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Flipping the Advanced System Dynamics classroom

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ABSTRACT

This paper describes lessons learned while teaching Advanced System Dynamics, at the Faculty of Technology, Policy and Management at Delft University of Technology. The course is an elective for Master students of the faculty who are already familiar with system dynamics modelling. We report on the course in the academic year 2014-2015, the first year in which a new teaching style was adopted - a "flipped classroom" approach was employed. In particular, the student and teacher evaluations of this approach which places student learning centrally are discussed. Conclusions on the usefulness and the role of flipping the classroom in system dynamics modelling are drawn. Further, this document includes the full lesson plan, and can be useful for other system dynamics teachers who are interested in adopting an active learning approach.

KEYWORDS

System dynamics, collaborative learning, education, teaching, flipped classroom, engagement, face to face teaching, engineering education

1 INTRODUCTION

A master's program of the Faculty of Technology, Policy and Management focuses on understanding of complex systems in order to improve decision making. In this light, students have the option to gain state-of-the-art knowledge on modelling, simulation and gaming. The course "Advanced System Dynamics", an elective within the masters curriculum, deepens the theoretical and practical knowledge of students and hones their System Dynamics skills. In 2014, we decided to increase the level of interaction with students in our teaching of system dynamics at masters level. This choice was grounded in the core position of system dynamics modelling within the bachelor and masters' curricula. The students at the Faculty of Technology, Policy and Management are interdisciplinary engineers, familiar with a wide range of modelling techniques, without specializing in a particular approach prior to conducting their master's thesis work. Our new interactive teaching method was designed to improve the students ability to justify their modelling strategy, increase modelling knowledge and particularly to increase their skills in building and formally testing and using their models. In short, we wanted to "make them ready for using system dynamics in their career after they graduate" and to do this we flipped the classroom.

The core idea of the flipped classroom is to alter the traditional approach of a teacher communicating (sending out) information to a class and students passively receiving it. In a flipped classroom, instruction that used to occur via classical lecturing is now accessed through other means, (e.g. online syllabus, video clips) whenever possible, and the classroom becomes the place to work through problems, to advance concepts and to engage in collaborative and active learning (Bergmann & Sams, 2012; Tucker, 2012). Especially in higher education, where students are learning to master the concepts in which they are instructed, class time that focuses on knowledge application may allow the teacher to detect errors in thinking by the students (O'Flaherty & Phillips, 2015; Pluta et al., 2013).

It is our contention that real learning happens when students hit obstacles, feel stuck and then manage to find a successful way of solving the problem. As a faculty member with extensive system dynamics modelling experience in research, teaching and practice, and a graduate of this faculty with the experience of learning system dynamics through several courses and teaching system dynamics, we embrace the principle that working through problems and taking a step back are key to deepening the conceptual understanding of a system. Sometimes another pair of eyes can help a student understand their own mental model, and how it may need adjustment and improvement. We know that students cannot build original models after seeing a demonstration of such models, and we have observed that working collaboratively on models can improve students' results (Fisher, 1998). From system dynamics modelling practice and Group Model Building sessions, we have learned that the perceptions of others can be extremely helpful in advancing our own mental models (Andersen et al., 1997; Vennix, 1999).

Taking these principles into account, we aimed to maximize the most valuable assets we have as teachers, namely our time and attention. In the assignments, the core of the course, students worked in project groups of 2. These assignments became the major activity of the course with students working and teachers available to answer questions and facilitate learning. This tutorial type setting was used to create a safe space for learning and exploring the material. In these settings, an issue sometimes came up that was then shared with the entire group. In self-study hours, students had autonomy in accessing information that was available through the online learning environment (e.g. Blackboard). Parallel to the tutorial setting, practitioners delivered lectures on the use and application of system dynamics in the world outside academia.

This paper reports on the design and delivery of the course "Advanced System Dynamics", and on the lessons we learned in flipping the classroom when teaching system dynamics. First, we provide an overview of the course, its students, the course structure, and its assessment. Then we provide the case study description used by the students for their model. Third, we describe and discuss the results of the assignments. Then we report and discuss the students evaluation of the course. In concluding, we reflect on the use of the flipped classroom setting in our course and the relevance of this analysis for others..

2 OVERVIEW ADVANCED SYSTEM DYNAMICS

2.1 Course specific characteristics

The course is credited with 4 ECTS (equals 112 hours including lectures, tutorial hours and self-study hours). The course forms a component of the Simulation, Modelling and Gaming Specialization profile or can be chosen as an elective. This means that students enrolling in the course are mainly final year students of the Master Program "Systems Engineering, Policy Analysis and Management". All students attending the course have completed a bachelor degree in engineering, and the majority have an interdisciplinary bachelor degree from the Faculty of Technology, Policy and Management. This means they are skilled system thinkers, and are familiar with conceptualization, policy analysis and complex, messy problems. For this course, students are expected to have prior knowledge of System Dynamics, as well as knowledge of (minimally) one other modelling method such as discrete simulation, agent-based modelling, hydrodynamic modelling or spreadsheet modelling. In fact, prerequisite knowledge includes basic course and project work in System Dynamics, and students are advised to only participate in the course when their previous grades exceeded a 7 out of 10. Although students are familiar with System Dynamics and have even made (smaller) System Dynamics models, this course requires them to build their own complex model and test it formally. To prevent a high teacher workload, owing to the grading work load, the maximum number of students was set at 30. 26 students were enrolled in the reported course. Students complete the assignments in project teams of two students. .

Upon completion of the course the student has knowledge of: a) the possibilities and limitations of the System Dynamics modelling method; b) the relevant scientific literature on selected topics in the field of System Dynamics such as the use of data, model structure and behavior, model validation under uncertainty, serious gaming with System Dynamics, group model building and exploratory model analysis. Additionally, the student has the skills: c) to make an informed choice as to when to use System Dynamics; d) to apply the theoretical knowledge on building, validating and communicating models in a problem situation; and e) to understand current literature and recent advances in the field of System Dynamics.

The course comprises seven topics: "Why System Dynamics?", use of data, model behavioral analysis, validation under uncertainty, group model building, exploratory model analysis and games in system dynamics. The theory underpinning these topics is applied in a number of assignments related to a case which is runs in parallel to the theory component. Guest lectures by experts in the practice of System Dynamics form an integral part of the course to provide the students with insights in the use of system dynamics modelling in practice.

2.2 Course structure "Advanced System Dynamics"

The course was scheduled in the second quarter of the academic year. Weeks 1 to 4 focused on the traditional modelling cycle, end week 3 on Group model building, week 5 on Exploratory Modelling Analysis (EMA), week 6 on System Dynamics and games and then a wrap-up in week 7. The full schedule is shown in Table 1. Attendance at tutorials was strongly advised and active attendance of guest lectures was obligatory – in exceptional cases an additional assignment was allowed instead of attendance if requested in advance. Students were strongly advised to ask questions to the guest lecturers, so as to make the lecture more interactive. The students were to hand in five assignments and an optional additional assignment was available should they need to raise their grade. The assignments were designed to accord with the system dynamics modelling cycle and engender iterative improvement of the model that students were building (Slinger et al., 2008). Assignment 1a and b contributed 40% to the total grade, whereas assignments 2 to 5 weighed equally (15% each). To give more insights in the course assignments, the model description from assignment 1 and a selection of other assignments are presented in the appendix.

- *Assignment 1a and 1b:* model building, data, validation and documentation (40% of total grade). The students are required to develop a system dynamics model of a water infrastructure supply system in Greater Kirkwood, South Africa, that is battling to meet growing demand (see Section 2.4. for the case study description). The model must exhibit satisfactory reference behavior. Some potential policy measures aimed at ameliorating the situation can also be explored (preliminary testing). However, the students' key focus should be on understanding the modes of failure of the present system. Evidence of use of the theoretical material and reference data should also be provided. The students are encouraged to keep their model as small as possible, while still containing the key dynamic structures. The theory material on data was provided online and included information on different types of data, use of data in system dynamics, different delay structures, how to formulate table functions (lookups) and other useful tips. The model documentation had to include a justification for a LOOKUP function formulation, and evidence of three different validation tests apart from sensitivity analysis (as this is the subject of assignment 2). Additionally, reporting of the choice of model boundary, assumptions, reference run behavior, was required. Particular choices of functions such as delays, pulses etc. also require justification if they are used.

- *Assignment 2* : sensitivity analysis (15% of total grade). The students undertake four exercises relating to sensitivity analysis of graphical functions (cf. Eker et al., 2014). They were required to distort a table function by (i) manually multiplying a given table function f by a distortion function h point by point, and plot the result. it, (ii) showing a table distortion by using the sensitivity tool of Vensim, and (iii) distorting by applying a single-triangular distortion function on a modified model. Additionally, they are asked (iv) to interpret the results of only double-triangular with static end points, and observe "non-monotonic/meaningless" distortions. Finally, they discuss and evaluate these different types of the distortion method in a plenary discussion.
- *Assignment 3* : model behavioral analysis (15% of total grade). Students are asked to investigate model behavior loop dominance analysis (cf. Ford, 1998). Students are to identify four candidate loops for their variable of interest, and then analyze over 4 atomic behavioral pattern intervals to identify the dominant loops. Students may analyze their own models from assignment 1, or on a suitable model on Asian flu that was supplied to them. Additionally, students are required to hand in a theory-based report and discuss the results and the method, including its weaknesses.

Table 1: Course schedule with assignments, theory lectures, guest lectures and self-study

Wk	Day	Type	Topic
1	Tue 11/11/14	Introduction to course and case	Introduction to course (different uses of modelling cycle, methodological paradigms) Introduction to case and model documentation *Assignment 1a*: model building and documentation
	Fri 14/11/14	tutorial	Model building and documentation (bring laptops)
	Before Tue 18/11/14	*self-study*	Collegerama on data and validation *Assignment 1b*: use of data & validation
2	Tue 18/11/14	tutorial	
	Fri 21/11/14	guest lecture	
	Sun 23/11/14	*Send Assignment 1a & b*	
	Before Tue 25/11/14	*self-study*	Collegerama sensitivity analysis of graphical functions *Assignment 2*: Sensitivity analysis
3	Tue 25/11/14	tutorial	
	Fri 28/11/14	guest theory lecture	
	Sun 30/11/14	*Send Assignment 2*	
	Before Tue 2/12/14	*self-study*	Collegerama model behavioural analysis *Assignment 3*: model behavioural analysis
4	Tue 2/12/14	tutorial	
	Fri 5/12/14	guest lecture	
	Mon 8/12/14	*Send Assignment 3*	
5	Tue 9/12/14	guest lecture	Using exploratory modelling
	Before Fri 12/12/14	*self-study*	Collegerama exploratory modelling and analysis (EMA) *Assignment 4*: Exploratory model analysis
	Fri 12/12/14	tutorial	Exploratory modeling and analysis (bring laptops)
6	Tue 16/12/14	theory lecture	System Dynamics and games *Assignment 5*: systems thinking gamelet or game related to own model
	Thurs 18/12/14	*Send Assignment 4*	
7	Tue 6/1/15	guest lecture	SD in practice (incl. Haaglanden model)
	Tue 6/1/15	*Send Optional Assignment*	
	Wed 7/1/15	*Send Assignment 5*	
	Fri 9/1/15	Course wrap-up and Presentation of games	

- *Assignment 4*: exploratory model analysis (15% of total grade). Students analyze the model they built in Assignment 1 to answer: "What are the main uncertain factors (7 to 15 factors) in this model?" and "What are justifiable ranges/values for these factors?" The results are analyzed and policy implications of the findings are discussed. Preliminary
- *Assignment 5*: systems thinking gamelet or game related to own model (15% of total grade). For the final assignment, students are asked to design a (serious) game or gamelet that can be played in the classroom. The final lecture, students and teachers assemble to play each other's games. The game should explain (an aspect of) system dynamics (e.g. system archetypes, system behavior, actor behavior) and the duration of gameplay should be minimally 4 minutes.
- *Optional Assignment*: Model selection and approach. In the introductory lecture students were introduced to the concept that uses of System Dynamics Modelling range from Group Model Building through Exploratory Model analysis to SD and games, each emphasizing different aspects of the modelling cycle and adopting different stances on SD modeling. In this assignment, students are required to compare and contrast two non-traditional uses of SD modelling with each other. They are required to refer to the course reading material, as well as the additional reading resources, and may of course extend beyond this reference material. With the group..

2.3. Assignment evaluation

Assignments were submitted on the Monday and graded as soon as possible, usually by Friday of the same week. In this way, students could learn from the feedback on their assignment and iteratively improve their model.. The students received a grade as project group for each assignment. The grading of the first assignments focused on the quality of the modelling, considering the following aspects as applicable in the assignment. Additionally, students were graded on their documentation and reflective thinking, (cf. Slinger et al., 2008):

- Elegance, readability (no "spaghetti", clear naming of variables)
- Units (no corrective constants)
- No non-SD (delayppl, reservoirs, integers)
- Numerically robust
- Missing or wrong constructions
- Superfluous constructions
- Missing effects (behaviour)
- General Remarks (general impression of group skill).

The grading of the subsequent assignments differed according to the topic, but was indicated to the students in terms of 3 to 5 criteria that would be applied. Assignments 2, 3 and 4 were traditional exercises with right and wrong answers that were graded based on the materials handed in by the students. The games from assignment 5 were presented by playing the games in a group, and by the one-page handout from the students where they justified their choices and explained how their game related to SD. To get an excellent mark for Assignment 5, games were relevant to SD, met the time constraints, were fun and original.

Additionally, each student group was required to post a question related to the material of the week on the online discussion forum. Fellow students were invited to respond. These questions and responses allowed the course coordinator to take the pulse of the class and respond in the flipped classroom to any confusion or uncertainty. The questions served as a starting point for many (small) group discussions

2.4 Student evaluation

At the end of each course at Delft University of Technology, an online course evaluation questionnaire (Evasys) is sent to each student. The questionnaire comprises standard evaluation questions from the university, supplemented with course specific questions by the course manager. The evaluation survey consisted of several closed and open-ended questions relating to the course coherence, feedback on the individual lecturers, the contents of the course, the education methods, assessment, course organization, study load and overall learning. Finally, we added two general open-ended questions on "which parts of this course do you consider good?" and "which parts are less satisfactory and should be improved in the future?".

4 RESULTS AND DISCUSSION

Of the 26 enrolled students, 25 completed the course and one student quit after week 2 (due to issues unrelated to the course). The final grades were between 6.5 and 9.0 out of 10. The Dutch grading scale goes from 1 (poor) to 10 (outstanding). A 6 is a pass, 7 is satisfactory, 8 is good, 9 is very good, and a 10 is outstanding. The mark 9 is not frequently given and 10s are extremely rare (NUFFIC, 2013). For this class, the average grade was 7.62, and both the median and mode grades were 7.5. Overall, these are very satisfactory results. The lowest grade, a 6.5, was obtained by dint of additional teaching input and an optional extra assignment. The student in question completed the assignments 2-4 alone, receiving additional individual teaching time to compensate for lacking a project partner.

Table 2: Assignment grades and final grades per student (avg. = 7.62)

Student	Assignment 1	Assignment 2	Assignment 3	Assignment 4	Assignment 5	Weighted Total	**Final Grade**
1	6.00	6.00	(6.00)	7.75	7.00	64.13%	**6.5***
2	8.20	7.30	6.00	6.50	7.00	73.00%	**7.5**
3	7.40	6.60	6.50	6.75	7.00	69.88%	**7.0**
4	7.90	7.60	6.50	7.00	7.00	73.75%	**7.5**
5	7.80	6.80	6.00	8.50	6.50	72.90%	**7.5**
6	7.40	6.60	6.50	6.75	7.00	69.88%	**7.0**
7	7.80	6.50	6.00	8.50	7.50	73.95%	**7.5**
8	7.90	8.20	6.00	8.00	8.00	76.90%	**7.5**
9	7.60	7.10	6.50	8.25	7.00	73.68%	**7.5**
10	7.50	6.50	7.50	7.50	8.00	74.25%	**7.5**
11	7.80	6.50	6.00	8.50	7.50	73.95%	**7.5**
12	7.90	8.20	6.00	8.00	8.00	76.90%	**7.5**
13	7.80	6.80	6.00	8.50	6.50	72.90%	**7.5**
14	8.30	8.00	7.00	8.00	7.00	78.20%	**8.0**
15	7.20	8.30	7.50	8.75	7.50	76.88%	**7.5**
16	7.50	6.50	7.50	7.50	8.00	74.25%	**7.5**
17	8.90	8.40	8.00	9.00	7.50	84.95%	**8.5**
18	8.80	9.20	9.00	9.00	8.50	88.75%	**9.0**
19	8.20	7.30	6.00	6.50	7.00	73.00%	**7.5**
20	8.30	8.00	7.00	8.00	7.00	78.20%	**8.0**
21	7.90	7.60	6.50	7.00	7.00	73.75%	**7.5**
22	8.90	8.40	8.00	9.00	7.50	84.95%	**8.5**
23	7.20	8.30	7.50	8.75	7.50	76.88%	**7.5**
24	8.80	9.20	9.00	9.00	8.50	88.75%	**9.0**
25	7.60	7.10	6.50	8.25	7.00	73.68%	**7.5**

5 STUDENT EVALUATIONS AND DISCUSSION

The response rate of the anonymous course evaluation was relatively high (16 out of 25 students) and the open-ended questions were answered elaborately. An e-mail requesting the students to provide feedback on the Advanced SD course was mailed to each course participant. It included an explanation that we had changed the teaching method in their year compared with previous years - specifically the tutorial sessions – and that students' honest opinions would be really helpful in crafting the course further. This section describes and discusses the students' feedback.

5.1 Selection of closed questions

Overall, the course was received well. Students were asked to answer the questions based on a rating from 1 (totally disagree) to 5 (totally agree). The results are depicted with boxplots, where the red line represents the average value for the respective statement. No respondent graded the course as being insufficient (<6). Most students (76%) awarded the course an 8 or higher. We cannot attribute these values entirely to the flipped classroom,as the previous ratings of the course were also high. However, by exploring the different attributes of the evaluations we can gain insights in how students experienced the course.

The course was graded with a 6 (n=1), 7 (n=3), 8 (n=8), 9 (n=2) and 10 (n=1), which makes the overall grade for the course a high 8 (Figure 4). Although students found the course challenging, most students indicated they learned a great deal.

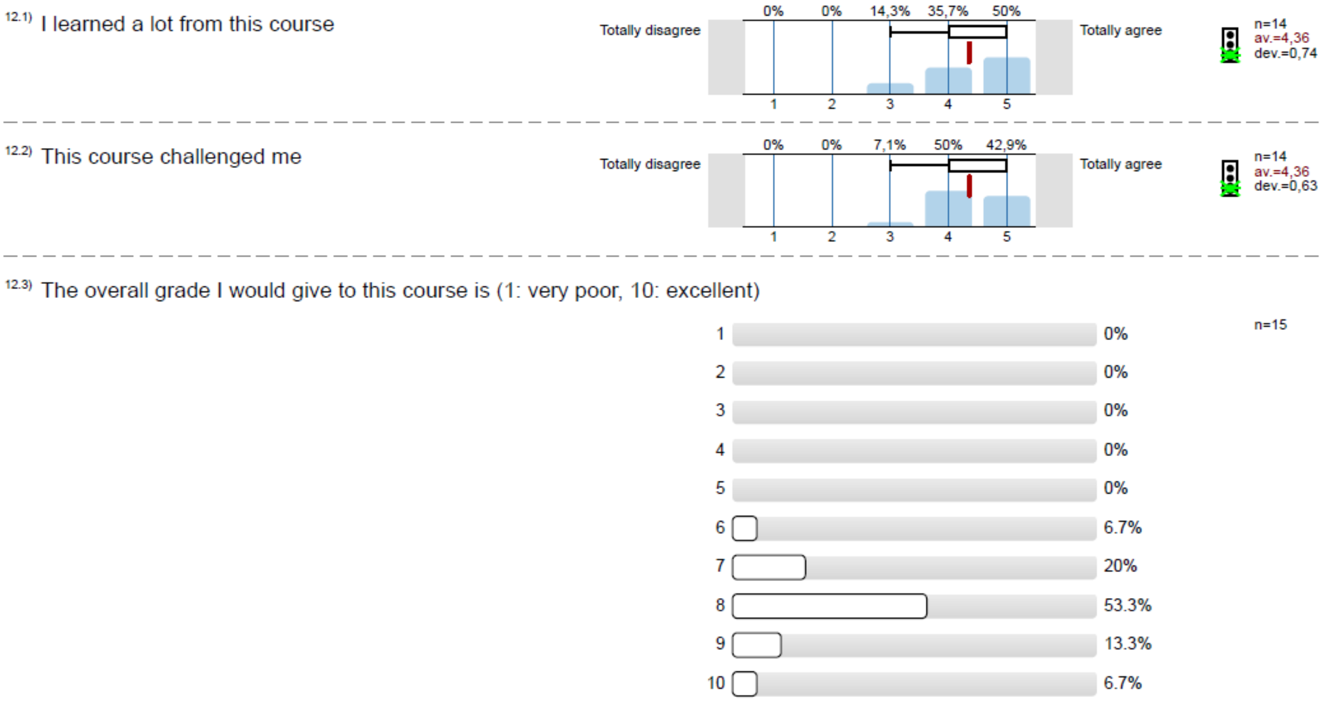

Figure 4: Student evaluations of the course as a whole

There was more variation in the students' evaluations of the clarity of the course objectives. However, the study materials such a books, notes and slides supported students in obtaining the required knowledge. The obligatory assignments were all understood to be supporting the overall course objectives (Figure 5).

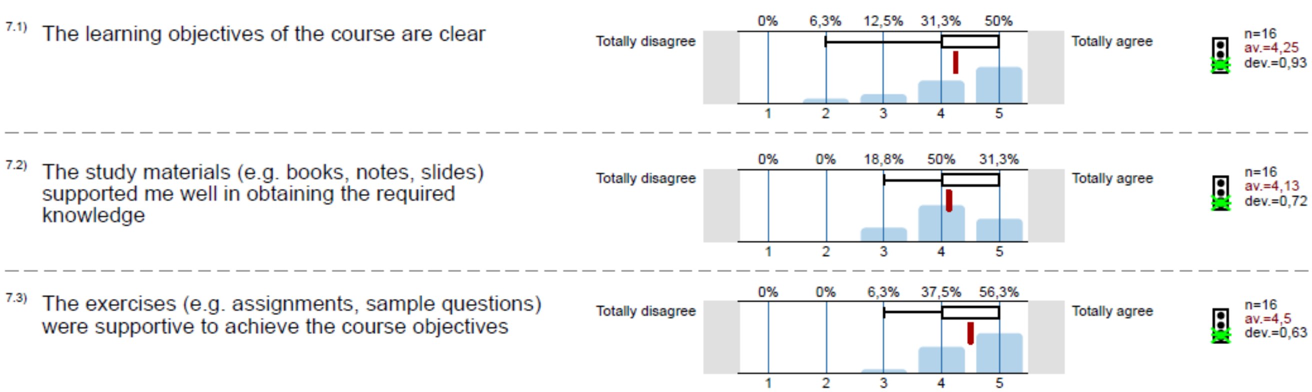

Figure 5: Student evaluations of general course content

Questions on the appropriateness of the teaching methods, including the flipped classroom-style tutorials, the guest lectures and the tools, reveal that students appreciated the structure and organization of the course. Opinions varied strongly on the use of digital tools as well as the structuring of electronic learning environments. This is understandable as the online lectures were simply clipped from videos of live lectures (collegerama) and were no high quality videos filmed specifically for this course. One student found the availability of study materials or feedback on the assignments not to be timely. This is difficult to explain as grading the assignments promptly formed a focal point of the teaching of the course (Figure 6).

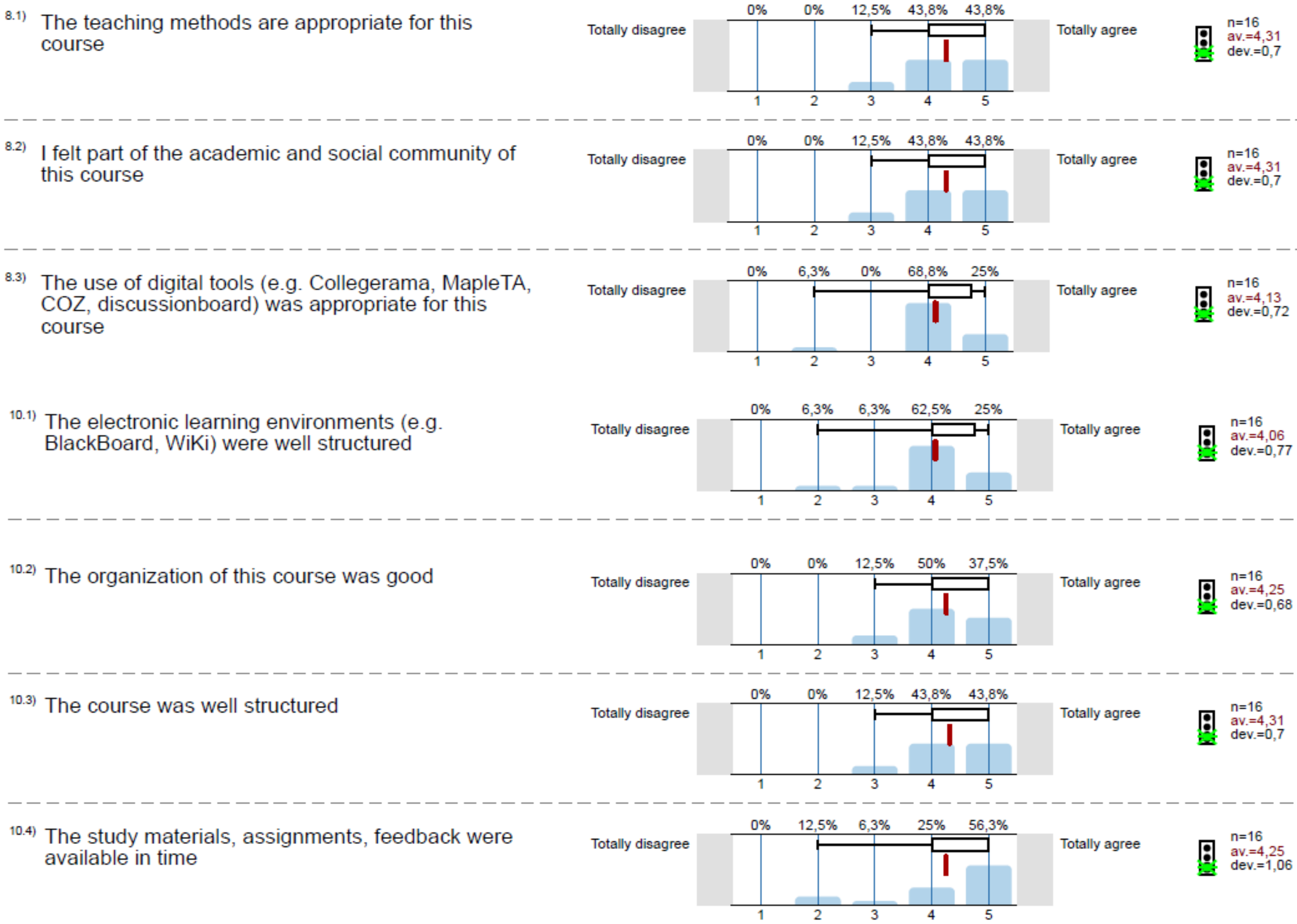

Figure 6: Student evaluations of the teaching methods, i.e. the flipped classroom, the guest lectures and the digital tools organization of the course, including the course structure and the study materials

Clarity regarding the assignments and how they would be assessed was not achieved for all students (Figure 7). However, the assessment methods (the assignment) were considered suitable for the course structure. Respondents also indicated they studied regularly, which was an important course objective. The study load was considered consistent with the amount of credits the students received for the course.

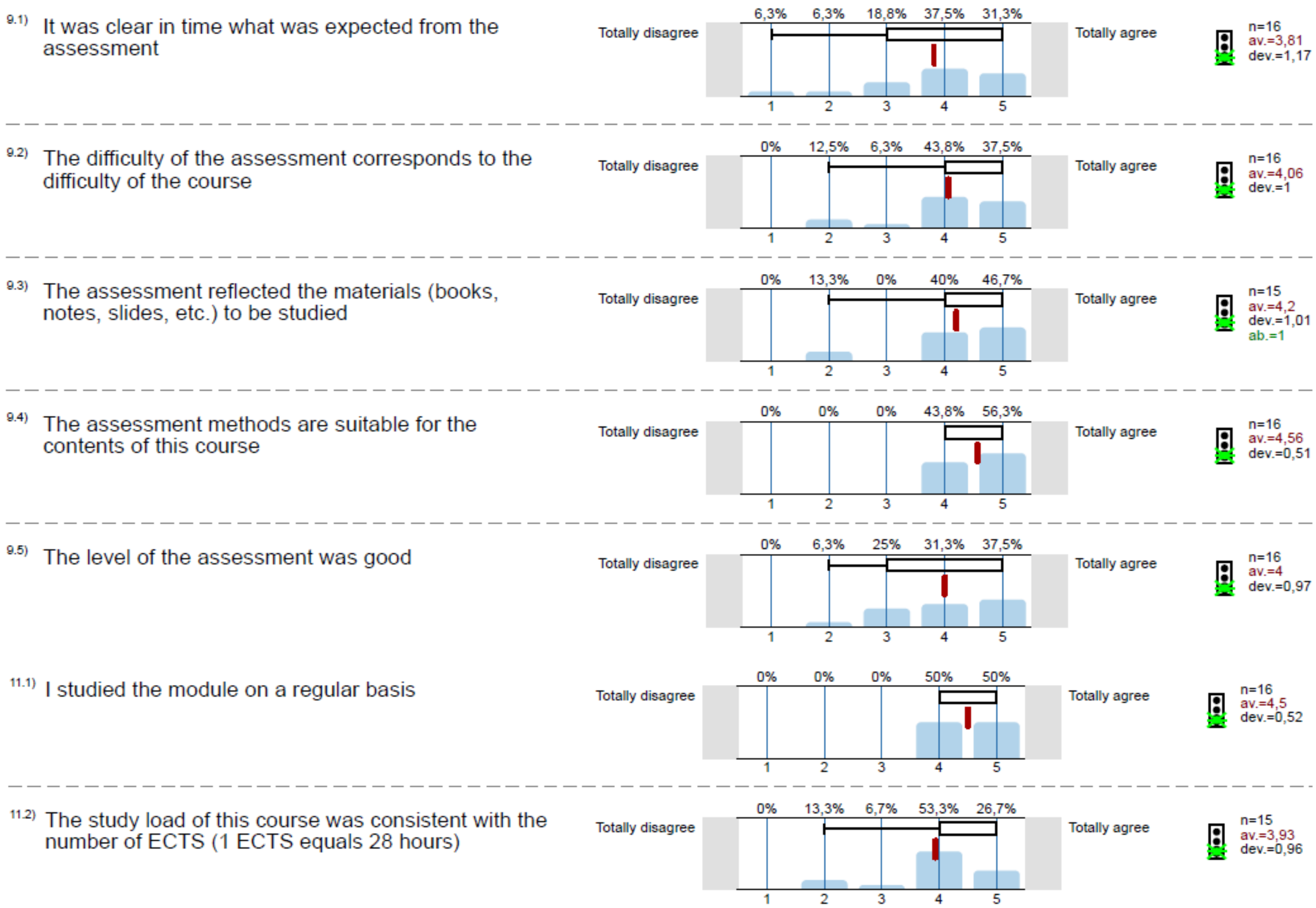

Figure 7: Student evaluations ofthe study load and assessment of the course

Student responses to the questions on the teaching style of individual and guest lecturers, as well as the coaching and feedback, varied between lecturers with scores ranging between 3 and 5. Overall, the students responded positively to the coaching and feedback, which is an essential aspect of teaching system dynamics modelling in flipped classroom mode (e.g. Figure 8). Because the study load was quite high and because of the interactive teaching format, teachers and teaching assistants made a point of being available to students for (emergency) questions, although students were encouraged to solve problems first among themselves. This is reflected in the (unanimously) high marks for teacher accessibility.

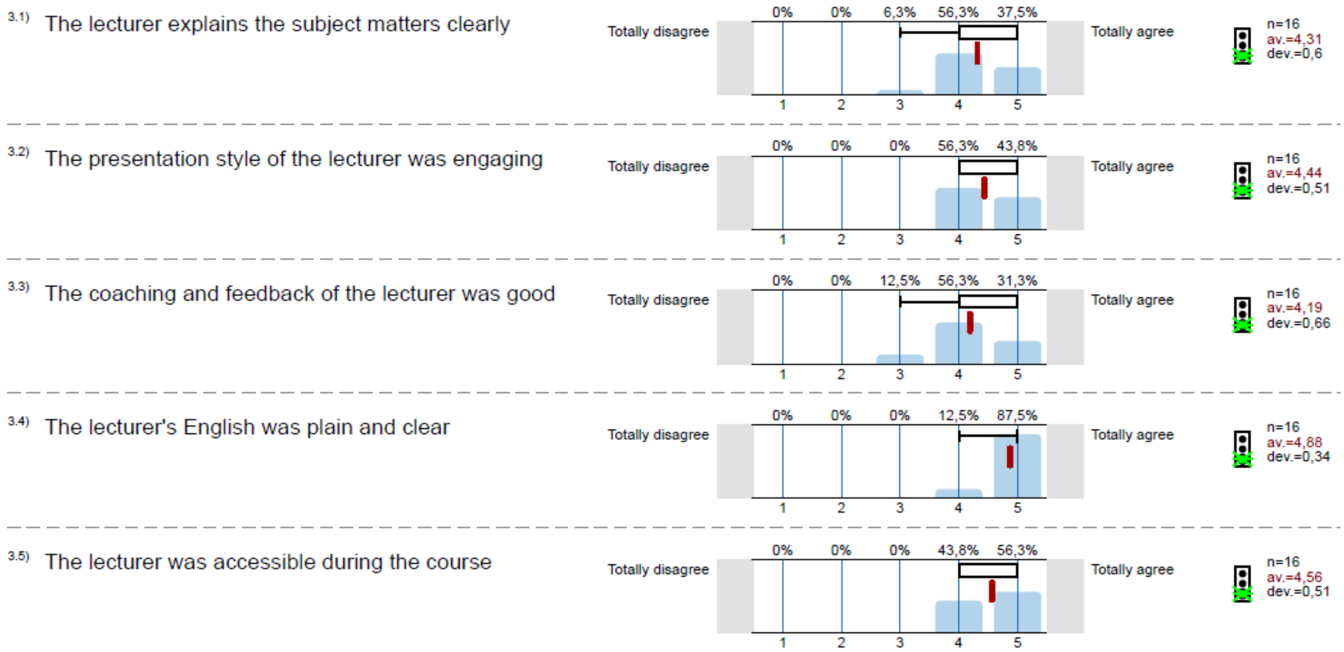

Figure 8: Student evaluations of the main lecturer's teaching style

The Advanced System Dynamics course was part of a specialization track within the master's program, with strict enrollment requirements. This may also have contributed to the high score on course coherence (Figure 9). The teachers and the course structure explicitly aimed to include the practicability of system dynamics modeling in the world within and outside academia. Guest lecturers explained how they used system dynamics in their profession. This may have contributed to the higher relevance of this course for the study programme.

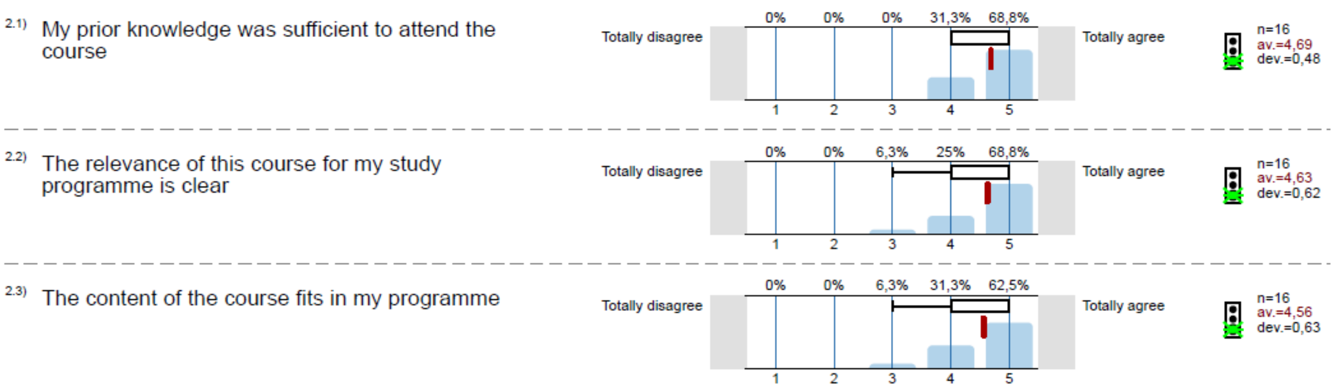

Figure 9: Student evaluations of the coherence of the course

In conclusion, the course was evaluated positively. The course structure and the teaching methods were experienced as appropriate in helping the students achieve the learning goals . The open ended questions in the next section shed further light on the experiences of the students.

5.2. Student responses to the open questions

The students answered two open questions (Tables 3 and 4). The regularity of the assignments, the tutorials and the ongoing supervision of the students throughout the course made it an intensive experience. Although several of the students re-iterated the challenging aspect of the assignments and the relatively heavy workload, most of the respondents agreed that although challenging, the level of the course was appropriate. The re-activation and subsequent deepening of the students' system dynamics skills (acquired in previous courses) was much appreciated. The attention that went to the application of system dynamics in practice was welcomed by some students, as some students were already planning the topic for their master theses or even their next career step. Other students did not appreciate this as much.

One student mentions the competitiveness of fellow-students when it came to sharing knowledge, or even closing their laptops. This was observed by the teachers and corrected. Additionally, the grading system was non-competitive, as grades were assigned independently of other students' results.

Finally, a student stated "Now I can look at the world from a new perspective" - hopefully one that incorporates dynamic feedbacks!

Table 3: Students' appreciation for the course components

Which parts of this course do you consider good?
Assessment in chunks (assignments) Different speakers Workgroups
I did like the tutorials, they are very helpful. Did like the guest lectures.
I loved the course, think it was a challenging and good elaboration on the System Dynamics skills we already had
Regular lectures and assignments
Several assignments and strict deadlines stimulated me to study on regular basis I am glad there was no examination
The assignments were very challenging and appropriate for the course. The fact that we dealt with a real life problem made it very interesting.
The course setup was very suitable and created a strong learning curve. Preparing the lectures up front and receiving feed during the workshops was very helpful in finishing the assignments. The assignments covered a variety of topics, and were quite challenging, tough fun, which made the assignments quite pleasurable to work on. Also the guest lectures were nice to attend, since they provided clear insights in the application of SD in practice.
The course was challenging. I needed a lot of hours, but it was 4 ECTS in 7 weeks, so that was fine. I really liked (most of) the guest lectures, although they were not necessary to pass the assignments. [the module managers and main teachers] are both very enthusiastic when they are teaching, so as a student it is easy to get enthusiast as well. The gaming assignment was the less informative, but really fun to do!
The extended use of SD and actually learning and applying of important steps in the image of the model
The mandatory assignments were very good and helped for putting theory into practise. Assignment 1 was ok (sic.) demanding, but the rest (2-5) could be more difficult. However, if difficulty increased, maybe the learning objective was undermined. The guest lectures were rather interesting (e.g. group modeling). The lecturers helped a lot in the tutorial sessions and were clear on their answers!
All of lecturers were very friendly and provided cake + coffee to mitigate the late Friday lecture!
This course challenges me really. Now I can look at the world from a new perspective.

Fortunately, the respondents also suggested improvements for the future. Not all suggestions are feasible or accord with the learning objectives of the course. For instance, a "hands-on lecture" in the programming language "R" does not contribute to the understanding of system dynamics modelling as a whole. Also, there is not much the lecturers can do about course scheduling, even though they know that Friday afternoons are not popular time slots for most students.

On the other hand, new course design choices such as handing in a question in advance of the tutorials online were not unanimously perceived as positive by the students. Because of the indications that asking questions did have a positive effect on student engagement in the tutorials, we have chosen to retain this requirement in future.

One remark related to the impracticability of undertaking model behavioral analysis on their own model. However, an alternative suitable model was provided for that assignment, so that students are not limited in their learning by the specifics of their own models.

The competiveness that was noted by a respondent is detrimental to the learning objectives of the course and of the active learning style. The teachers observed and corrected this behavior in the second week of class. Either way, future set ups of a flipped classroom need to be sensitive to competitiveness amongst students while learning.

Table 4: Students' suggested improvements for the future

Which parts are less satisfactory and should be improved in the future?
Guest lectures were not that interesting. I'd rather have an extra lecture on data analysis (hands on lecture on R for example).
Having to post a question before the lectures
I think Assign. 5 on game design was a bit abstract and could be designed better. Playing the games was fun though. Maybe some tutorials could be provided on BB regarding how to work with EMA workbench or identification of patterns (BATS, see guest lecture).
It would be nice to have more time for the first and biggest assignments
Schedule the second lecture - Friday at 15:45 - another day if possible
The EMA workbench was impossible to install on our computers even though there was someone to help with that. ("Probably [a colleague] has changed something, I don't know why it doesn't work") EMA is often presented as the "holy grail" of our System Dynamics department, and it is supposed to be "very easy," but I have never heard any student use it successfully or even install it and that makes it a bit frustrating. Either provide full support for the use or leave it out of the program.
The guest lecturers did not seem to be well informed on our prior knowledge. Some of them started to explain very basic things, which made the guest lectures a lot less interesting. The workload on the first two weeks was really high. It might be considered to stretch the model building and validation a week longer and let the course end in the 8th week.
The model we created was nice and worked very well, but was not suitable for all of the assignments. It lacked some dynamic behaviour to do the Model Behavior Analyses as well as we wanted to. I think that more groups struggled with this problem. It might be useful to make a standard model for this test which every group can (or have to) use.
The working load of the first two weeks was quite high. Also the other assignments were quite demanding. The working load of the course more resembles 6 ECTS than 4. The assignments were very good and 'learningful' (sic.) tough. They definitely should be maintained in this course in the years to come. Afterwards I am very glad I took this course.
There was a sense of competition among students during working classes. When asking for help others would sometimes close their laptops for example. In other words: I did not experience a lot of learning from others (except from my teammate).
Group making could be better, I had problem to make a group, and I did it alone!
Watching the lectures on collegerama (online) works well, however it is still harder to get completely hold of the content (can't directly ask questions to the teacher), even though you can ask questions on the discussion board. Feels like there might be to many different topics in the course. Having fewer topics more in detail would lead to a better understanding of the content.

6 IN CONCLUSION

Overall the class has been highly successful. However, improvements are always possible. The biggest challenge for the teachers lies in completing the grading in time for the students to learn and improve on their mistakes. However, reports documenting the model and its analytical use tend to be long. Limiting the number of pages further can reduce quality and prevent the students from doing a thorough job, whereas we are aiming for subject mastery. But with a growing student population and a growing interest in simulation modelling courses, grading many modelling reports may not remain feasible for teachers. Considering different model documentation methods, or adding a student peer review assignment to lower the teacher's workload are potential solutions.

Further, we will need to persist in addressing the observed gaps in students' skills. As scholars in an interdisciplinary field, students are high level conceptual thinkers and are competent in the application of diverse methods and tools. However, students were not readily able to justify their choice of when to choose which modeling approach. This meta-level analytical skill requires further development and forms a topic of discussion within the faculty. Indeed, in a recent revision of an introductory level modelling class in another masters' program, the students receive instruction in multiple modelling methods, including System Dynamics, within one course.

Indeed, not all students saw the value of obligatory attendance of the guest lectures, supplied by practicing system dynamics in the Netherlands. We could consider taking a more blended learning approach and using online video material instead with students doing a small assignment to show they have taken cognizance of the material. However, not many guest lecturers would come to speak in a classroom with no attendees, but might be willing to video-record their talks, which could then increase the number of face to face teaching moments for the regular assignments.

Also, student satisfaction should remain monitored when flipping the classroom, as students were less satisfied with the teaching format than a more traditional approach. As outcomes of successful teaching approach should consider critical thinking, and improve student engagement within and outside the class (O'Flaherty & Phillips, 2015).

This paper indicates a number of positive student learning outcomes of flipping the classroom for graduate students with an interdisciplinary background. The learning objectives were met and all students competed the course knowing the possibilities and limitations of system dynamics modeling. Students were able to make an informed choice as to when to use System Dynamics, and to apply the theoretical knowledge on building, validating and communicating models in a problem situation. The flipped classroom, and related methodologies such as "hybrid" and "blended" learning allow instructors to deliver the application side where students struggle with real-world problems and see the modeling in context (Freeman, 2000). Apparently, there is limited evidence to support that the flipped learning approach is more effective than conventional teaching methods in general (O'Flaherty & Phillips, 2015). System dynamics modelling and other types of simulation modeling require a different educational approach than the traditional one. It would be fascinating to engage in a system dynamics specific study of this pedagogical approach.

However, as teachers, we were happy with the responses of the students, with their work and with their enthusiasm for simulation modelling in general, and system dynamics in particular. A number of students have continued their system dynamics education by undertaking a masters' theses on the subject. For others system dynamics remains an important component in their modelling repertoire.

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A ASSIGNMENT 1A : MODELLING KIRKWOOD'S WATER CRISIS

To give an idea of the level of complexity the students were dealing with, this section describes the case study as it was given to the students. The case study is based on a real life events in Greater Kirkwoord, South Africa, and is based on research previously presented at International System Dynamics Conferences in 2013 and 2014 (Clifford-Holmes et al., 2014; D'Hont et al., 2013).

A.1 Modelling Kirkwood's Water Crisis

The student is required to develop a model of the situation of ongoing crisis in Kirkwood in which demand for water services continues to grow, the water infrastructure cannot cope, and there are insufficient financial resources and technical capacity to address the problems adequately. The students' task is to show that the recent crisis in Kirkwood in which residents resorted to violent protest owing to failures in water service delivery, is symptomatic of these underlying problems.

Figure A1: Water from a communal tap in South Africa

Figure A2: Recent protests in Kirkwood over water service delivery failure

Background extract from d'Hont et al (2013): "Addressing stakeholder conflicts in rural South Africa using a water supply model":

"Following the apartheid era, the democratically-elected government of the Republic of South Africa undertook to ensure that all citizens had access to basic water services. This was a significant challenge given that the water resource and water services were no different from the other resources and services in South Africa, which were inequitably distributed across racial groups in a purposeful and designed manner. In particular, the technical supply of water services was primarily designed for the white minority. From 1996 onwards numerous changes at a national level resulted in a complete restructuring of water policy and legislative frameworks. The changes relevant to water services include: the Constitution of 1996, which positions access to water as a basic human right for all; the Water Services Act of 1997, which separates provision and regulation in a decentralised manner; the National Water Act of 1998, which legislates a basic human needs reserve that comes before all other allocations in the country, and the policy of free basic water, which was formalised in 2001.The Constitution differentiates three spheres of government, namely national, provincial and local government (Juta's Statutes Editors, 2010), with the responsibility for service delivery residing in the 'local government', or municipal, sphere. One of the service delivery duties of the local government is to ensure the provision of water and sanitation services to all users within a municipal jurisdiction. The Sundays River Valley Municipality (SRVM), located within the Lower Sundays River Valley sub-catchment, within the Eastern Cape province of the Republic of South Africa (Figure A3), is struggling with this task.

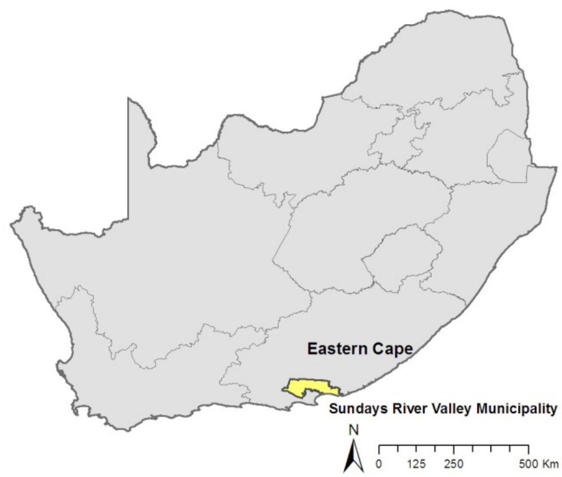


Figure A3: Location of the Sundays River Valley Municipality within South Africa (d'Hont et al 2013)

With no large urban settlement, and a combination of multiple small towns and commercial farming, the SRVM is a primarily rural or prototypical 'Category B3' municipality. As of 2009, 111 of the 278 municipalities in South Africa are classified in this category (World Bank, 2009: 10-11). As such, the SRVM does not stand alone in South Africa in its struggle with the provision of water and sanitation services to citizens living within the municipal boundaries. Nor is it alone in having to deal with contentious issues related to the historical design and operation of its water supply system."

A.2. Model related information

Population

Ten thousand people resided in Kirkwood in 2001 and forty thousand people lived in the surrounding Lower Sundays River Valley. The endogenous growth in population in the Lower Sundays River Valley (LSRV) is estimated at 1,2%. People move into the urban area of Kirkwood every year – both from rural areas and from other small towns in LSRV e.g. Paterson, Addo, Enon-Bersheba. The immigration rate to the urban area of Kirkwood is estimated to be 1,5% per annum. The emigration rate from Kirkwood is 1% per year. Of the total Kirkwood population, 3% moves into households that are not connected to the water supply system (i.e. they contribute to the ongoing growth in unconnected households). The average number of people per household is 3,9 (2001 SA census figure).

Water system

The goal of the water system is to have sufficient water to meet demands and to deliver to users the water they require. However, when there is insufficient water to meet demand, then the water system ideally delivers water to users in proportion to their demand. The water use per connected household is 347 k*l*/year whereas the annual average water use per unconnected household is 180 k*l*/year. Water is delivered to connected households, unconnected households (via communal pumps etc.) and to other urban users, whose use is about 50% of that of the current total household demand (i.e. connected and unconnected). The rate of connecting households to the service network is 8%/year. In 2001 there were about 700 households connected to the service network, and there were 1500 unconnected households.

Finances and infrastructure

The currency in South Africa is the South African Rand (international symbol ZAR, South African symbol R). The percentage of the municipality's income that is used for water infrastructure maintenance is 40% on average. The average annual maintenance cost per unit of capacity (Ml/year) is kZAR2,5. However, in reality the amount spent on maintenance each year is this money plus the annual financial bail-out that the municipality receives from the central government. This is currently kZAR 150 per annum. It is unclear if this financial bail-out will persist in the future. If this bail-out were to cease, the municipality will experience a financial crisis.

The average lifetime of the water infrastructure is 30 years (based on 5 classes of infrastructure assets in the depreciation table of the Amatola Water 2012 Annual Report), assuming that 8% of the infrastructure receives regular maintenance per year. In 2001, the infrastructural capacity for Kirkwood was 1825 Ml/year (approximately 5 Ml/day). The water that is produced by the aging infrastructure of Kirkwood, is produced by pushing the infrastructure over its design capacity; sometimes it exceeds the design capacity by as much as 30%. Continued over-extension of the infrastructure makes it age more quickly, increasing its obsolescence rate. It takes 5 years on average to refurbish or construct infrastructure, but it takes 1/10th of a year to acknowledge, or plan to address, the discrepancy in infrastructure. Not all water service delivery costs can be recovered, nor are all bills paid. There are substantial water losses due to leakage – with an average loss percentage of 30%. But, only about 40% of the costs of household service delivery can be recovered. 75% of other urban water users (shops, hospitality industry etc.) are billable. Revenue derived from water service provision is influenced by the percentage cost recovery, the volume of water supplied (and billable) and the unit charge (ZAR 1000 per Ml or ZAR 10/kl). It is diminished by the costs of maintenance and the annual budget reconciliation of the municipality. All money is used up by the municipality each year.

Service delivery crisis

The South African water law (1988) as specified in the DWA 2002 norms and standards (nr. 4) specifies that a basic amount of 10l/person/day must be supplied. In effect this means that the municipality should ship in water when service delivery ceases owing to infrastructure failure. One tanker load of water has a volume of 11k*l* .

The discrepancy between the water delivered to the users (unconnected, connected and other urban users) and their demand for water, determines how well the municipality is doing in meeting water demands. When there is a water service delivery crisis, the ratio of the total discrepancy to the total delivered water can be much greater than 1, driving the technical staff of the municipality to devote attention to the crisis and neglect primary activities (routine maintenance) or other secondary activities like refurbishment and infrastructure construction, or even planning. Under a crisis situation, the attention given to the crisis compared with other activities can attain ratios of 10:1.

Technical staff

In 2001 there were 10 technical staff in the service of the municipality. In addition the lack of sufficient technical staff means that they experience work pressure and so do not achieve the normal production rate per person per year of 20 Ml/year. When there are few staff compared with the staffing capacity required to undertake the work, there is a staffing crisis and the productivity can decrease almost to zero. When there are more staff than required the productivity per staff member can increase by up to 50%. The municipality hires one new technical staff member every two years and technical staff remain in the organization an average of 10 years

The activities of technical staff in relation to infrastructure are constrained by staff capacity or finances. When there is either a financial or technical constraint on primary and secondary activities then the attention is divided pro ratio between primary and secondary activities. In addition, the attention given to secondary activities is divided as follows:

- 25% of the available attention is given to long term and short term planning (recognition of the discrepancy between the current infrastructural capacity and the capacity that is necessary to meet anticipated demands)
- 75% of the available attention is given to infrastructure construction.

APPENDIX B: ASSIGNMENT 1B – DATA AND VALIDATION

1. Generate three data series, each having 150 data points, using the following functions;
    - f(t)= 40+SIN(t/5)*50+5*t
    - g(t)= 55+SIN(90+t/5)*30+5*t
    - h(t)= 10+6*t
    -
    - Assume that data series generated by f(t) represents measured data from a real system, and that the data series g(t) and h(t) are model-generated outputs. Without using the formulae above in your argumentation, discuss the behavioral validity of the model-generated data based on quantitative evidence. Please refer to the behavior reproduction tests in Sterman's chapter on validation (see Reading Material on Model Building, Data and Validation on Blackboard).
    -
2. Justify your formulation of a LOOKUP function in the Kirkwood water crisis model. Please refer to the theory (and additional) material on table functions.
    -
3. Validate your Kirkwood water crisis model using three different types of validation test excluding sensitivity analysis (this is the subject of assignment 3). For instance, you could use extreme value analysis or behavior pattern tests, amongst others.
    -
    -

It is the intention that the model documentation of assignment 1a, together with the answers to questions 2 and 3 (above) of assignment 1b, provide a full documentation of a validated Kirkwood water crisis model. The model boundary, assumptions, reference run (demonstrating the current crisis), are documented and the behavior modes of the model are validated as far as possible. Particular choices of functions such as delays, pulses etc. are justified if they are used.

APPENDIX C: ASSIGNMENT 2 - SENSITIVITY ANALYSIS

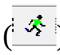
This exercise is part of the assignment 2 for the students, and was based on Eker et al. (2014), and also part of a Model Analysis Workshop "Sensitivity Analysis of Graphical Functions" at the32nd International System Dynamics Conference, 24 July 2014, Delft.

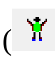
Exercise 3: application on a modified s-i-r model

1. Open the Vensim file named *Exercise 3.mdl*, which includes
   - a simple version of the SIR model with an alternative *Infection Rate* formulation where

     $$Infection\ Rate = Susceptible\ Population * f\left(\frac{Infected\ Population}{Total\ Population}\right)$$

     and *f* is a table function.
   - a single-triangular distortion function already implemented as *Distortion Function h*.

2. Simulate the model () and see the base run behaviour of the *Infected Population* (select *Infected Population* with  and click on ). Since parameter *m* is set to 0, the original table function is used in this simulation.

3. Click on *Start Sensitivity Simulation* () and open the *Sensitivity Simulation Setup* window.

4. Select parameters *m* and *p* as active parameters to be varied in the sensitivity simulations and assign ranges to them. Set the *Number of Simulations* to a number you wish, and select *Multivariate* as the sampling option. Click on *Next* and select *Infected Population* as the outcomes variable to be displayed in the sensitivity results. Click on *Finish* to run the simulations.

5. If you would like to see the results of each simulation individually, right click on the *Sensitivity Graph* () and select "Individual traces" as the display option. On the model view, select *Infected Population* and left click on the *Sensitivity Graph* to see the sensitivity of the *Infected Population* to the table function.

APPENDIX D: ASSIGNMENT 4 – EXPLORATORY MODEL ANALYSIS

Question 1

Analyze the model you have built carefully or choose to use the 2-area epidemic model supplied. What are the main uncertain factors (7 to 15 factors) in this model? What are justifiable ranges/values for these factors? Use the sensitivity analysis tools in Vensim to explore the behavior of your model over these ranges. Analyze the results and discuss the policy implications of your findings.

In your write up of the assignment, clarify which uncertain factors you have chosen and why, what ranges you have used and why, motivate your sampling technique, and your analysis of the results. The write up should be such that your analysis can be replicated by me, in theory.

Tips:

- You can export the data from the sensitivity analysis to tab separated or comma separated files for further analysis. Read the Vensim manual for details
- Many of the discussed techniques (PRIM, CART) are available in open source implementations. You could even use the code of the exploratory modeling workbench if desired.
- Ranges should be plausible and grounded in information.
- Reference the theory material.