Boosting deep learning in project-based class activities with peer-to-peer feedback

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Abstract

Project-based activities have been demonstrated to be an effective tool stimulating students to develop deep learning. In this study we test whether augmenting these activities with follow-up peer-to-peer feedback sessions can enhance this stimulation even further. For this purpose, we developed a basic rubric for peer-to-peer feedback and employed in a project-based class activity. The rubric includes guiding questions which help students address the quality of peer reports and the clarity of presenting results therein, and open, wondering questions encouraging students to find intuitive and counter-intuitive elements in the results obtained by their peers, given their prior knowledge from the course. Students are asked to give feedback and reflect on the received feedback in a written form. Our analysis of feedback's results obtained in real class conditions reveals clear signatures of deep learning in about 30 percent of feedback inputs and 60 percent of student reflections based on received feedback. We find that insufficient precision of peer reports and scarce knowledge of basic material from the lecture are among the main factors which can hinder some students in developing deep learning. Feedback inputs can also be used as a diagnostic of student performance. It can help teachers identify students exhibiting merely a surface learning approach and take some steps to mitigate potential causes.

Introduction

Student's approach to learning can be classified using a continues scale which spans between two limiting cases characterised as surface learning approach and deep learning approach (Biggs, 1999). Surface learning describes a basic approach which is predominantly focused on memorising the new material and reproducing it for a test. Students with this approach tend to reduce their learning effort and engagement to the level that is sufficient to accomplish the tasks and satisfy minimum criteria for passing the course. They do not develop ownership of the learning process or personal relations to the new knowledge, which are shown to be critical factors in achieving high-quality learning outcomes. On the other hand, deep learning concentrates on understanding the new material and thus preparing the ground for applying it to new situations. Deep learning is an ”umbrella” term which encompasses a wide range of various thought processes. It entails understanding and constructing meaning, critical thinking, relating new ideas to the previous knowledge and establishing multi-layer relations between different elements of the new and previous knowledge (Entwistle, 2009). Deep learning is also associated with developing personal relation to the new knowledge and perception of relevance, by making connection between the new material and more personalised context (Entwistle and Tait, 1990). This results in better transfer and retention of knowledge. Deep learning develops also general skills of critical thinking and exploratory reasoning in which one can easily formulate hypothesis, theorise about something, generalise or recognise exceptions.

Deep learning surpasses surface learning in all respects. It is therefore not surprising that stimulating and promoting deep learning has become the ultimate goal of teaching strategies at all educational levels. Deep learning can be stimulated in virtually all teaching situations. It has long been known that appropriately designed syllabus and assessment creates environment promoting deep learning in teaching involving rather traditional methods such as lecturing (Entwistle and Tait, 1990; Eizenberg, 1988). Better alignment between student prior knowledge and the new material, inspirational elements and formative assessment with questions triggering deep thinking are just examples of relevant factors in play. Deep learning can also be promoted by opening new spaces for experimenting within the frame- work of the new material. A good example of this strategy is project-based learning in which students confront the new knowledge with practical applications (Miller and Krajcik, 2019; Phyllis C. Blumenfeld and Palincsar, 1991). Teaching activities involving different kinds of discussions and group work can also promote deep learning. The key mechanism is interaction (Cleveland-Innes and Emes, 2005): students need to relate to different perspectives of understanding or perceiving the same content. Peer comments can broaden the context and meaning of the new content, while questions can direct thought processes towards uncharted territories.

Peer-to-peer feedback is a well-known instrument in academic teaching. It is commonly used to help students improve their written works, sharpen their reasoning, eliminate potential flaws and simply learn from each other. Its potential for promoting deep learning has been recognised in a range of studies (Filius et al., 2018b; Ray- mond Lynch and Seery, 2012). Peer-to-peer feedback appears to be a natural environment where students can better understand their own learning processes and synthesise information from multiple sources (Filius et al., 2018a). These are two main mechanisms through which students enter some levels of deep learning. Appropriately arranged feedback session can also enhance student commitment, which is yet another condition for developing deep learning. This happens more likely when a range of conditions are met: feedback is expected to be meaningful, timely and focused on student performance, and it should involve a dialogue in which students have enough time to receive comments, reflect on them and respond (Gibbs and Simpson, 2005; Andrade, 2005). Some studies demonstrated also that reflective responses in which students reflect on their own thinking and explanations (common elements of deep learning) are associated with feedback structure built upon open questions, wondering questions and leading questions (Marianne Ellegaard and Johannsen, 2018).

This study presents implementation and evaluation of peer-to-peer feedback as an element enhancing deep learning phase in a project-based class activity. The outline of the paper is as follows. In section 2 we describe the class activity and the reason, based on observations from the previous years of teaching the course, why the potential for deep learning is not fully exploited in real class conditions. In section 3 we describe the intervention and develop its key component, which is a rubric for peer-to-peer feedback. In section 4 we describe the results of implementing the intervention in the real class conditions. We summarise and conclude in the last section.

Class activities

The intervention developed and carried out in this project was a part of the course of basic cosmology for third-year bachelor students of physics in the Niels Bohr Institute. The main goal of the intervention was to stimulate deep learning phase in one of the main activities planned for the course classes. Activities of the classes were substantially restructured three years before. Compared to the previous edition of the course, the classes are more focused on hands-on sessions with a rather heavy load of numerical computations. Students learn how to use one of the standard packages for basic cosmological computations in python. The package is broad enough to open up a wide range of possible exploratory exercises which can demonstrate the practical meaning of concepts, relations and equations from the lecture, which are quite often introduced at a rather abstract level. Its potential is also sufficient for using it to interpret many cosmological observations. Working on theoretical modelling of actual cosmological data is yet another new element of the class program developed in the restructured syllabus of the course. This activity resonates well with commonly employed strategies for boosting deep learning through conducting small research projects (Miller and Krajcik, 2019; Phyllis C. Blumenfeld and Palincsar, 1991).

As with any sophisticated tool, using the above mentioned package for cosmological computational requires sufficiently deep understanding and awareness of how it works and how to interpret its output. This cannot be achieved completely without invoking deep learning. Learning new complex tools on a superficial level poses a risk of using them as the so-called black box where one cannot control if the output makes sense or is affected by ever occurring programming errors in user's script. The occurrence of common programming errors can be effectively minimised by providing students with a range of examples demonstrating good practices of coding. However, an extra challenge in the context of cosmology classes lies in the fact that students are in an early phase of developing their intuition about potential outcomes of concrete instances of cosmological computations. The progress of this phase is also tightly related to what extent students engage in deep learning of the course material. The exercise analysed and modified in the project aims at stimulating deep learning of the theoretical framework used to model expansion of the universe and predict a number of observable properties.

Problem-based activity

The class exercise consists of a set of computational problems which can be solved using the above-mentioned programming package for cosmological computations. The package is introduced a week before during an interactive class where students analyse a handful of pedagogical examples demonstrating good practices of programming. Students work on the assigned problems in pairs. All groups present their results during a dedicated presentation session in the following week. Students are also asked to verify their results with the leading teaching assistant before the presentation session. The format of all results is standardised and all outcomes can be presented in the form of a plot or a series of plots. The exercise is not graded. Each group passes if the students obtain correct results (and correct them if necessary) and present them to the class.

The problems developed for this class activity explore a wide range of aspects related to dynamical models of the universe and their observational implications. The problems contain some elements which are not directly discussed at the lecture or in the course's textbook, e.g. exact values of some quantities, effects of generalising something, complete mathematical description of models introduced at a qualitative models. At the same time they are formulated well within the framework of general concepts and theories explained at the lecture. This interplay between known/familiar and new/surprising elements is meant to stimulate deep learning in this exercise.

Challenges

The initial setup of the restructured syllabus assumed that student presentations can naturally bring the entire class into a phase of deep learning. In order to facilitate this, students were instructed to discuss each other's results and raise ”why ?” or ”what if ?” questions after the presentations. Involvement in the discussion was not, however, a formal requirement to pass the class exercise. Despite an active role of teachers in stimulating the discussions, this setup turned out to be quite ineffective for several reasons. First, students seem to be focused primarily – if not exclusively – on their own tasks required to pass the class exercise: solving the problem and delivering the presentation. Second, the majority of them do not exhibit sufficient interest in exploring results from their peers. Finally, oral presentations supported with slides are unavoidably affected by some imperfections such as lack of precision. This quite often degrades the clarity of the conveyed message and thus discourages students from initiating any deep discussion (what to ask about if it is not clear what is done ?).

Teaching intervention

Deep learning can be thought as a process of navigating between what is familiar or expected and new or surprising elements of the knowledge. A natural means to trigger deep learning is to reflect on what one can explain, understand or derive based on already acquired knowledge and what is found to be new, surprising or perhaps loosely connected to the previous knowledge. The main idea of the developed intervention was to extend the original class activity (solving the problems followed by oral presentations) by three extra elements which would make students reflect on each other's results in the context of the knowledge acquired during lectures and individual studies. The new elements were included as additional requirements for passing the class activity.

The first element is a concise written document describing results obtained by students. Students work on the problems in pairs, but they are instructed to write their reports individually. The reports are expected to be brief (maximum 2 pages, typically 1 page) and present the material in a way that is fully understandable to peers.

The second element is a peer-to-peer feedback and it is the key part of the intervention. Here, students are asked to read three reports from their colleagues and provide feedback. The feedback consists of two parts. The first part concerns the presentation: readability of the text, the quality of plots and a general clarity of the conveyed message. The second part puts focus on reflecting on the results presented in peer reports in the context of their knowledge from the course. Students formulate their feedback following five guiding questions which are shown in Table 1. The two last questions (Q4 and Q5) are open, wondering questions which are meant to stimulate students to reflect on their own thinking and explanations (Marianne Ellegaard and Johannsen, 2018). From the teacher's perspective, these questions also probe to what extent deep learning is involved (Entwistle, 2009; Brookhart and Chen, 2015). Providing feedback for three peers is mandatory; however, reacting to the received feedback is optional. Before the feedback session students are taught about general guideline for giving constructive and respectful feedback. Making students aware that their feedback is an integral part of the class activity increases their motivation and commitment, which are necessary conditions to make feedback productive and meaningful (Andrade, 2005). The feedback is run using an online tool implemented in the university platform *Absalon*.

The third element of the intervention is to prepare the final reports. Students are asked to implement selected suggestions from the received feedback (optional, but encouraged) and write two short paragraphs addressing questions Q4 and Q5 from the feedback's rubric, from their own perspective (mandatory). Answering the two open questions makes students think critically about the received feedback in relation to their prior understanding of their own results (Filius et al., 2018b).

Table 1. Guiding questions of peer-to-peer feedback employed in the developed intervention. The first set of questions (Q1-Q3) concerns the quality of reports, whereas the second (Q4-Q5) is meant to stimulate students to reflect on results of the problems in the context on their knowledge acquired during the course.

Q1	Do you understand what is shown on the plot given explanation provided in the report ? possible answers: (1) no answer (2) I do not understand what is shown on the plot (3) unclear - I had to look up some the meaning of some items (variables, units, models etc.) (4) clear, but I had to guess some things (variables, units, models, labels on the plot etc.) (5) absolutely clear, easy to understand the plot
Q2	What do you particularly like about the report in terms of presentation ?

Q3	What improvements would you suggest ?
Q4	Describe what is surprising/new/counter-intuitive to you in the presented results. Why ?
Q5	Describe what part(s) of the presented results can you relate to what you have already learnt from the lectures/textbook.

Motivation and expectations

The first element of the intervention is expected to help each student understand the problem she or he works on and the obtained results. In this context, writing is a means to organise thoughts, make logical connections between different elements of the conveyed message and think critically about the content (Çavdar and Doe, 2012). Students are additionally challenged by the fact that they are asked to describe their results to their peers rather to the teacher. It is also worth emphasising that the importance that students write their report individually. This simple requirement active students who otherwise would be passive or partially withdrawn in a group.

The key part of the intervention lies in peer-to-peer feedback. This activity is expected to stimulate students to think *deeply* about results from their peers and their own findings. Basic questions about what is intuitive and counter-intuitive are expected to encourage them to relate the new facts to their current knowledge and expand their *physical intuition*: qualitative understanding of dynamical behaviour of physical systems under consideration, predicting orders of magnitude of relevant physical quantities etc. The goal of the feedback is also to improve written communication skills. From the teacher's perspective, it can also be used to assess to what degree the potential of deep learning in this class activity is limited by the precision with which students communicate scientific results in their reports.

The third new element complements the feedback session. Here, students confront their prior understanding of their results with comments they receive from their peers. Deep learning is expected to be stimulated by the fact that intuitive and counter-intuitive elements of the new material (results of the class problems) in the eyes of different students would be never the same. It is these differences in perceiving the new material by different students what creates the potential for deep learning (Filius et al., 2018b).

Available data and questions to be addressed

Data available for analysis include written reports, both from the phase before feedback and the final version, and student inputs from the feedback session. Potential signatures of deep learning processes can manifest themselves in the actual answers to question Q4 and Q5, and differences between their versions in the feedback inputs and the final reports.

Basic questions which we attempt to address in the project are: how complexity of the answers varies across students ?, how often do answers reveal signatures of deep learning ?, can feedback inputs stimulate *deeper* understanding in students receiving the feedback ?

Results

The class exercise and the intervention was carried out in a class of 24 students. 19 student participated in the activity and accomplished all tasks of the intervention.

Feedback: quality of reports

All students indicated that they experienced some difficulties in understanding what is presented in the reports of their peers, in a fully straightforward way. It is perhaps alarming that the quality of all reports were marked as 3 or 4 (see Table 1) indicating that virtually all reports are not sufficiently precise and self-contained through the eyes of the peers. About 70 percent of the students received comments suggesting a better clarification of the problem (what do we consider and why ?) and the meaning of new terms which were not explicitly explained in the lectures. Other suggestions of improvements concerned with small editorial issues and readability of the plots. Only 60 percent of the students implemented selected suggestions in their final reports.

In two instances, the students found small factual mistakes in their peers' results. The mistakes were not recognised in a definite way, but rather as issues which cannot be consistently reconciled with other facts. Both cases are good examples of insightful comments based on critical thinking. On the other hand, we found one case where a relatively trivial mistake (wrong labelling on the plot) was not spotted by any of the three students providing feedback, but it gave rise to confusion in how to interpret the results.

Indication of deep learning

The answers to questions Q4 and Q5, both in the feedback and the final reports, varied quite substantially across the students. Although the actual content of the answers can be quite diverse, it may exhibit similar patterns reflecting the relations to the prior knowledge acquired by the students from the lectures and individual studies. One can expect that it is the relation between the prior knowledge and the student answers what reflects the level of learning (Entwistle, 2009). As an attempt to construct a metric quantifying degree of deep learning involved in the activity, we consider three levels of relations between student answers and the prior knowledge (see Table 2). The scale is a simplified version of the levels of understanding, with surface and deep understanding as the limits, adopted in many studies (see e.g. Entwistle, 2009).

Table 2. Three-level scale of answers to questions Q4 and Q5 in the feedback and the final reports. The scale is used to quantify degree of deep learning in the activity. The highest level (3) indicates the strongest signature of deep learning.

	Answers to question Q4 (intuitive elements)	
	Level description	Examples
1	recognising basic concepts/variables introduced in lectures/textbook	”I recognise and understand variables explained in lectures”, ”We talked in lectures about three types of ...”

2	identifying familiar instances in a broader/more general range of cases considered in the exercise	”In the first plot I can see the relation which I have been taught about ...”, ”The plots for [special cases] is something we have already seen in the lectures.”
3	attempts to provide a qualitative explanation based on the knowledge from lectures/textbook (reasoning)	”The look-back time [variable] would be shorter, *because* the universe would be smaller”, ”If there is more matter *then* the universe is ...”
	Answers to question Q5 (counter-intuitive elements)	
	Level description	Examples
1	recalling some parts of the material from the lecture/textbook as surprising	”The concept [from the lecture] is still counter-intuitive to me”
2	exact mathematical description of cases introduced in the lecture/textbook on a qualitative level	”It surprises me that the values of [...] decrease so fast ...”, ”I did not expect the redshift for half age of the universe to be only 0.6”
3	counter-intuitive effects of generalising something	”In this lectures we have not talked about what happens if [...], so it was a quite surprise that ...”, ”It is surprising how big the effect of [...] on [...] is.”

The first level indicates a low degree of deep learning and describes a student who can only recall very basic concepts learnt from the lecture, as a means to understand what is presented in the peers' reports. Student answers do not reveal any traces of ”why?” or ”what if ?” auxiliary questions, but rather simple ”am I familiar with any element from the report ?”. In extreme cases, surprising elements recalled by some students turn out to be a part of the basic material covered by the lectures or the textbook. This indicates that these students are lagging behind in the course pace and perhaps this is what prevents them from entering a deep learning phase.

The second level involves confronting non-trivial elements of the prior knowledge with the new material from the class exercise. Here, students can identify special cases of models, physical conditions etc. known from the lectures and explain different manifestations of their basic properties. Attempts to make qualitative predictions for the new cases or generalisations would underlie level 3 of the proposed scale. This level involves more advanced deep learning exhibiting thought processes such as establishing new relations and correspondences between various elements, broadening operational definitions of new terms, contextualisation. Making predictions based on mathematical and physical intuition is not always accurate and sufficiently precise so that the final conclusion comes as an outcome of question Q4 or Q5. What matters here, however, is that the student's thinking goes beyond the rigid boundaries of the course material.

Figure 1 shows the distribution of the proposed three- level scores of deep learning measured separately for students answers in the feedback and the final reports. The scores were estimated by the same teacher based on the descriptive scale summarised in Table 2. The scale is relative and it was gauged by picking the most representative cases of the highest and lowest level in the first turn of reading student inputs. The obtained results can be interpreted as a plausible indication that peer-to-peer feedback stimulates deep learning. About 30 and 60 per cent of student answers to both Q4 and Q5 questions were ranked at least 2 in the feedback phase and the final reports, respectively. It is tempting to interpret a higher fraction of high-level answers in the final reports as an effect of stimulation stemming from the received feedback. In fact, we found several cases where the answers in the final reports attempted to provide an explanation to what is raised as a counter-intuitive element in the feedback input. On the other hand, the apparent difference between an average level of deep learning in the feedback phase and the final reports may also reflect the fact that the students knew their results obtained by themselves to a larger extent than those from their peers, which they knew solely from reading their reports.

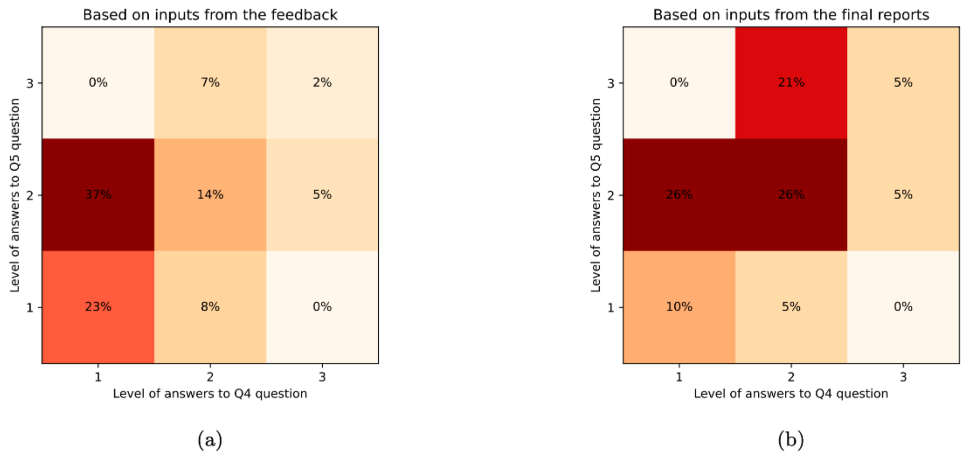

Fig. 1. Distribution of answer levels in the feedback inputs (left) and the final reports (right). The highest level and the lowest level indicate respectively the highest and (see Table 2 for exact description of the scale).

Summary and discussion

Compared to the previous setup of the class activity, where deep learning was supposed to be triggered in a spontaneous discussion following student presentations, the proposed peer-to-peer feedback appears to be a more effective method. Perhaps the main reason lies in the fact that students are compelled to given in-depth interpretation of the results and share their thoughts with their peers. This exchange of thoughts can be regarded as a special case of dialogue which was demonstrated to be an effective means to stimulate deep learning in various teaching scenarios. Unlike traditional oral dialogues, the developed activity entails exchanging written documents. Since writing is thought to be a factor organising and improving critical thinking, one may suspect that a written form of dialogue could prompt deep learning more effectively than improvised oral discussions.

The results of the intervention suggest that the students wrote reports which were not perceived as fully understandable by their peers. This lack of clarity, precision or sufficient explanation is a potential obstacle to achieving a deep learning phase: one cannot learn deeply about something what is presented in an obscured way. Therefore, the proposed activity will need to be modified in a way that would help minimise this problem. An easy solution would be to separate the feedback session addressing the quality of reports (questions Q1-Q3) from that addressing the actual results. The students would be asked to improve their report according to the first feedback so that their results and reports would be fully understandable to their peers. This simple modification could also enable a more formal intervention of teacher who could double check if peer-to-peer feedback catches all imperfections or flaws affecting readability of the reports.

Peer-to-peer feedback can be used as a diagnostic to identify students taking a surface learning approach in class activities. Recurrent instances of surface learning approach may indicate that these student are lagging behind for some reason. In these cases, teachers can take some steps which would help students identify and eliminate potential causes of their inefficient learning.

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