction**
  - Can we classify the steps of concept building automatically via machine learning in very restricted lesson planning scenario?

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Task: Machine

Activation

Prototype

Concept

Application/ Transfer

Outside of Basis Model

Order	Description of Classroom Action	HKS
1	Teacher greets the students	Outside
2	Students obeserve an experiment	Activation
3	...	

Numeric

Text

Classifier (logistic regression, decision tree, ...)

Design

Data (Schröder et al., 2020):

» Paper and pencil-test

» 126 Lesson plans (1231 segments) of pre-service physics teachers

Task: Plan a lesson on Newton‘s third law of motion

Goal: Students should be able to explain the law after the lesson

Human Analysis

» Paraphrasing

» Segmentation

» Digitalization

» Assignment of chain of phases ➔

order	Description	Phase (label)
1	Start by explaining the general rule of Newton‘s third law	Concept
2	...	...

Machine learning

- Pre-Processing
- Machine learning: model selection & evaluation (cross-validation, hyperparameter tuning, 30% test data)

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A first step: Shallow Learning to assign chains of lesson phases

Multinomial Logistic Regression

	precision	recall	f1-score	N
Activation	0.74	0.68	0.71	72
Prototype	0.68	0.82	0.75	142
Concept	0.96	0.61	0.75	44
Application / transfer	0.70	0.75	0.72	64
Outside of the basis model	0.67	0.13	0.22	15
accuracy				**0.72**
macro avg	0.75	0.60	**0.63**	337
weighted avg	0.73	0.72	0.71	337

- Cohen’s Kappa = 0.60 (acceptable, Caspar & Wirtz, 2002 p. 49; Geller, 2015, p. 85)
- This would allow group-feedback for this planning situation
    - Are “all” steps of concept building in the lesson plan?
    - Is there enough application?

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The algorithm is interpretable

Higher regression coefficient

Concept	
Feature	English (Example word in German)
merksatz	mnemonic sentence (Merksatz)
tafelbild	blackboard image (Tafelbild)
na	short for Newton's Law (Newtonsches Axiom)
order	-
tafel	blackboard (Tafel)

Generic term

Content specific term

Position in the lesson

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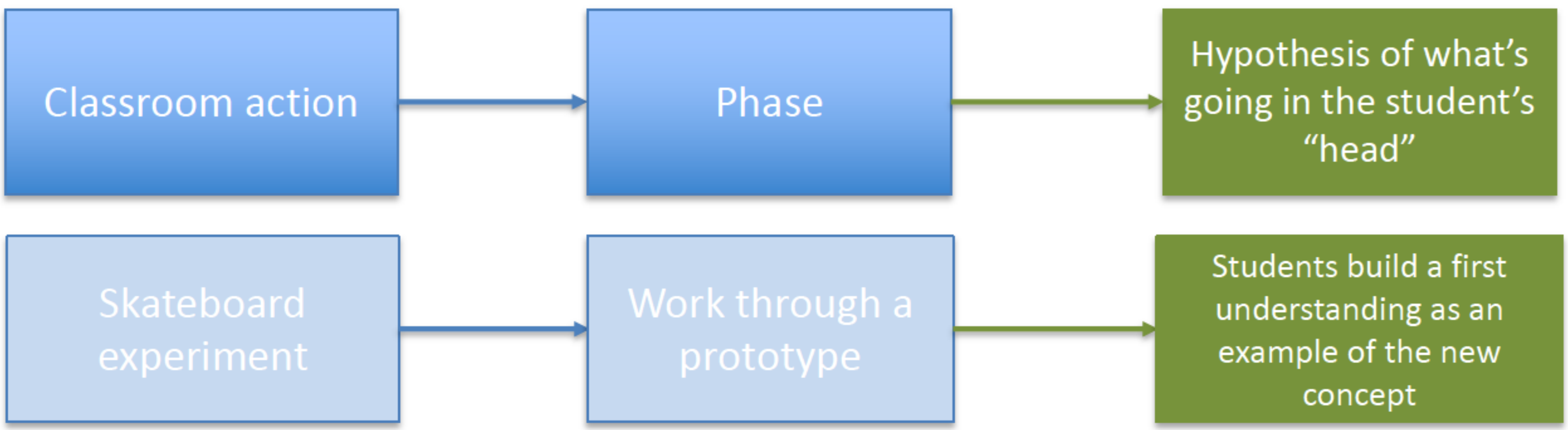
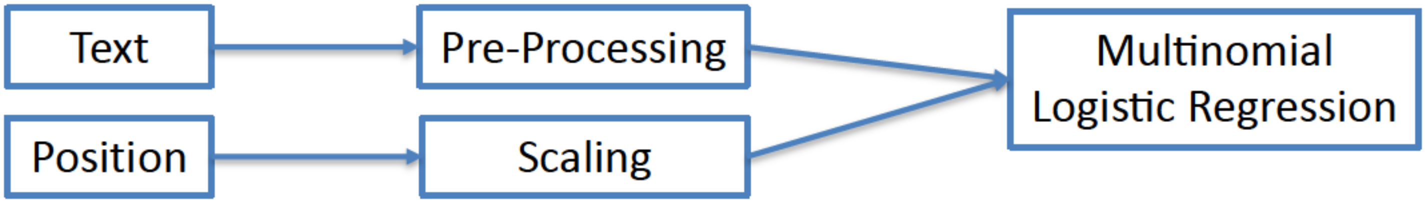
In principle we build a machine which makes hypothesis on learning process

» Does this machine make hypotheses about (intended) learning processes?



But how should it think? Limitations and possible extensions



- Account for context of the classroom action to be classified (Gerber, 2007)

Demonstration of an experiment with skateboards and explaining, why the active person will also be accelerated

Is this a prototype or an application?

- Other basis models

What do we learn for future research?

Common Question: „Will Artificial Intelligence Replace Teachers in the Future?“ (AnalyticsInside, 2021)

What are the possibilities?

- ➢ Science Education and STEM Education have to provide answers related to categories most important to us
  - » Science Assessment (Zhai, Shi, & Nehm, 2021; Zhai, Yin et al., 2020)
  - » For teaching performance: Deep structure characteristics (Fischer et al., 2003) ➔ less evidence
- This study provides first evidence that this might be possible
- Challenges
  - Cohen’s kappa of 0.6 in a very restricted scenario shows that it will be challenging to provide such a classifier in general
  - Also content specific terms (Newton’s third law) are used for prediction
  - Logistic regression seems to be a good classifier: accuracy vs. substantial validity of the reasoning process

What do we learn for future research?

"[...] planning of instructional action according to hypothesized learning processes is usually primarily intuitive." (Gerber, 2008, p. 35 translated)

A machine would add to the teacher

We should try it

Thank you!

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Tanja Mutschler
Prof. Dr. Andreas Borowski

Jan Schröder
Prof. Dr. Josef Riese

Dr. Christoph Vogelsang
Prof. Dr. Christoph Kulgemeyer

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References

- Araya, R., Plana, F., Dartnell, P., Soto-Andrade, J., Luci, G., Salinas, E., & Araya, M. (2012). Estimation of teacher practices based on text transcripts of teacher speech using a support vector machine algorithm. *British Journal of Educational Technology*, *43*(6), 837–846. https://doi.org/10.1111/j.1467-8535.2011.01249.x
- Fischer, H. E., Klemm, K., Leutner, D., Sumfleth, E., Thiemann, R., & Wirth, J. (2003). Naturwissenschaftsdidaktische Lehr-Lernforschung : Defizite und Desiderata. *Zeitschrift für Didaktik Der Naturwissenschaften*, *9*, 179–208.
- Geller, C. (2015). *Lernprozessorientierte Sequenzierung des Physikunterrichts im Zusammenhang mit Fachwissenserwerb [Learning process-oriented sequencing of physics lessons in connection with knowledge acquisition]*. Berlin: Logos.
- Gerber, B. (2007). *Strukturierung von Lehr-Lern-Sequenzen im Physikunterricht*. Universität Bern.
- Hattie, J., & Timperley, H. (2007). The power of feedback. *Review of Educational Research*, *77*(1), 81–112. https://doi.org/10.3102/003465430298487
- Haudek, K. C., & Zhai, X. (2021). Exploring the effect of assessment construct complexity on machine learning scoring of argumentation (preprint). In *Virtual Annual International Conference of the National Association for Research in Science Teaching (NARST)* (pp. 3–22).
- Jescovitch, L. N., Scott, E. E., Cerchiara, J. A., Merrill, J., Urban-Lurain, M., Doherty, J. H., & Haudek, K. C. (2021). Comparison of machine learning performance using analytic and holistic coding approaches across constructed response assessments aligned to a science learning progression. *Journal of Science Education and Technology*, *30*(2), 150–167. https://doi.org/10.1007/s10956-020-09858-0
- Lee, H. S., Gweon, G. H., Lord, T., Paessel, N., Pallant, A., & Pryputniewicz, S. (2021). Machine learning-enabled automated feedback: supporting students’ revision of scientific arguments based on data dawn from simulation. *Journal of Science Education and Technology*, *30*(2), 168–192. https://doi.org/10.1007/s10956-020-09889-7
- Muckenfuß, H. (1996). Grundpositionen Wagenscheins – kritisch hinterfragt [Basic positions of Wagenschein - critically discussed]. *Der Mathematische und Naturwissenschaftliche Unterricht*, *49* (8), 455–462.
- Mutschler, T., Buschhüter, D., Schröder, J., Riese, J., & Borowski, A. (2021). Theoriekonformität von Unterrichtsplanungen im Fach Physik vor und nach dem Praxissemester. In S. Habig (Ed.), *Naturwissenschaftlicher Unterricht und Lehrerbildung im Umbruch? Gesellschaft für Didaktik der Chemie und Physik online Jahrestagung* (pp. 258–261). Universität Duisburg-Essen.
- Nehm, R. H., & Härtig, H. (2012). Human vs. computer diagnosis of students’ natural selection knowledge: testing the efficacy of text analytic software. *Journal of Science Education and Technology*, *21*(1), 56–73. https://doi.org/10.1007/s10956-011-9282-7
- Nehm, R. H., Ha, M., & Mayfield, E. (2012). Transforming biology assessment with machine learning: automated scoring of written evolutionary explanations. *Journal of Science Education and Technology*, *21*(1), 183–196. https://doi.org/10.1007/s10956-011-9300-9
- Oser, F., & Baeriswyl, F. J. (2001). Choreographies of teaching: bridging instruction to Learning. In V. Richardson (Ed.), *Handbook of Research on Teaching* (4th ed., pp. 1031–1065). Washington: American Educational Research Association.
- Reyer, T. (2004). *Oberflächenmerkmale und Tiefenstrukturen im Unterricht. Exemplarische Analysen im Physikunterricht der gymnasialen Sekundarstufe*. Berlin: Logos.
- Schröder, J., Riese, J., Vogelsang, C., Borowski, A., Buschhüter, D., Enkrott, P., … Schecker, H. (2020). Die Messung der Fäigkeit zur Unterrichtsplanung im Fach Physik mit Hilfe eines standardisierten Performanztests [Measuring the skills of lesson planning in the subject of physics using a standardized performance assessment]. *Zeitschrift für Didaktik Der Naturwissenschaften*. https://doi.org/10.1007/s40573-020-00115-w
- Wulff, P., Buschhüter, D., Westphal, A., Nowak, A., Becker, L., Robalino, H., … Borowski, A. (2020). Computer-based classification of preservice physics teachers’ written reflections. *Journal of Science Education and Technology*. https://doi.org/10.1007/s10956-020-09865-1
- Zhai, X., Shi, L., & Nehm, R. H. (2021). A meta-analysis of machine learning-based science assessments: Factors impacting machine-human score agreements. *Journal of Science Education and Technology*, *30*(3), 361–379. https://doi.org/10.1007/s10956-020-09875-z
- Zhai, X., Yin, Y., Pellegrino, J. W., Haudek, K. C., & Shi, L. (2020). Applying machine learning in science assessment: a systematic review. *Studies in Science Education*, *56*(1), 111–151. https://doi.org/10.1080/03057267.2020.1735757
- Zhai, X., Haudek, K.C., Shi, L., Nehm, R.H., & Urban-Lurain, M. (2020). From substitution to redefinition: A framework of machine learning-based science assessment. *Journal of Research in Science Teaching*, *57*(9), 1430–1459. https://doi.org/10.1002/tea.21658