Blended Learning and Automated Evaluation in GIS Education

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Abstract

For many years, GIS has been a flexible tool for a wide range of spatial tasks in the spatial planning curriculum of at TU Wien. The steadily increasing number of students, the rising number of participants struggling with solving analytical problems, as well as suboptimal evaluation strategies initiated a total redesign of the course. We have rebuilt the didactic concept to better support the learning process and strengthen the understanding of learned skills, and have automated large parts of the evaluation, which allows for a more thorough assessment of quantitative results.

Keywords:

GIS education, blended learning, automated evaluation, spatial analytics

1   Introduction

When ESRI launched their first version of ArcView GIS 2.0 in October 1995, we seized the opportunity to implement a basic GIS course for the students of spatial planning. The course was designed as mandatory within the first section of a two-stage diploma curriculum (TU Wien, 2011). Within this curriculum, the courses were part of the analytical modules that have a clear focus on methodological approaches. Providing students with critical spatial-thinking skills, abilities and knowledge is essential not just for geography students (see Bearman et al., 2016) but also for aspiring spatial planners. According to Kedron et al. (2016), introductory courses frequently fail to address fundamental GIS concepts and theories. As a result, the objective of our original GIS course was to introduce the principles of spatial data acquisition and data handling and, in particular, to impart basic methods of spatial analysis. These objectives remain almost unchanged in the new, revised, course: we still aim to teach the skills needed to use GIS software in a professional setting, based on a hands-on approach.

Given that the initial number of students was about 30 to 40 per year and that our didactical as well as our GIS-specific expertise at the time lacked grounding in real-world applications, we started with a very conventional concept: classroom-style teaching via a data projector, short exercises to do at home, and an extensive final project that students worked on in pairs.

As the number of students increased significantly to more than 200 in 2010 (TISS, 2019), this original concept was in need of adaptation. The great variation in individuals' GIS-skills showed unsatisfactory developments: the quality of individual outputs was decreasing slightly but steadily, and we were observing an increasingly collaborative way of organizing work, with a tendency to share tasks according to personal preferences and capabilities. The necessary knowledge and expertise to solve more demanding tasks were held by just a handful of highly dedicated students, while others consequently reduced their inputs.

We noticed that a growing number of students were unable to carry out analytical tasks successfully on their own and subsequently transform their findings into meaningful GIS-based cartographic outputs. We also noticed students using various vector graphics applications instead of GIS-based tools to tackle basic tasks like calculating simple buffer features. Finally, we had to recognize that an increasing number of students did not apply GIS methods within subsequent higher-level courses, even if these methods would have been the most appropriate for the specific tasks. At the same time, students complained about the excessive workload and the overall intensity of our introductory GIS-course.

This summary may sound like a common complaint from disillusioned academic instructors. But we quickly decided to take these facts as a challenging opportunity to re-design our didactic approach and address criticisms by both lecturers and participants. As a result, we launched a complete overhaul of the structure of the course and of substantial elements of its content. The new focus was on encouraging basic expertise in handling spatial data, developing and implementing analytical mapping, and applying spatial analysis techniques. The redesign process specifically aimed to achieve a high level of practical relevance, support for different learning styles, a clear and consistent sequence of lesson-specific content, and the elimination of excess material. Thus, classroom-style teaching, where participants simply replicate the lecturers' activities, did not seem appropriate. The new paradigm is to guide students through an efficient process of skill-building.

The following guiding principles emerged during the redesign process, which was reflective:

- being able to verify quantitative analytical results
- evaluation of students individually, as a measure to counter the problem of 'free-riders'
- establishing a scalable course design

- encouraging students' personal curiosity as a means of encouraging them to solve tasks individually.

Implementing these principles resulted in a number of components that are linked within a formal conceptual framework. At the core, a step-by-step manual and a corresponding video-based series of web-lectures are complemented in the classroom by a competent academic team of supervisors and tutors.

While this new approach turned out to be promising in principle, the way the results were assessed continued to be an object of discontent and discussion. The evaluation of the exercises was still partly based on the subjective judgement of cartographic outputs and was thus in stark contrast to the initial intention of introducing basic objective methods of spatial analysis. The skill-building process implements a loop-style structure, where instructive and reflective elements feed into each other.

2 Didactic Concept

Stop teaching GIS - Teach how to learn GIS instead. (DiBiase, 2018)

2.1 General Considerations

The relaunched didactic concept offers a application-oriented learning process. Students work out the contents independently, either on their own or in pairs. They learn to develop their own creative approaches to spatial tasks. Students' individual performance is then evaluated in exams.

The course is organized as blended learning, with both online elements and face-to-face contact, as our experience echoes that of Ooms et al. (2015): social interactions between lecturers and students are an important part of the learning process, complementing digitally offered learning materials.

An E-Learning platform is used to organize the course. Such platforms have been widely used in Austrian universities for many years (Bratengeyer et al., 2016). In addition, they have the advantage of offering a scalable solution, irrespective of student numbers (Painho et al., 2002, p.3). Although our course design is software agnostic, we use ArcMap 10.6.

The development of the course content went hand in hand with discussion of the course's scope and sequence, which has already been discussed in connection with GIS by Foote (2012). His considerations are based on the experimental learning cycle developed by Kolb (1984), an idea from constructivist learning theories:

Rather than viewing learning as the transmission of knowledge from teacher to learner, or as a purely behaviourist process, constructivism considers how learners 'construct' or build their understanding of new experiences, phenomena and processes based upon their existing knowledge, motivations and preconceptions. Constructivism positions the teacher as a facilitator of learning, as a guide who develops activities or

realistic problems which promote student exploration and discovery. (Foote, 2014, p.86)

The main point is that students should learn from their own experiences. Indeed, it is the central theme of the new concept. As Foote (2014, p. 87) also notes, it is not enough to just move from session to session: it is important that individual activities and tasks are well inter-connected, to give students the opportunity for personal active experiences – e.g. troubleshooting when they find errors – and to reflect.

2.2 Course Structure

The course comprises several didactic components, which are iterated six times throughout the semester. We call this the Didactic Loop (see Figure 1). Tests are held after the third and sixth loops. Each cycle starts with a Skill Building Week, where students acquire basic knowledge for the Exercises which follow. The Exercises, the new skills are consolidated and refined in preparation for the tests. They give students active hands-on experience and a chance to reflect on the contents of the Skill Building Week. Each Exercise comprises two tasks: an analytical task where geo-related methods are in focus, and a cartographic one in which the geo-processed results are mapped. This two-fold structure is reflected in the Exercise Evaluation. Students need to reach a minimum number of points in both subtasks throughout the course.

The individual results are presented on the E-learning platform after each Exercise Evaluation. Students can view their current scores there anytime. After the Feedback Element, a new loop starts.
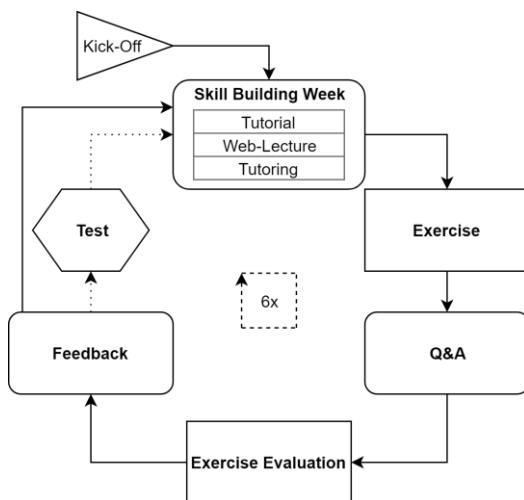

Figure 1: The Didactic Loop

2.3 Skill Building Week

Goal: The aim of the Skill Building Week is to learn how to use new tools, concepts and methods in preparation for the Exercise. In addition, the previously learned skills are repeated and consolidated.

Format: Based on written tutorials and web-lectures (in the form of videos), students are introduced to the content of the unit (the Didactic Loop) using practical examples. As Painho et al. (2002) note, GIS lectures have to deal with both the theoretical background and its practical implementation. The tutorials follow a how-to style, with substantial amounts of background information, and are complemented by web-lectures. Students can watch the video at their own pace and as often as they wish. The use of videos gives lecturers more time for supervising and supporting. Students can learn anytime and anywhere, following their own study rhythm (Painho et al., 2002, p.3). They do, however, need to be encouraged to watch the web-lecture, which requires additional study discipline (Ooms et al., 2015).

Simultaneously, we offer a supervised tutoring session in the faculty computer lab, where students can take advantage of additional support from experienced senior students in 3-hour blocks. We thus combine complementary learning elements that enable knowledge acquisition in different formats.

2.4 Exercise

Goal: The aim of the Exercise is to reflect on the tools and concepts learned in the previous Skill Building Week and to actively apply them independently. This involves students recombining the knowledge acquired to date and structuring their own workflows. The Exercise is designed in part so that students gain experience in order subsequently to be able to self-solve new GIS tasks. Students should be able to transfer what they have practised to similar problems, or to solve new problems they have not been exposed to before.

Format: Our Exercises cover a wide range of GIS applications - from calculating weighted population density, data acquisition via open-data portals, to basic raster calculations. All these spatial applications are accompanied by cartographic visualization tasks and thus follow Jakab et al. (2017), who note three key aspects in GIS lectures: data collection, data manipulation and data dissemination.

To better understand the scope and format of an Exercise, we present an example from the course: Exercise 3 (of 6) focuses on a site search for recreational areas based on the following characteristics (see also Figure 2):

Forest areas (as defined by Corine Land Cover classes) that are:

- close to urban areas (urban buffer) and
- free of traffic noise (noise range depends on road type, or presence of street buffer)
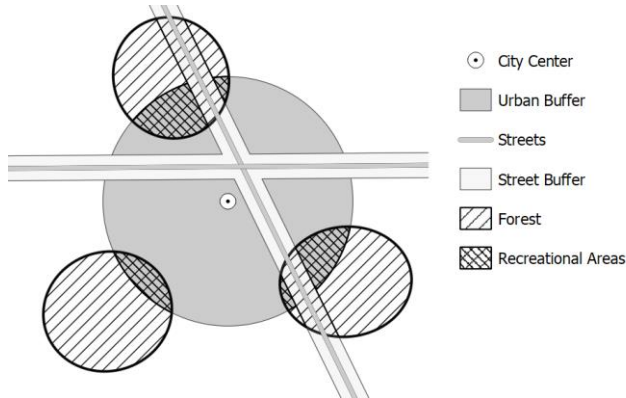
Figure 2: Schematic illustration of Exercise 3. The aim is to calculate and visualize the recreational areas.

To obtain the correct result, individually students have to use geoprocessing tools (such as Buffer, Dissolve, Intersect, Spatial Join and Clip) and common space-related methods taught in the Skill Building Week, elaborating the workflow on their own. The result (here, the combined sizes of the recreational areas in hectares) has to be calculated for each municipality of the region and stored in a dBase table. As part of the exercise, students receive an e-mail containing a tip in the form of the result for one spatial entity. For Exercise 3, this is the size of the recreational area of one municipality. Using this clue, they can check whether their own calculations are correct. (See also section 3.2)

In addition, students must create an aesthetic and user-friendly map, conforming to cartographic guidelines, on which the results are visualized.

The Exercises are released only after the Skill Building Week. During the Exercise elements, students are provided with assistance in multiple ways:

- Forum within the E-Learning-Platform: students can ask questions that are answered by other students, tutors or lecturers.
- Tutorial Appendix: here, further tools are introduced briefly; they are not used in the tutorial itself, but help with the Exercise.
- A Q&A (discussed in 2.5 below).

In addition, students are asked to look for other sources of support. The use of specialized forums such as StackExchange is encouraged as part of the Exercise.

2.5 Q&A

Goal: The Q&A aims to help students deal with difficult aspects of the Exercise. In addition, the search for a solution demonstrates how GIS troubleshooting and task-solving works.

Format: Students have the opportunity to ask questions about the Exercise within the framework of the Q&A session. They are advised to come up with questions they want to ask before the class begins. Solutions for these questions are worked out in groups (approx. 15 students + 1 lecturer). When working on a particular issue, an individual student's screen is shared on a data-projector and other students are encouraged to weigh in on the problem. The issues are solved by other students (based on their solutions to the same problems) or by the lecturer. The value for the students is that they get an answer to an Exercise-related question and see how GIS problems are solved by experienced GIS users. The Q&A is over when students have no more questions, or when the time is up.

2.6 Exercise Submission & Evaluation

The completed Exercise task is submitted to the E-learning platform. The students upload a zip-archive containing the results from the subtasks Cartography (.png-image) and Spatial analytics (dBase-table). How these are handled is discussed in Section 3 (Evaluation) below.

2.7 Feedback

Goal: The students receive cartographic feedback on the Exercise. In addition, general and organizational information about the course is given. Because attendance at Feedback sessions is mandatory (in contrast to all other elements), we can reach all students directly at the same time.

Format: After each Exercise, a Feedback session with all participants takes place. For the cartographic Feedback, anonymized maps are projected for all to see and to be discussed by students. Lecturers then give feedback and advice. Our aim is to encourage students to have a critical perspective on their own work. This format allows constructive feedback that can be implemented in subsequent Exercises. In this way, students learn that the evaluation of maps is often influenced by subjective factors. The discussion is complemented by the use of interactive tools, such as a poll-app, where students can evaluate the maps by smartphone using a scale of points. The result is then projected in a real-time poll.
The Feedback session completes the Didactic Loop, and a new Loop then starts.

2.8 Test

Although other studies (Bowlick et al., 2016; DiBiase, 2018; Harvey & Kotting, 2011) show that GIS skills can be successfully measured by evaluating projects, we decided to organize individual assessments (or Tests). With the current framework conditions - notably the high student counts - we can only check individual performance on the basis of individual tests, as group work may lead to a free-rider phenomenon (Joyce, 1999). We still observe a large discrepancy between group work ratings and individual test results. (See Figure 6 in Section 4.)

For the in-class Test, a short spatial task (similar in scope to a single Exercise) has to be solved individually in the computer lab. The Test comprises several analytical subtasks and cartographic representation of the results. As in the Exercise, we supply check-values (hints) at sub-task level and thus provide students with the means to verify their intermediate results.

Students who have solved the Exercises on their own should be able to master the Test as well: the intention of the Test is to determine whether group members have understood the Exercises.

Quantitative results are checked manually. The map is evaluated in two stages:

- Required map elements: Are all required map elements present?
- Jury evaluation: Each lecturer evaluates maps individually on the basis of a checklist. The average of the lecturers' scores is calculated. If the deviation between them is high, the lecturers consult with each other again. The aim is to counteract the criticism of subjectivity.

The course includes two Tests. Students are allowed to repeat one of them in the case of a negative grade.

3 Evaluation of quantitative results

To enable a large-scale evaluation of quantitative GIS results, which was one of our main goals, and to limit the amount of work required to run the course, many repetitive elements from evaluation to communication need to be automated. During the semester, the students hand in 6 datasets of calculations with 6 corresponding maps for evaluation; the last time we ran the course, we evaluated a total of 355 submissions. The Evaluations take place between the Q&A and Feedback elements.

3.1 Specifications for an automated evaluation tool

To be of value for the course, the evaluation, even though automated, should be flexible enough to allow for the assessment of both single students and groups. Furthermore, it should allow for a flexible Exercise structure that supports the evaluation of varying spatial entities – as in the Exercise described in section 2.4 above, for which students need to calculate the total recreational areas within municipalities.

A further useful aspect of automation lies in communication with students: the tool needs both to produce feedback and to communicate results and mistakes to students.

In order to provide a transparent overview of the whole evaluation process and the student's personal rating as it evolves with each didactic loop, we use a collaborative spreadsheet platform where individual results are documented for each Exercise.

Lastly, feedback and evaluations need to be aggregated and uploaded back to the E-learning platform.

3.2 Data Preparation

We created a student-to-data relation model to allow for flexibility in assigning students to groups and ultimately to the data for which they are tasked to produce results (see Figure 3).
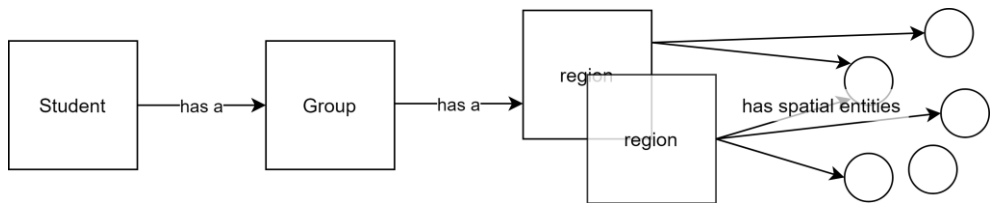

Figure 3: Relation Diagram

Students are assigned to groups, and groups consist of at least one student; a student cannot be part of multiple groups. Each group is assigned one region, which can vary from Exercise to Exercise. Each region covers the geographical entities for which students have to calculate results. Regions can overlap, and multiple groups can be assigned to the same region. Students are not aware of the regions: they are just presented with the geodata.

For reasons of convenience, we designed the evaluation tool so that it evaluates only one set of spatial entities within an Exercise (for example one set of shapes, points or lines). While results can stem from multiple calculations for each Exercise, all results need to be spatially aggregated to the same spatial entity type. This approach reduces the complexity of the evaluation tool.

The process of assigning districts to regions as well as preparing the corresponding sets of geodata within these regions is done within the class lectures. The first region-building step is done manually, with the aim of creating similar levels of complexity between regions. The second step – preparing the dataset for each region – is automated where possible.

3.3   Reference Results

We check the students' numerical results against reference results that we have produced beforehand. An important part of producing the reference results is to calculate them on a by-region basis, because the results for a region vary depending on which other spatial entities are included or excluded in the calculation. To differentiate between multiple results for the same spatial entity belonging to different regions, each result and entity combination is assigned a separate ID. This allows linking each

student to the IDs of the spatial entities for which they have to produce results, as depicted in Figure 3

3.4 Automated Evaluation

When the students have completed an Exercise, they upload an archive (which contains a dBase file that includes the results and a map file) to the E-learning platform, from where it is fetched and fed into the assessment tool. Figure 4 shows the evaluation process.
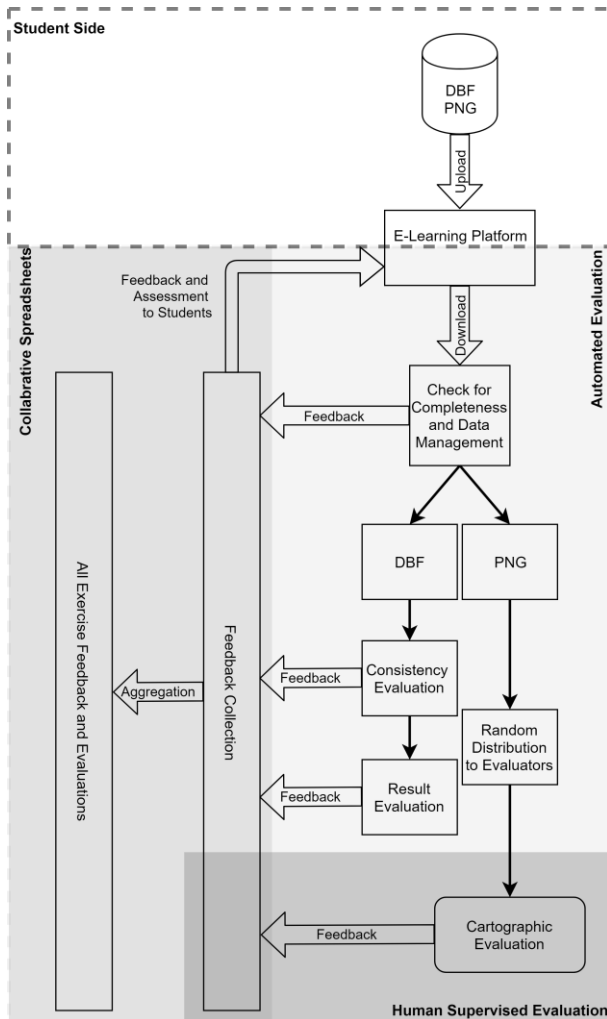

Figure 4: Evaluation Process.

The data archives submitted by students are downloaded and checked for completeness, in our case for a PNG file and a dBase file. The files are then sorted for further processing. All map files are distributed randomly to human evaluators. Since we aim for consistency and fairness when assessing the results, we set up a formal scheme. A 'scorecard' provides a multi-level framework for evaluating the cartographic products.

For the numerical results, the dBase files are read into the evaluation script using dbfread[1]. Internally, they are then represented as pandas[2] DataFrames. The data is checked for consistency, for example for whether all required fields are present in the dataset and are of the required type. If there are any issues, feedback is generated.

The required results for a given student group are fetched from the reference results and joined to the results handed in by the students. The two sets of results are then compared with each other. Lastly, either positive feedback is generated if the dataset meets all expectations, or discrepancies are recorded.

All feedback and evaluation results produced by the tool are outputted to the collaborative spreadsheets. They are combined with the map evaluations, and points for each Exercise are then calculated. The point score plus the feedback are prepared for uploading to the E-learning platform.

The tool is also used to issue students with hints for every Exercise. The hint usually consists of the expected result or results for one randomly chosen spatial entity (a check value) to which the students are assigned. This can be problematic when students think they have solved a GIS problem because the check values line up with theirs but in fact their solution contains errors. To mitigate this problem, we plan to introduce a second check value that is the sum of all correct values. All check values are sent to the students automatically via email.

3.5 Exceptions

When processing the student submissions, a small number of problems arise from inconsistencies within the data; these exceptions need to be dealt with. Figure 5 shows some common data errors we have observed in the past and which we try to correct in the data consistency phase.

One common problem is incomplete submissions, where the map file and/or the dBase file is missing. The omission may be deliberate, because the group was not able to solve the task, or the wrong files may have been submitted. For map files, it is common for students to submit a file in the wrong format; more troublesome is the submission of the wrong dBase file. There are two factors involved here that compound each other: Windows hiding the file extension for known files from the

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[1] https://github.com/olemb/dbfread

[2] https://pandas.pydata.org/

user as a default setting, and ArcGIS generating metadata for dBase files. This results in a file named my_dbase.dbf.xml (clearly an xml file), but since Windows hides the xml extension, the user sees 'my_dbase.dbf' displayed in their Windows file-manager app. This is highly misleading, sometimes even for experienced users. As a consequence, several students submitted this xml file instead of the dBase file required.

Other common errors are easy to handle, for example, capitalization mistakes, where all column names (in the reference results and student results) simply get changed to lowercase. Others are more problematic, like data-type mismatches. Some of these mismatches are correctable. For example, a frequent mistake in Exercise 2 was to hand in files with a float ID field, while an integer field was required. Other mismatches are more problematic. In Exercise 3, a string-type ID field that contains letters and numbers is used. If we receive a file where the ID field-type is changed to an integer, it is not possible to reconstruct the correct ID because the string information is lost. In this case, a group would fail the Exercise. In one instance, during the two runs of this class, a group handed in a corrupted dBase file which contained a string value in an integer field.
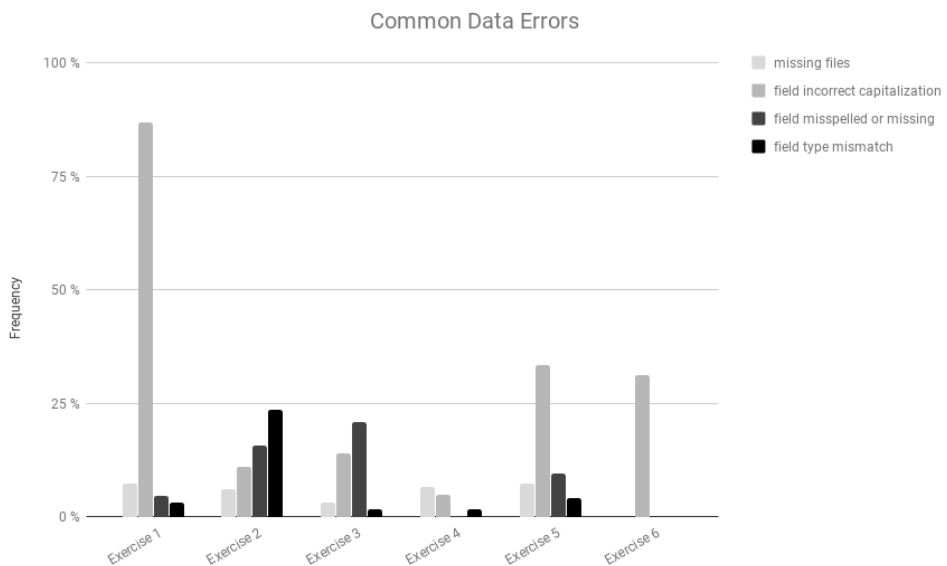

Figure 5: Common data errors in the 2018 course.

A further complication is the inconsistent way ArcGIS handles geoprocessing methods, which leads to problems when student results are checked against reference results. We calculated discrepancies of up to .4%.

4 Findings, Student Feedback and Future Work

If a course uses a highly automated process, this process needs to be well attuned with the concept of the course. Both have hard and soft limitations that can be worked around. For example, an automated evaluation process can produce basic feedback, but the feedback needs to be supplemented. On the other hand, Exercises need to be designed so that valid reference results are feasible to produce, meaningful and unambiguous.

4.1 Results

Comparing grades obtained during the redesigned course with grades from before 2017 is not really possible, because grading has become stricter. In the lecturers' opinion, the following goals have been achieved:

- We are now able to limit the number of 'free-riders' by implementing GIS examinations in front of a PC where each student needs to demonstrate GIS problem-solving skills.
- The automated evaluation enables the quantitative evaluation of exercises that are handed in by student groups. This is possible with little or no extra work and an improvement compared with guessing (by inspecting map documents) where students might have made mistakes in their results.
- The course has not only become more scalable by including automation, but also, by modulating the teaching group sizes, now fits the needs of the students and the setting (see: Feedback, Q&A and Skill Building Week group sizes).
- Cartographic evaluation of Exercises is now more streamlined and based on transparent criteria.
- Instead of classes in which students are told to 'just follow the instructions', they are now challenged to solve GIS problems on their own, and they receive the necessary support to do so.
- We provide the students with more feedback.
- Looking into the future, it will be easier to maintain the structure and quality of the course because of the better scalability.
- In our opinion, students who pass the redesigned course are more capable GIS-users than those who followed courses pre-2017.

Figure 6 is a scatterplot comparing the individual assessments in the tests (70 points in total) to the exercises (30 points in total) during the last semester. The plot highlights the problem of students who try to 'free-ride' (i.e. let their group or partner do the work). We are working on adapting the course without lowering requirements, so that more students are able to pass. The preliminary results from the 2019 course are encouraging.
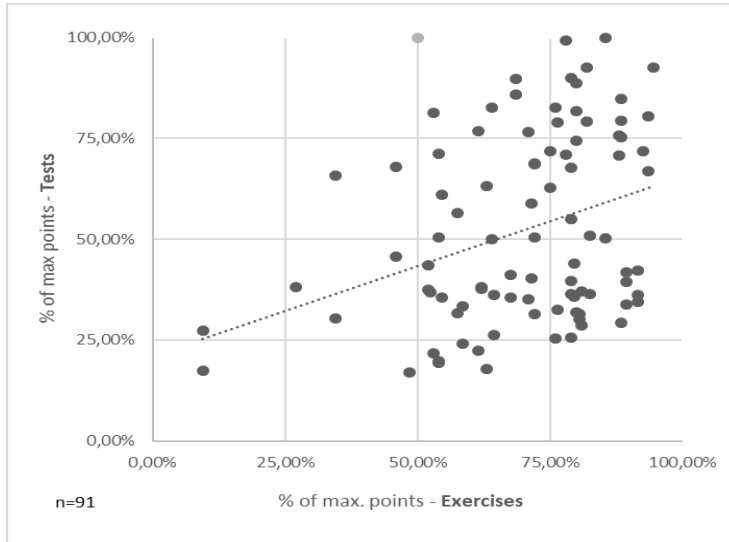
Figure 6: Test result percentage vs. Exercise result percentage.
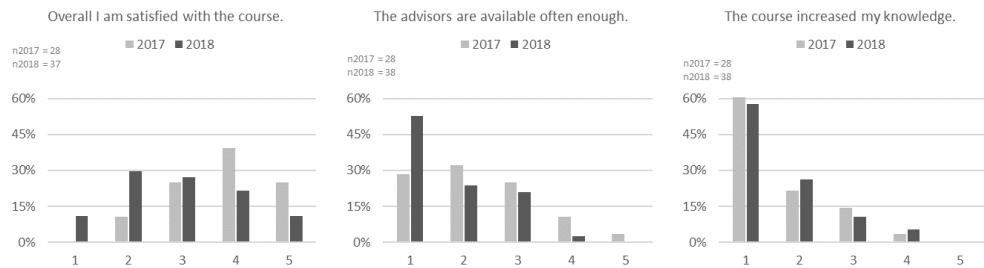
4.2 Student Feedback

Figure 7: Student Feedback. (1 = Yes, 5 = No).

The course evaluation by students is important for lecturers. Feedback at the end of every semester is provided anonymously and in digital form using a standardized questionnaire with approximately 25 questions.

The results show that changes in the course between 2017 (the year in which we first applied the new concept) and 2018 resulted in greater participant satisfaction, although there is potential for further improvement. The level of automation allowed improvements to the level of individual support received from lecturers. Small adaptations in the concept were made from 2017 to 2018, which are also reflected in the results. Students consistently rate their increase in knowledge as high.

4.3 Further Improvements

The conception of courses requires constant adaptation. Our aim is to integrate our experience gained during the last semester into the concept, in order to increase students' positive responses and improve the success rate.

The following points are currently being worked on:

- Second tip for Exercises: a second check value in the form of the sum of all results in order to further minimize uncertainties in solutions.
- Pretest: The Pretest will be similar in scope and level of difficulty to the actual test.
- Spatial Analytics within Feedback: this aims to demonstrate the most important methodical steps of the Exercise
- Tutorials: greater precision of the texts and cutting unnecessary parts.

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