Hydrol. Earth Syst. Sci. Discuss.,
https://doi.org/10.5194/hess-2020-206-AC1, 2020

Hydrology and Earth System Sciences Discussions

Interactive comment on "Teaching hydrogeology in the field: the bottleneck in student conceptual model development" *by* Joaquin Jimenez-Martinez

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Received and published: 3 October 2020

R: General comments In this manuscript the author aims to assess the importance of a student's prior knowledge on his/her results in fieldwork reporting (following an "inquiry-based learning strategy"), as well as the effectiveness of combined prior knowledge and fieldwork on conceptual model expression. The topic is interesting and nicely framed within the existing literature. The results however need substantial additional work to make this study publishable in HESS, as I specify in my comments below.

A: I am thankful for the positive feedback and the constructive comments, which I have addressed in detail below.

R: Specific comments I find the number of samples (17 students, 1 year) too low to be

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representative for a statistical analysis. The author could quite easily include previous years to increase the, number, and to reduce bias from including students from a single cohort. Especially when further divided in groups based on prior knowledge (PK) ranking, the regression analysis is done within groups of 11 and 6 students, which is clearly insufficient.

A: This is an aspect (i.e., increasing the statistics) that unfortunately will not be possible to be solved at short term. Previous editions of the field course cannot be included because the conceptual model (i.e., conceptual model expression - CME) was not evaluated. Last edition (June 2020) was cancelled, and there is not guarantee that 2021 edition can be carried out due to the current COVID pandemic.

As stated by the reviewer 2, despite the low statistics, the proposed methodology and the results yield very valuable information regarding the difficulties of teaching hydrogeology in the field, and the development of conceptual models by the students in general. This manuscript also proposes alternatives of how we could train our young groundwater hydrologists.

R: The way prior knowledge (PK) is assessed is also quite limited. It corresponds to the total number of followed courses out of the 14 courses selected that have a link to groundwater. In my opinion some of these courses, such as geology, hydrogeology and cartography, should have a much larger weight than for instance "forest and landscape", given their larger importance for conceptual model building.

A: The reason because courses such as "Forest and landscape" were included in establishing the prior knowledge rank relies in the fact that the course also includes aspect related to land uses and their control on hydrogeological processes. In particular, aquifer recharge rate estimations were performed in forest and cropped soils. Courses like "Forest and landscape" were included in order to cover the wider and heterogeneous background of the students in the 2019 edition. For the particular course on "Forest and landscape", which could apparently be less aligned with the groundwater field course, its exclusion would not change the rank and groups (see Table 1).

R: In addition, different ways of calculating this parameter and multiple ways of ranking (in two and three groups for instance, if a larger data set is used) should be tested to address uncertainty and evaluate the best approach. To give an example, in Table 1 student 8 has had only six courses and no geology, so I wonder if that student should not receive a low or intermediate PK rank. Student 15 has had more courses but also no geology. Student 10 has had five courses only, but they cover core subjects such as geology, hydrogeology, hydrology, hydraulics and GIS, which could allow that student to receive a high(er) PK rank.

A: The ranking in two groups was based on the methodology proposed by Sell et al. Journal of Geoscience Education (2006) and in the short number of students. I fully agree with the reviewer that a larger number of students (as mentioned in a previous comment) and the assignment of different weights to the courses would allow to address the uncertainty in the approach. While the proposed approach suggested by the reviewer would strength the analysis towards the appropriateness of the students' background, I consider the current approach (and due to the limited number of students) allows to highlight the heterogeneity found in students' background in the MSc Environmental Engineering studies at ETH Zurich, and most probably worldwide.

R: It is also not entirely clear if the Groundwater course (theory and modelling) corresponds to the Hydrogeology course. I assume not, as 16 out of 17 students followed hydrogeology, but only 76% followed the groundwater course. It is it not clear then why it is not part of the list of selected courses. In addition, why did only 76% follow the groundwater course? You could take this analysis a step further and integrate course marks into the analysis.

A: The Groundwater Field Course is a module of a larger annual course called Experimental and Computer Lab. To attend this module (Groundwater Field Course), it is not mandatory to attend the Groundwater course (theory and modelling) offered at ETH for the same Master studies. Therefore, some of the students have attend the theoretical/modelling course offered by ETH Zurich (13/17, 76%), others have attended similar courses in previous years and/or institutions (2/17), and some of the have never attended a theoretical/modelling groundwater course (2/17). Therefore, marks from theoretical/modelling groundwater courses have not been included in the analysis.

R: Inquiry-based learning (IBL) was quantitatively assessed from the written report on a scale of 0-6. It is not clear how/why this scale was used and if it simply corresponds to the report mark. It is not clear if all reports were assessed by the same person and what the degree of subjectivity was. More importantly, the fact that the students worked in groups (which is good practice) questions to what degree the reports were then really individual. The latter could partly explain the high average score and poor correlation with PK. This would need to be addressed and discussed.

A: The scale stablished for marks at ETH ranges from 0 to 6, where 4 is the minimum mark to pass the course. The report evaluates the inquiry-based learning. The reports (for IBL) and the conceptual model expression (CME) were assessed by the same person in order to reduce the subjectivity. The reports were done in group of 4 students. I could check that all of them were actively involved in the elaboration of the reports. Although this can hide weaknesses and reduce the significance of the test, it also allows students to transfer skills between them, find effective peers to emulate, and tackle more complex problems than they could on their own. Nevertheless, this does not affect in the assessment of the relative importance of the previous knowledge (PK) in the conceptual model expression (CME).

R: The way conceptual model expression (CME) was assessed is even less clear. Where/how did the students deliver the conceptual model representation? Did they do that indeed individually? How was it marked? How does the marking affect the results? This requires much more information, as the author considers this to be the identified “learning bottleneck”: going from the split information to the integration of it.

A: Each student's performance at conceptual model expression (CME) was quantitatively evaluated from the conceptual model representation [0-6]. This consisted in an individual exam in which the students, with the information collected, had to elaborate a drawing (either 2D or 3D) indicating with arrows direction and magnitude of the main flow components (including recharge, evaporation, regional groundwater flow, connection between aquifers, relation river-aquifers) and indicate from which compartment each individual experiment was providing information (Table 2). The evaluation of the students' performance in the CME exams includes as main criteria the number of how many flow components and correct direction were included, and the appropriate spatial location of the individual experiments.

R: To be able to further evaluate the identified "learning bottleneck" we also need to look at the fieldwork itself. The 5-day fieldwork described is indeed good for the students to increase their inquiry-based learning capabilities. However, fieldwork is done at the plot scale, and nothing is mentioned about its upscaling to the aquifer scale. This is odd, as conceptual hydrogeological models need to integrate the flow system concept, and include recharge, (intermediate) flow and discharge zones, which you are unable to find at the plot scale. Therefore, additional fieldwork or field excursions would be needed to help improve the understanding of conceptual model representation, which is not taken into account in the study.

A: We work with the students at the scale of an experimental site: an alluvial aquifer that includes a set of wells, a marked connection with a river, and different land covers (forest and agricultural soils). In this site it is possible to infer the flow system concept due to the superposition of aquifers, the marked regional flow and the connection with the existing river. The conceptual model, as intended in this course, was established by students (i.e., conceptual model expression, CME) for the experimental site. A conceptual model can also be stablished for an experimental site, or even smaller systems. However, I agree that cover a large extension could help for better understanding of hydrogeological conceptual models.

R: I do not fully agree with the interpretation of the results in Table 4. The low coefficients of determination (which need to be added to the table) indeed indicate weak or no correlation, but the author then suggests this could be because the correlation is nonlinear. However, the groups of 11 and 6 students are just too small to be able to come to significant conclusions, even if $p < 0.05$ (not clear in the table). In any case it is important to show the correlations in graphs, as visual inspection allows to understand the role of outliers on the correlation coefficient (or coefficient of determination).

A: I guess reviewer referrers to Table 5. Regression analysis between the variables IBL (inquiry-based learning) and CME (conceptual model expression) for the two PK (prior knowledge) groups: high (filled triangles) and its linear regression trend (continuous line); low (empty squares) and its linear regression trend (dashed line), is shown in the attached figure 1.

R: It would further be important to see/discuss if support can be found for the statement that "when approached with a conceptual model, students may extract only those elements they consider relevant and incorporate them to their mental model, resulting in a mental model that differ from the conceptual model presented". This could be done by having students draw and explain conceptual models at different stages in their academic career, starting when they first arrive at the programme. I do believe that the more we explain and describe conceptual models, with drawings, simulations and animations, the more the students can start to correct their own mental models on groundwater flow systems.

A: This is a hypothesis formulated and studied by other authors e.g., Greca and Moreira (2000). It is extremely difficult to evaluate which elements students consider relevant and which ones they incorporate to their mental models. The evaluation of the students' conceptual model at different stages of their career is beyond the purpose of this study. I fully agree that this approach sounds the most suitable to evaluate the evolution of their mental model on groundwater systems. This aspect is mentioned in the concluding remarks. The evaluation at different career stages will be included in the discussion section.

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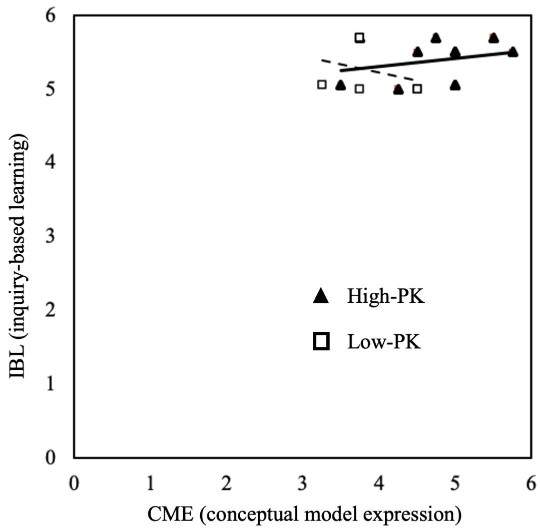

Fig. 1. Regression analysis