Teaching Thinking-Back-and-Forth in Practical Work: an Educational Design Study in Secondary Education

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Abstract: Practical work provides the opportunity for students to make a connection between hands-on activities and minds-on concepts. In this study, lesson design principles were investigated for stimulating Thinking-Back-and-Forth (TBF) between hands-on and minds-on aspects. Nine practical lessons intended to stimulate minds-on learning experiences were designed. These lessons contained an assignment and guidance aimed at stimulating TBF and mitigation of the cognitive load of hands-on aspects. Student learner reports were evaluated for reported minds-on learning, and the lessons were video-recorded. Results show that the design principles stimulate minds-on learning. Therefore, educational practice can benefit from using the design principles described.

Introduction

During practical work, many science teachers primarily focus on the domain of observables or hands-on aspects, instead of stimulating students to make a clear connection with the domain of ideas or minds-on aspects, which has been identified as a major cause for the relative ineffectiveness of practical work [1, 2]. We use the term Thinking-Back-and-Forth (TBF) to indicate any reasoning activity in which students have to use at least one aspect from both domains [3] and we have identified a framework containing four main categories in which these activities can be grouped, i.e. *Explain, Conclude, Predict,* and *Design an experiment*. The sources for activities within these main categories vary from literature on the pedagogy of practical work [e.g. 4] to learning about the nature of science and learning inquiry skills [e.g. 5]. Since practical work, by its nature, requires students to become engaged with hands-on aspects, TBF is required to create an effective environment in which students can reach minds-on learning experiences. Although an appreciable number of studies focus on the effectiveness of practical work, actual practice has not benefitted much [3, 6]. Interviews with teachers indicate that the TBF framework may hold the potential to contribute to filling this gap [3], since it provides a means to improve existing practice in relatively small and tangible steps. In our study we have designed nine different lessons that aim to stimulate TBF and thus encourage minds-on learning experiences.

We have used three design principles for practical lessons with the intend to stimulate TBF and thus reach student minds-on learning experiences, namely: 1. Each lesson contains a central TBF assignment that focusses attention on a limited number of related activities within one or two TBF-categories, 2. Early in the lesson mitigation of the cognitive load of the hands-on aspects takes place, and 3. Guidance aimed at stimulating TBF occurs throughout the lesson. The research question is: to what extent do the three central design principles for TBF during practical lessons stimulate minds-on learning experiences?

Method

We have designed nine different practical lessons for physics and chemistry for grades 7 till 10 in close cooperation with the teachers who eventually taught these lessons. Each lesson was performed twice, resulting in eighteen lessons. Learner reports in the form of a written questionnaire from all 305 participating students were collected. These questionnaires contained two questions. For Q1 students had to complete the sentence ‘During this lesson I have learned …

and …', and Q2 requested the students to complete the sentence 'During this practical work I have thought hardest about … and about …'. All remarks were scored as either minds-on or non-minds-on. If a student made a minds-on remark on both Q1 and Q2 this constituted a minds-on learning experience. All lessons were video-recorded and two researchers analysed these recordings to establish to what extend the design principles were adhered to. We used a binary logistic regression model to research differences between lessons and the effect of possible predictors (e.g. TBF category or grade) regarding number of minds-on learning experiences reported. Finally, we qualitatively selected some meaningful examples of the implementation of the design principles.

Results and conclusions

Investigating the video-recordings revealed that the teachers adhered to the design principles almost completely. Only the post-work class discussion was omitted in seven lessons, due to lack of time. The learner reports show that on average 61% of the students reported a minds-on learning experience, with percentages ranging from 31% to 96%. Practical lessons not designed by our design principles investigated in previous research, only achieved MO learning experiences with 37% of the students on average [7]. The difference between these percentages indicates that our design principles do stimulate minds-on learning experiences during practical work. The only statistically significant effect we could establish concerned the least performing lesson, that differed distinctly from most others. The qualitative description revealed that a less adequate mitigation of the cognitive load during this lesson may have impeded the students to engage in TBF. Quantitatively, we could not establish any other effects.

The main conclusion is that the design principles described do stimulate minds-on learning experiences for the majority of the students. Furthermore, the positive effect appears to be possible for a diversity of lesson content and for TBF-activities in all four TBF-categories. Therefore, educational practice regarding practical work can benefit from designing lessons such that they contain a clear assignment aimed at stimulating TBF, mitigate the cognitive load of the hands-on aspects and provide guidance aimed at TBF throughout the lesson.

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