QUANTIFYING DEEP LEARNING IN GEOMATICS ENGINEERING BY MEANS OF CLASSROOM OBSERVATIONS

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Abstract – *On the spectra of soft-hard and pure-applied disciplines, geomatics engineering can be categorized as hard and applied, similarly to other engineering disciplines. One can expect that geomatics engineering would score lower in deep learning as such patterns have been observed for other engineering disciplines compared to soft and pure ones. Some students in upper level courses in geomatics engineering may still struggle with fundamental knowledge from lower level courses. This makes it hard for instructors to create an environment for deep learning. They may have to spend a significant amount of class time reviewing basic concepts, and not as much time is left for building up more complex concepts and problem solving. In order to be more successful in tackling higher level learning outcomes, it would be useful to identify areas of troublesome knowledge and specific threshold concepts in key geomatics engineering courses. By addressing these concepts, instructors can eliminate, or at least minimize, the bottlenecks in the learning process. This is the aim of the teaching and learning research study presented in this paper.*

The main method for collecting data for this study is classroom observations complemented by minute papers at the end of each course unit. Even though the study is in its early stage, some correlations between the type of lessons delivered and the student cognitive and behavioural engagement can be seen, and some concepts can already be identified as probable threshold concepts. As far as the authors are aware, this is the first study on threshold concepts in geomatics engineering.

Keywords: geomatics engineering, deep learning, threshold concepts, troublesome knowledge

1. INTRODUCTION

Geomatics engineering has emerged as an evolution of surveying engineering in response to rapid advances in engineering technologies. Geomatics engineering students are now fully engaged in learning the new technologies in discipline specific and technical elective courses. A fourth year student is expected to demonstrate deep knowledge of fundamental geomatics engineering concepts and apply

this knowledge in various contexts and tasks including engineering design and a capstone project. In their second and third year, however, students can struggle to understand and retain the fundamental engineering content. A few examples are the lack of grasp of the important concepts of random and systematic errors of data collected by the geomatics engineering instrumentation, their respective mathematical modelling and optimal values found by means of least squares estimation, as well as univariate and multivariate error propagation. These examples are from what we consider to be an area of troublesome knowledge, various aspects of which are covered in the undergraduate curriculum in the Department of Geomatics Engineering at the University of Calgary.

Data errors can also be viewed as threshold concepts in the context of a particular geomatics engineering course. According to Meyer and Land [1, 2], a threshold concept is a “conceptual getaway”, which leads to a positive and irreversible transformation in learning when students encounter the troublesome knowledge related to the concept. A threshold concept is a difficult concept, but not every difficult concept is a threshold one. Threshold concepts are bottlenecks in student learning, which demand a reconfiguration of the learning process so that the bottleneck is eliminated.

According to Kelly and Cranton in [3], transformative learning associated with threshold concepts is discipline and context dependent. For example, a standard deviation of a random variable may not be a threshold concept in a general engineering statistics course, but a standard deviation associated with a random reading error of a tape measurement can be a threshold concept in a geomatics engineering course. If students overcome this threshold concept by experiencing an irreversible transformation in learning, then they will be able to apply the concept in new and more complex contexts, which is an attribute of deep learning. Another area of troublesome knowledge that geomatics engineering students frequently encounter is gravitation, gravity, rotation and inertia, all related to the shape of the Earth. A plethora of threshold concepts perhaps resides in this area and requires a positive shift in understanding to be able to relate the Earth’s shape to many

important geomatics engineering applications such as positioning and navigation.

In such areas of troublesome knowledge, instructors spend more time teaching and reviewing the course material and perhaps the threshold concepts even in senior level courses. Our main goal is to identify areas of troublesome knowledge and specific threshold concepts in two second and one third year courses and observe and assess teaching and student learning in these areas. We have formulated our inquiry to investigate whether and how teaching provides an environment which facilitates deep learning in these areas of troublesome knowledge.

2. SCHOLARLY INQUIRY

The term *deep learning* used by Entwistle and Peterson in [4] was based on Marton's and Säljö's work [5], who investigated how students responded to assigned learning tasks. Deep learning means that a student organizes knowledge in a structured way and is able to connect new information to already acquired knowledge. By adopting deep learning, the student synthesizes information and connects facts in order to develop meaningful knowledge structures as per Ambrose *et al.* in [6]. On the contrary, *surface learning* infers that a student accumulates information in order to accomplish a learning task without organizing this information in a structured way. If a student engages mostly in surface learning rather than in deep learning in areas of troublesome knowledge, they cannot build the solid engineering knowledge base required for accomplishing high-level learning outcomes such as problem solving and design.

Entwistle and Peterson [4] review a number of learning environments that support the deep learning approach in higher education. Some of these environments are "[providing] ... understanding aims", "[relating] teaching directly to prior knowledge and understanding aims", "[identifying] troublesome knowledge and threshold concepts", and "[providing] extensive, carefully selected examples to develop accurate concepts". The full list of learning environments can be found in Table 4 in [4]. Deep learning is also a discipline-specific phenomenon. As part of the engineering family, geomatics engineering can be classified as a hard discipline in the "hard-soft" spectrum and as an applied discipline in the "pure-applied" spectrum in Biglan's topology [7] and [8]. Laird *et al.* find in [9] that engineering scores lower in deep learning compared to "soft" and "pure" disciplines. Their findings agree with the findings in earlier studies that engineering students engage less in deep learning [10]. Some researchers report that instructors in the engineering disciplines offer less activities aligned with deep learning than soft and pure disciplines [11].

In order to assess whether learning environments support deep learning in the three examined courses, we have designed and implemented a set of research tools.

These tools include both direct and indirect methods of collecting data of student learning and include classroom observations of lessons, minute papers written by students at the end of each course unit to identify difficult concepts, end-of-term surveys on the teaching and learning process in a particular course, think-aloud sessions, and student self-reflections related to lab assignments. These are complemented by collecting term marks and final grades. Due to the early stage of the study, this paper focuses on the classroom observations and minute papers completed to date.

3. METHODOLOGY OF CLASSROOM OBSERVATIONS

The content of the implemented observation protocol and the processing of the collected observation data are explained in the following two sub-sections. These are followed by a brief description of each studied course.

3.1. Observation protocol

A lesson is defined as a topic within an academic lecture, but it may be an entire lecture or a tutorial session. The classroom observation protocol is adopted and adapted from the work [12] by Arshavski *et al.* The protocol starts with a brief description of the lesson, the number of students in attendance, the place and timing of the lesson (close to the beginning, middle, or end of a course unit), and any unusual circumstances during the lesson. The level of knowledge and skills practised during the lesson are also noted as (1) basic knowledge, skills and procedures, (2) concept development and problem solving, or (3) inquiry learning and engineering design. In order to assess the classroom learning environment, four observation categories are formulated (see Appendix A).

The first category is *geomatics engineering knowledge* (Table A1), which assesses the depth of the introduced and discussed concepts in the lesson, the explicit connections of the lesson to real-world scenarios and engineering problems, the connections made by the teacher to other concepts taught in the course or other geomatics engineering courses. The second category (Table A2) considers *instruction and feedback* provided to students during the lesson by assessing the formulated learning goals and the defined criteria for success, the strategies applied by the teacher to monitor learning, and the specific feedback and assistance in learning provided to the students. The third category (Table A3) is *student cognitive engagement*, which includes the presence of open-ended questions requiring high-level thinking and discussions, opportunities presented to students to summarize, synthesize and generalize solutions and facts, to contrast solutions and provide interpretations of an engineering problem or a scientific phenomenon. Lastly, *student behavioural engagement* (Table A4) is observed and

assessed together with evidence of demonstrated satisfaction, confusion, or frustration.

Some learning environments listed in [4] are aggregates of the observation criteria discussed above. For example, “Relate teaching directly to prior knowledge and understanding aims” in [4] is a combination of criterion 4 in Table A1 and criteria 6 and 7 in Table A2. “Teach so as to clarify meanings and arouse interest for students of contrasting abilities and goals” combines criteria 13 and 15 in Table A3. Other learning environments such as “Identify troublesome knowledge and threshold concepts” cannot be observed directly during a lesson. However, if students encounter troublesome knowledge or their learning is blocked by a threshold concept, their behavioural engagement will be impacted. The students will not be able to follow the teacher’s instructions when completing a learning task and answering questions. They will probably show hesitation, confusion, or even frustration during the lesson.

3.2. Processing of classroom observations

An assessment scale with four parameters common for all four observation categories is defined as follows: 0 - not observed, 1- minimal, 2- to some extent, and 3- emphasized. This scale is used to aggregate the observation data in each category by means of the following simple algorithm:

1. The sum (summary) of each column (scale parameter 0, 1, 2, and 3) is calculated for each category.
2. A weighted mean is calculated for each category, where the weights are the scale parameters.
3. A score for each category is calculated by scaling the weighted mean with a coefficient which is the ratio of the sum of the scales (i.e., 6) and the number of questions in each category (e.g., 4, 5, or 6). This is necessary so that scores can be compared across the four categories. For example, if the observer marks all questions as “emphasized” in a category with four questions, the weighted mean is 2.0, the coefficient is 1.5, and the score is 3.0.

For each lesson, the scores can be plotted in a cumulative bar graph as shown in Fig. 1. The change in the bar’s length is indicative of an improvement (or the lack thereof) in the learning environment of the respective course. It should be noted that the improvement can be measured only relatively in the sequence of lessons. Thus, there are no threshold values of the scores that can help one distinguish between a learning environment which facilitates deep learning and a learning environment which is lacking in this respect. In general, one can assume that a score of 2.5 or higher in all four categories means that the learning environment facilitates deep learning.

3.3 Description of the observed courses

Two second and one third year courses in the 2018 winter term at the Department of Geomatics Engineering are being observed. The attributes of the courses, namely the day, time, duration, average attendance and teaching style, are shown in Table 1. The two second year courses are:

- *Surveying* (GEO-2A), which includes basic surveying concepts and computation routines, field survey procedures, and teamwork. The course has the typical structure of a second year course in geomatics engineering with three 50-minute lectures per week and a three-hour lab period.
- *Least Squares Estimation* (GEO-2B). The course content includes theory of errors and adjustment of observations, mathematical models, as well as statistical testing in geomatics engineering. This course also has three 50-minute lectures and a three-hour lab period.

It should be noted that GEO-2A deals with practical aspects of the concepts taught in GEO-2B. For example, observation errors of angles, distances, coordinates are calculated and discussed in various practical scenarios. Although strong correlations likely exist between threshold concepts in these two courses, no such correlations are studied in this paper.

Table 1: Attributes of the observed courses.

Course	GEO-2A	GEO-2B	GEO-3
Time	9:00-9:50	11:00-11:50	12:00-12:50
Day	MWF	MWF	MWF
Average attendance	80%	71%	90%
Teaching style	70% slides and 30% board	mainly board	50% slides and 50% board

The third year course *Geodesy* (GEO-3) teaches abstract concepts related to gravitational attraction, gravity and the shape of the Earth and uses prerequisite knowledge from differential geometry, integral and differential equations, potential theory and boundary value problems. The traditional lectures and lab assignments are complemented by a research assignment to engage students in active learning.

As classroom observations alone cannot support a hypothesis of the existence of threshold concepts in a lesson, feedback from students is collected by means of minute papers at the end of each course unit. The minute paper asks students to identify a concept that they still find vague, difficult, not-well explained or not well-understood and to explain why they think that is. The number of

students, who submit a minute paper, varies per course and lesson.

4. RESULTS AND ANALYSIS

Three or four lessons have been observed in each course in the first four weeks of the winter term. The attributes of the lessons are given in Table 2 for GEO-2A, Table 3 for GEO-2B, and Table 4 for GEO-3. The last row in each table shows whether the lesson is supplemented by a minute paper at the end of the respective unit.

Table 2: Attributes of the observed lessons in GEO-2A.

Lesson	#1	#2	#3
Type	lecture	lecture	tutorial session
Duration	50 min	50 min	50 min
Attendance	80%	80%	87%
Teaching style	slides and board	slides and board	board
Cognitive level	basic concepts	basic concepts	problem solving
Minute paper	yes	yes	no

Table 3: Attributes of the observed lessons in GEO-2B.

Lesson	#1	#2	#3	#4
Type	lecture	lecture	lecture	tutorial session
Duration	50 min	50 min	50 min	90 min
Attendance	74%	68%	71%	32%
Teaching style	board	board	board	board
Cognitive level	basic concepts	basic concepts	basic concepts	problem solving
Minute paper	yes	yes	yes	yes

Table 4: Attributes of the observed lessons in GEO-3.

Lesson	#1	#2	#3
Type	lecture	lecture	tutorial session
Duration	50 min	50 min	30 min
Attendance	90%	90%	90%
Teaching style	slides	slides and board	board
Cognitive level	basic concepts	basic concepts	problem solving
Minute paper	one for all three lessons		

4.1. Analysis of GEO-2A

The scores for the three observed lessons, namely (1) systematic and random errors in taped distances, (2) systematic and random errors in angle observations, and (3) traversing (a combination of distances and angles), are provided in the cumulative bar graphs in Fig. 1. The score for the instruction and feedback category in all three lessons is “emphasized”, i.e., close to or exactly 3.0, meaning that teaching likely generated an environment for deep learning. It is not surprising that the geomatics engineering content was not strongly emphasized (scores 2.2 and 2.4), and the lessons were mostly lacking in discussing real world problems and connecting surveying to other geomatics engineering disciplines. This is because the classroom observations were made early in this course, which builds a knowledge base and develops basic skills in using engineering tools as a fundament for a series of third and fourth year courses. Student cognitive engagement was low during the two lectures (1.4 and 1.8) perhaps due to the use of slides (see Table 1), which provided the lesson content and various examples illustrating the taught basic concepts, but it improved largely to 2.4 during the tutorial session on the board. The course appeared to be deficient in contrasting different solutions or interpretations of engineering problems, as well as in relating and applying the acquired knowledge to a novel situation. The scores for these criteria improved significantly for the tutorial session, where a real-world problem was reviewed and discussed with the students actively participating in the lesson. Finally, the student behavioural engagement was clearly emphasized during the tutorial (2.8) compared to the first two lessons (2.25).

Nine out of 21 minute papers identified that the concepts taught in lesson #1 were still muddy, a fact supported by the low scores of cognitive and behavioural engagement. Thus, it can be concluded that errors in taping distances can be an area of troublesome knowledge and various random and systematic errors may be threshold concepts. The minute papers related to lesson #2 did not reveal similar information.

4.2. Analysis of GEO-2B

Four observation sessions have been run in the GEO-2B course so far: (1) types of functional models, (2) multivariate error propagation, (3) introduction of the least squares method, and (4) parametric least squares adjustment. The first three lessons were during regular lecture periods, while the fourth one was a tutorial session during a laboratory period. The first observed lecture ended with a ten-minute long group learning activity. The second observed lecture started with a short active learning exercise, where the students were given a minute or two to review their notes from the class before and then attempted to explain the meaning of the error propagation concept taught in the previous lecture. The third observed lecture

did not have a planned active learning exercise and was highly theoretical. All three observed lectures did include frequent short questions meant to engage the class. The observed tutorial included solving a multi-step problem where the students, either individually or in small groups, were prompted to identify model parameters, collect data, write out observation equations, and ultimately solve the problem via a least squares adjustment. The instructor was circulating among the groups and guiding the students where necessary. At the end of each step, the solutions were written on the board by the instructor with the help of the students. As seen in Fig. 2, the cognitive engagement of the students was directly proportional to the presence of planned classroom activities and was indirectly proportional to the amount of theory delivered, i.e., the more theoretical lesson #3 achieved the lowest score of 2.0 compared to 2.8, 2.2, and 2.4 for the more engaging lessons #1, #2, and #4, respectively. It should be noted that while the laboratory/tutorial attendance is generally lower than the one for the lectures, the attendance for the observed tutorial was particularly low because the session happened to be on the Friday before a week-long reading break.

While the first observed lecture appears to be one of the more successful lessons, the minute papers associated with the topic in question revealed that the students were still struggling with the classification of the functional models in least squares estimation. The minute papers for the other three lessons did not provide any significant findings.

4.3. Analysis of GEO-3

The concepts of gravitational attraction (lesson #1) and gravity (lesson #2) in GEO-3 had been perceived by many students as complex long before initiating this study. The results from the classroom observations in Fig. 3 and the minute papers supported this notion. For example, the student cognitive engagement score is low for both lesson #1 (0.8) and lesson #2 (1.4) compared to the instruction and feedback category (2.2 and 2.3, respectively). Perhaps the low scores can be explained by an amalgamation of factors: the more traditional lecturing style in these two lessons, the high level of abstraction of the course material, and the large number of differential and integral equations, among others.

Lesson #3, which was solving problems on the board related to gravity and gravitational attraction, scored high in the geomatics engineering content category and also showed an improved learning environment (evident from the longer bar) compared to the first two lessons. The improvement was mainly due to addressing specific geomatics content (a maximum score of 3.0) and also due to the better cognitive engagement of the students (1.6). At the same time, the behavioural engagement was 2.0 in all three lessons meaning that the students asked questions, showed perseverance when solved problems, and were satisfied with their learning to some extent, but never

immersed themselves completely in the lessons. This finding aligned with the fact that even after the third lesson some students were not able to transform positively their learning as evident from the comments in few minute papers. For example, one student wrote “[I have difficulties understanding] how gravity applies to various concepts [...] probably because there are a lot of terms and [it is] hard to remember what they mean this early.”, or as another student wrote “I am struggling to understand most of the section about the gravity field. I think it is mostly because there are a lot of complicated equations...”. The first comment deserves some dissection. Learning in this course happens through three different avenues (learning of theoretical concepts, learning of data acquisition methods, and learning of computational procedures), which exhibit complex and often iterative interrelatedness. One should take into account that learning of gravitational attraction and gravity remains relatively niche until higher level procedural knowledge is built and applied later in this course to solve real-world problems. Thus, student learning of the concepts, which may appear as threshold once immediately after they are taught, may be transformed positively when their practical applications are revealed to the students. However, one cannot overlook the fact that the likely reason why gravitational attraction and gravity were pinpointed as troublesome by the second student is the complexity of the mathematics and physics behind them, and that not all students are equipped with the knowledge and tools required to understand such complex concepts.

5. CONCLUDING REMARKS

We have described a method based on classroom observations and minute papers to investigate whether learning environments in three geomatics engineering courses can facilitate deep learning. Other methods included in the project but not discussed in this paper are student reflections on learning, think-aloud sessions, end-of-term surveys and analyses of term and final grades. Testing of this methodology is ongoing in the winter term of 2018. Although our investigation is still in its early stage and many more data will be collected, classroom observations seem to provide meaningful information in terms of the student cognitive and behavioural engagement necessary for deep learning. Quite naturally, the student engagement was higher during the problem solving lessons compared to the more traditional and theoretical lectures. Namely, the more problem solving and active learning were incorporated in the lesson, the higher student cognitive engagement was.

Figure 1. Scores for the three GEO-2A lessons in each observed category.

Figure 2. Scores for the four GEO-2B lessons in each observed category.

Figure 3. Scores for the three GEO-3 lessons in each observed category.

Minute papers seem to be able to complement classroom observations to reveal concepts that may be threshold. It is worth pointing out that a minute paper should be done at the end of a course unit after students have been exposed to more active learning in tutorials and individual and group lab assignments, have gained “hands-on” experience, have been given opportunities to reflect on their learning and have made plans for improving it. Once some threshold concepts are exposed, the course instructors can at least address them in class and also attempt to mitigate them. In a future study, the authors plan to attempt to address the transformative student learning aspect associated with threshold concepts.

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APPENDIX A: OBSERVATION PROTOCOL

Table A1: Geomatics engineering content.

<i>Scale: 0 - not observed, 1 - minimal, 2 - to some extent, 3 – emphasized</i>	0	1	2	3
1. Teacher discussed key geomatics engineering concepts in depth.				
2. Teacher emphasized meaningful relationships among different concepts.				
3. Teacher made connections to real-world problems.				
4. Teacher connected information to previous knowledge.				
5. Teacher made connections to other geomatics engineering disciplines and areas of knowledge.				
Summary				

Table A2: Instruction and feedback.

<i>Scale: 0 - not observed, 1 - minimal, 2 - to some extent, 3 – emphasized</i>	0	1	2	3
6. Teacher provided clear learning goals to students.				
7. Teacher provided clear criteria for success to students.				
8. Teacher used different strategies to monitor student learning and understanding throughout the lesson.				
9. Teacher adjusted instruction based on evidence of student learning.				
10. Teacher provided specific feedback to students.				
11. Teacher provided assistance when students struggled.				
Summary				

Table A3: Student cognitive engagement.

<i>Scale: 0 - not observed, 1 - minimal, 2 - to some extent, 3 – emphasized</i>	0	1	2	3
12. Teacher asked students open-ended questions that required higher level thinking and engaged them in discussions.				
13. Teacher asked students to explain and justify their thinking.				
14. Students were given opportunities to summarize, synthesize and generalize.				
15. Students were asked to contrast different answers, solutions, or interpretations of an engineering problem or a scientific phenomenon.				
16. Students were asked to apply knowledge to a novel situation.				
Summary				

Table A4: Student behavioural engagement.

<i>Scale: 0 - not observed, 1 - minimal, 2 - to some extent, 3 – emphasized</i>	0	1	2	3
17. Students followed directions, responded to teacher's questions and were engaged in tasks during the lesson.				
18. Students asked the teacher and/or other students questions.				
19. Students showed perseverance when solving a problem.				
20. Students showed satisfaction during the lesson.				
21. Students showed confusion during the lesson.				
22. Students showed frustration during the lesson.				
Summary				