Reply to reviewer 1 "Learning about water resource sharing through game play" by T. Ewen and J. Seibert

Reply to RC1: M. Jones (Referee)
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RC1 comment 1: The paper documents a range of games available and how one particular game, Irrigana, appears to be developing as a learning platform. The sample size on which the analysis is based is small and further analysis would be useful in future to support the conclusions drawn.

AC1 reply: Thank you for this helpful comment. We agree and plan to continue collecting feedback from Irrigania users in the future in order to increase the sample size, and support the conclusions drawn in this paper.

RC1 comment 2: To provide more context for those unfamiliar with Irrigana, it would be useful to provide example input scenarios, decisions and outcomes, preferably visualised, to help the reader appreciate more fully the value and potential of the game.

AC1 reply: We had discussed whether to put in specific game scenarios from Irrigania, but decided that including a reference to the original paper by Seibert and Vis was likely sufficient. Given this helpful comment, we have included two scenarios with game decisions and outcomes in the revised manuscript (Table 1) to help the reader better understand how the game is played, and potential scenario outcomes.

RC1 comment 3: More importantly, to support the evaluation of game play benefits, it would be useful to include the survey questionnaire used. Similarly, including the survey results as a table would be useful to clarify the description of the evaluation.

AC1 reply: We weren't sure on the format for including both the questions and responses from the survey and agree that this could be improved. As suggested by the reviewer, we have included Table A1 (Appendix) in the revised manuscript with the survey questions and summary of survey results.

RC1 comment 4: The paper also presents an evaluation of the benefits to learning about water resource sharing derived from developing games. This element of the paper needs to reviewed; the paper would be improved if it identified the specific points of student learning on water resource sharing that have been derived from developing new games.

AC1 reply: We thank you for this helpful comment. In the paper, we briefly discuss (in the "Discussion and Conclusions" section) what types of learning the students gained from their game development, including: soft skills, critical thinking, problem solving, team work and time management. We agree with the reviewer that these points could be further discussed in the paper. We have now added more text into the Discussion and Conclusions section where learning outcomes in both game play and development are discussed and relevant literature cited.

RC1 specific comment 5: Section 2, Irrigania as a teaching tool Page 2, Line 25 - The text notes that Irrigana assumes "...cost of groundwater increases with increasing depth to groundwater." It would be useful to understand the basis on which this depth increases, presumably the amount and duration of pumping. In this context, it would also be useful to understand how any interactions between groundwater rivers are represented. These points may be covered by Siebert Vis, but a brief comment here would help appreciate the conceptual hydrological system represented in Irrigana and therefore, to what scenarios the game can be applied.

AC1 reply: The cost per field of irrigating with groundwater is given by: $g < 8 : 20$ $g \geq 8 : 20 + (g-8)^2$, where g is the depth to groundwater (in arbitrary units) and dependent upon the amount of precipitation during a given year (determined by a "precipitation indicator" where a normal year = 1; a dry year = 0; and a wet year = 2) as well as the number of fields irrigated with groundwater. In contrast, the cost of irrigating with river water is fixed at 20, but the revenue depends on the precipitation indicator(0;1;2), the number of fields irrigated with river water, and the number of farmers in the village. This is described in detail in Seibert and Vis, and we have now include a short description of this in Section 2 (page 3, lines 23-27) so the reader can better understand outcomes of different scenarios between different resources used.

RC1 specific comment 6: Page 2, Line 26 - The text states maximising income is the goal of the game, while previously revenue is mentioned. To improve clarity it would worth being specific that the income is net of farmer costs, if this is the case, and differs from revenue.

AC1 reply: This is a very good point, and see that we've used the two words interchangeably. To improve clarity we have now specified that income is net of farmer costs, and differs from revenue (page 3, line 29).

RC1 specific comment 7:
Section 2.1, A survey of using Irrigania: Although there were few respondents to the survey, it would be useful to understand where all of the Irrigana users were based, whether they responded or not. This would provide extra information on the geographical spread or restricted distribution of responses and so the international penetration of Irrigana as a learning tool.

AC1 reply: We have added this information into a summary of the survey in Table A1 (Appendix).

RC1 specific comment 8:
It is important to include the survey questionnaire used to underpin the results presnted and conclusions drawn. Although this may take up a significant amount

of space, it would be useful as the questioning is multi-stage and not simple to follow with a text- only description. It would help as well to present the survey results as a table, including the number of respondents at each stage of the questioning. This should help make the results more accessible to the reader and enable an appreciation of the confidence in the conclusions that have been drawn. This would also help the explanation of results on
page 4 line 17-18 and on page 5 line 21-28.

AC1 reply: We have included this information into Table A1 (Appendix).

RC1 specific comment 9:
The use of brackets rather than commas can be a matter of personal preference, but in Section 2.1 this results in parts of the text being awkward to read. A particular example to address is on Page 4, Line 16 where nested brackets are used, but are incomplete. To aid the reader, I'd suggest that this and other sentences be reworded to allow many of the brackets to be removed.

AC1 reply: Thank you for this comment, we have reformulated this sentence and removed brackets to make this more readable, and have read through and tried to remove unnecessary brackets throughout.

RC1 specific comment 10:
Section 3 Page 6, Line 12, reference to Figure 1 - Suggest spiltting Figure 1 left and Figure 1 right into separate figures. This would help enable an explanation/translation of the German text labelling to be included. Unfortunately, the text is inaccessible for those unfamiliar with German.

AC1 reply: We agree and we have now split these figures (now Figs 1,2) and have included the translation of the German text in the caption for (the current) Figure 1 left.

RC1 specific comment 11:
Page 6, Line 13, reference to Figure 2 - It is useful to have Figure 2 included to illustrate game development, but referencing of Figure 2 left (Line 21) and Figure 2 right (Page 7, Line 1) needs to be clarified. For example, it's unclear if there should be a reference to Figure 2 middle and if so, it's very unclear what Figure 2 left actually illustrates and what it adds to the documentation of game development.

AC1 reply: Thank you for noticing this. The figure numbers are incorrect in the text and the references should be to Figure 1 left and right and not Figure 2 left and right. We have now separated these figures to make the text clearer (now Figs 2, 3).

RC1 specific comment 12:
Page 6, Line 25, reference to Figure 3 - Including an explanation/translation of the German labelling would help understanding of the Wiapuna game.

AC1 reply: We agree have now included a translation of the German text in the figure (new Fig 3).

RC1 specific comment 13:
Page 7, Line 12, reference to Table 1 - Column headers include Price/year and Yield/year, but the units for price and yield are no specified. If the intention is that they are dimensionless and illustrative in the context of the game, then this needs to be clarified.

AC1 reply: These values are given in arbitrary monetary units, and have added this to the caption in Table 2.

RC1 specific comment 14:
Section 3.1, Evaluation of learning outcomes The key messages from game development seem to relate mainly to insufficient time, planning challenges and need for re-timetabling of other course modules. This is interesting, but the evaluation would benefit from documenting more substance on the value and benefits to learning about water resource sharing derived from the games developed. In this context, the conclusions on the game development state that the "students had to think through the intricacies and complexity of water resource sharing, as they thought through players' moves and water resource outcomes", but there is no detail on what these intricacies and complexity were. This is in contrast to the learning experiences from using Irrigana noted in Section 2.1, which at least highlights that the learning has been that "cooperative behavior and communication were both key to succeeding".

AC1 reply: Thank you for this helpful comment. We have now added more text into the Discussion and Conclusions section to elaborate upon the learning outcomes from game development, and to tie together with learning outcomes from game play (see also reply to RC1 comment 4). You can find the added text on pages 10-11, with relevant references.

RC1 specific comment 15:
It would improve the paper's contribution if it identified the specific points of learning on water resource sharing that have been derived from developing the games.

AC1 reply: Yes, we agree and have added more discussion on this (please see replies to comments 4, 14).

RC1 technical correction 16:
Page 1, Line 23 - Reference to Johnson, 2012 should either be Johnson et al. or the paper is missing from the reference list.

AC1 reply: Yes, this is incorrect and should refer to Johnson et al. (2012). We have corrected this in the text.

RC1 technical correction 17:

Page 2, Line 20 - To improve clarity, suggest rewording as follows, ".... role of cooperation in, and competition for the use of water as a limited common-pool resource"

AC1 reply: Thank you, this has been reworded.

RC1 technical correction 18:
Page 3, Line 15 - Reference should read Lecoutere et al. (2015)

AC1 reply: Thank you for noticing this, it has been corrected.

RC1 technical correction 19:
Page 5, Line 21 - Rewording suggested as follows "Additional analysis was carried out considering user data collected since July 2013, when user histories began to be saved; this excluded data collected during our own use of Irrigana. This was done to further analyse how ......"

AC1 reply: We have reworded the sentence for clarity.

RC1 technical correction 20:
Page 7, Line 7 - Insert "a" as follows, ".....Heins (1994), as a way to show.."

AC1 reply: Thank you for noticing, we have corrected this.

We would like to thank Michael Jones for his very careful review of our paper and his valuable comments. By including his more substantial comments on the irrigania questionnaire, and further clarifying the learning outcomes, we feel that our manuscript has been substantially improved.

Reply to reviewer 2 on "Learning about water resource sharing through game play" by T. Ewen and J. Seibert

Reply to RC2: Anonymous Referee #2
Received and published: 13 June 2016

RC2 comments:
The paper presents an interesting and innovative learning tool to understand resource management and use. The manuscript begins with a review of a range of games available but no critical input is provided as to what the limitations are of the reviewed examples and why the new game presented is different. No important contribution is put forward as to 'what is the new aspect this new game provides that hasn't been provided already by the other games?' the review is therefore short of analytical substance and would require more work in order to identify gaps in the current knowledge and use of these types of games and how the new game presented is different and ultimately better?

AC2 reply: We thank the reviewer for this helpful comment. We have now included more literature in the introduction to help identify the gaps in the current literature regarding other types of games that are currently used for teaching about water resource sharing. We hope this helps to better compare Irrigania with the other games, and allow the strengths of Irrigania to be better identified.

RC2 comment:
The manuscript lacks a proper discussion of the implications of the use and results of the game once it has been played.

AC2 reply: This is a very helpful comment. In the text we wrote that "cooperative behavior and communication were both key to succeeding", which was actually based on feedback from teachers who had discussed the outcomes with their classes after the students played. In some cases, students played on more than one occasion, and usually students notice that these factors (cooperative behavior and communication) are key to succeeding and so approach the next game with this in mind (and thus usually change their strategy based on this outcome). We have now tried to make these "implications of the use and results of the game" more clear in the text, and have added text to the Discussion and Conclusions section on pages 10 and 11.

RC2 comment:
The manuscript should include a section on implications for management, and a discussion as to how these results are relevant in the real world?

AC2 reply: Thank you for this helpful comment. We have now included some text (see reply to RC2 comment above), supported by relevant literature, which helps to support how the learning outcomes from both playing and developing games might be carried over from the classroom into the workplace.

RC2 comment:
How can managers/practitioners learn from this new knowledge and advance groundwater management? What should be the lessons and messages to take home with that?

AC2 reply:
Although we refer to the fact that Irrigania may be useful for water resource managers, we don't currently have any feedback from this user group to (we feel) support any further comments on this. We have however commented on this in the text as regards to student learning in the classroom, and how this learning in the classroom setting may be relevant for these students in further careers in water management (see replies to RC2 above). The new text can be found on pages 10,11.

RC2 comment:
The scope of the manuscript is therefore limited to the 'classroom' and doesn't do much to advance 'further and wider knowledge' on groundwater management. The manuscript therefore lacks 'vision' and would require re-

thinking as to the real lessons to be drawn from the work that is presented.

AC2 reply: Although the scope of our manuscript is indeed clearly focused on "classroom" aspects, we believe that learning about groudwater management starts in the classroom -- it is in the classroom where future water resource managers are trained, and think that this learning does get carried forward. It would be nice to have some feedback/data from water resource managers and practitioners to further identify real lessons. Although our data is currently limited to teaching about water resource sharing in the classroom, we strongly believe that there is value in this information to better improve our educational programs and training in water resource management. We do however agree with this comment insofar as we could try to connect our findings with how they might feed into real world lessons. We have added some text to address this in the discussion (pages 10,11, see also replies above).

RC2 comment:
Further details on the data used (as suggested by the other reviewer) in the form of a table with descriptive statistics of the results would be interesting to have.

AC2 reply: Thank you for this comment. We agree and have added a summary table of the survey (Table A1), also according to RC1's comments (and outlined in replies to RC1 comments 3, 8). We hope this will help to clarify and better explain the results, and improve the readability of the manuscript.

We would like to thank reviewer #2 for all the helpful comments and questions. Although we would like to be able to better address the questions related to "vison" and real lessons in water resource management, our current study (and data) is limited to the classroom. We have however tried to add discussion into the final section to address these points, as they are relevant and would be very interesting to pursue as a follow-up to this study.

Summary list of all relevant changes to the manuscript:

- Abstract: added findings and results, lines 16,17, 18-20
- Section 1: corrected citation Johnson et al., 2012 page 1, line 25
- Section 1, page 2, lines 6-15, 18-35: added a more critical appraisal of current literature on game play for water resource sharing (with relevant literature), to make clearer in what ways Irrigania is a good tool for teaching about water resource sharing and advances this. Revision to support comments by the editor (Iain Stewart) and RC2.
- Section 2, page 3, lines 24-27: added description of cost/revenue to irrigate with groundwater/rain water as revision to RC1 comment 5.
- Section 2, page 3, line 29: explanation of income (net of farmer revenue and costs), RC1 comment 6
- page 4, lines 4-14; 19-27, text added to explain two scenarios of game play added in Table 1, RC1 comment 2
- page 5, line 2, added brackets to Lecoutere et al. (2015) ref, RC1 technical correction.
- page 5, line 11, added reference to Table A1, summary of survey results, RC1&RC2 comments
- page 7, lines 6-7 reworded sentence for clarity, RC1 comment technical correction
- page 8, line 35, removed German text as it's now added in Table/Figure as English translation
- Section title 3.1, "Evaluation of learning outcomes" changed to "Evaluation of "Water Games" course. Discussion of learning outcomes has been added to Section 4, so we have changed the title to better reflect the text in this section.
- page 10, line 26-page 11 line 4, continued page 11 lines 14-24, text added with discussion of learning outcomes of playing and developing games, and broader reaching effects of taking lessons from the classroom to the workplace, RC1 comments 4,14, editors comments.
- page 11, last sentence, removed as it no longer fit with new text.
- modified Figure/Table numbers accordingly in main text
- references added: Burton 1989; Burton 1994; Corrigan et al., 2015; Hummel et al., 2010; Jones 2011; Madani 2010; Magombeyi et al., 2008; Medema et al., 2016; Ruben 1999; Wouters et al., 2009.
- Figure 1 added, to show the interface of Irrigania game play, RC1 comment 2
- Figure 2, 3 now split, RC1 comment
- Figure 3, have added English translation of German text to figure
- Figure 4, added English translation of German text on boards to caption
- Figure 5, added English translation of German
- Table 1 added to show two Irrigania scenarios
- Table 2, added "units" for price, RC1 comment
- Appendix, Table A1 added with summary of Irrigania survey results, RC1, RC2 comments

Learning about water resource sharing through game play

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Abstract. Games are an optimal way to teach about water resource sharing, as they allow real-world scenarios to be enacted. Both students and professionals learning about water resource management can benefit from playing games, through the process of understanding both the complexity of sharing of resources between different groups and decision outcomes. Here we address how games can be used to teach about water resource sharing, through both playing and developing water games. An evaluation of using the web-based game *Irrigania* in the classroom setting, supported by feedback from several educators who have used *Irrigania* to teach about the sustainable use of water resources, and decision making, at university and high school levels, finds *Irrigania* to be an effective and easy tool to incorporate into curriculum. The development of two water games in a course for master students in geography is also presented as a way to teach and communicate about water resource sharing. Through game development, students learned soft skills, including critical thinking, problem solving, team work and time management, and overall the process was found to be an effective way to learn about water resource decision outcomes. This paper concludes with a discussion of learning outcomes from both playing and developing water games.

1 Introduction

One of the best ways to engage students and instill enthusiasm for hydrology is to expose them to hands-on learning. Using (serious) games in the classroom can engage students, and inspire enthusiasm, while also helping to solidify formal concepts learned in standard curriculum. Learning through games has been shown to increase soft skills, such as critical thinking, creative problem solving, and teamwork (Johnson et al., 2012), skills that are important for future water resource managers. When teaching hydrological concepts, and especially in the context of water resource sharing, where compromises between different interest groups need to be made and conflicts sometimes arise, games can be a good tool to enact different real-world scenarios. Learning through game play can thus be instructive in showing the complexity involved in the management of water resources, for both students and professionals alike (Douven et al., 2012; Rajabu, 2007). The active participation in mock decision making, through to the outcomes of those decisions using games, also allows different learning goals, including critical thinking and problem solving, to be better realized (Wu et al., 2012).

There are several games that focus on water resources, many of which have been used and tested at various levels in educational settings. Some examples include: *Aqua Republica* (aquarepublica.com), an on-line game aimed at promoting sustainable water resource management under growing water demand and scarcity; the *World Water Game* (Deltares, 2015), where the player decides on measures to avoid water shortages in different regions of the world; and *Water: more than just a game*, from the Swiss Federal Office for the Environment (FOEN, 2015), where the player can take different water management actions for a city and rural areas along a stream reach. These types of games focus on the player as a single actor, playing to optimize prosperity for the entire society or system. Although single actor games can have a high degree of realism by trying to simulate a real system as much as possible (Medema et al., 2016), the game can become overly complex, making it more difficult to understand and less attractive in educational settings (Jones, 2011). Although there can be a high degree of realism in simulating the system, the idea of an individual actor is fundamentally unrealistic; in reality there are almost always many actors involved in water resource decisions. Multi-player, role-playing games, in contrast to single player games, allow different actors to interact, and are inherently more realistic as they provoke social learning and collaborative task activity (Hummel et al., 2010), and can thus be very useful in learning about water resource sharing in educational settings. Role-playing games may or may not have limited decision options that are evaluated in a quantitative way. Examples of role-playing games with a focus on water resource sharing where players have limited decision options include board games like the *River Basin Game* and *Globalization of Water Management* (Hoekstra, 2012), that demonstrate issues related to sharing a common resource in an up- and downstream setting, incorporating the concepts of a water footprint and virtual water trade. Other role-playing games based on negotiations between different players include the Irrigation Management Game (Burton, 1989, 1994) and the River Basin Game (Magombeyi et al., 2008). In a recent review that explores using serious games for social learning and stakeholder collaboration in transboundary watershed management, Medema et al., (2016) found that serious games, including multi-player, role-playing games, provide a promising learning platform for developing partnerships and networks, and help to increase interaction and communication between diverse stakeholder groups. Role-playing games allow players to better understand different player (stakeholder) interests and perspectives, and player dynamics, leading to specific decision outcomes. Medema et al. (2016) summarize different characteristics of serious games that lead to success in supporting social learning and stakeholder collaborations. Among these characteristics, the degree of realism is important, but the multi-player, role-playing aspects are critical in exploring the dynamics and uncertainties involved in water resource sharing over a transboundary watershed, and ultimately lead to a better understanding of how optimal outcomes can be achieved with competing interests.

Building on the idea of better understanding multi-stakeholder decisions and how stakeholders reach an outcome (and not necessarily the optimal one), Madani (2010) suggested that game theory provides a suitable framework to study the behavior and decisions of stakeholders in water resource systems. Unlike conventional systems engineering methods which typically apply optimization methods, game theory offers a more realistic approach to studying water resource systems since people inherently have different interests, and do not always act with the best system-wide outcome in mind, which conventional methods might assume (Madani, 2010). Drawing on this, Seibert and Vis (2012) developed a web-based, multi-player game, which illustrates game theoretical aspects, called *Irrigania*, to teach about water resource sharing between several actors (or farmers) in educational settings. In *Irrigania* players act as farmers living in a village and decide how to irrigate their fields over several years, and are thus presented with water sharing situations with other farmers that are typical in real-world water-related conflicts. This game is simple in its rules, and there are few options for making decisions, which means that game outcomes can be more easily understood by students, making it a useful addition to a course on water resource management.

In the following, we address how effective games are in teaching about water resource sharing to different educational levels, through both game play and game development. An evaluation of *Irrigania* in the classroom setting is first presented, supported by feedback from several educators who have used *Irrigania* for teaching about water resource conflicts at both university and high school levels. We then discuss our experiences, together with student feedback, from a course on water games that we facilitated for masters students in geography, where students developed a board and computer game, to be used in secondary school classrooms.

2 *Irrigania* as a teaching tool

Since its inception, *Irrigania* (Seibert and Vis, 2012) has been used in different classroom settings and as an outreach tool, to teach about water resource sharing and to explore the role of cooperation in, and competition for the use of water as a limited common-pool resource (Seibert and Vis, 2012; Pierce and Madani, 2013; Cuadrado et al., 2014). The game is played between villages made up of several farmers (usually 4-6 famers per village). Each farmer has 10 fields and they can choose to irrigate the fields with a combination of rain water, river water or groundwater. Each irrigation source has a certain cost and revenue associated with it. Rain water and river water both have a fixed cost, while the revenue for river water depends on the number of farmers using it. For groundwater, the revenue is fixed, but the cost of groundwater increases with increasing depth to groundwater, where for $g < 8$: 20 and for $g \geq 8$: $20 + (g-8)^2$, where g is the depth to groundwater (in arbitrary units) and dependent upon the amount of precipitation during a given year (determined by a "precipitation indicator" where a normal year = 1; a dry year = 0; and a wet year = 2) as well as the number of fields irrigated with groundwater. In contrast, the cost of irrigating with river water is fixed at 20, but the revenue depends on the precipitation indicator (0;1;2), the number of fields irrigated with river water, and the number of farmers in the village.

The goal of the game is for each farmer to maximize his/her individual income (net of farmer revenue and costs), which to some degree requires considering the total village income. The game is usually played several times with different levels of communication and cooperation during play. Before play the moderator (teacher) sets the length of the game, rainfall conditions and whether or not communication between farmers and/or villages occurs (making the game either cooperative or non-cooperative), and whether users can see each other's input (information is shared). It is recommended that several rounds be played, and the settings adjusted so that different levels of information and cooperation can be explored. The game can also be played over several days, to give students more time to strategize and discuss results after a certain number of years have occurred, before continuing. The student enters the "farming decisions", i.e. the number of fields irrigated with groundwater and river water, and number of rainfed fields (for a total of 10 fields), through a simple interface (Fig. 1). The "economical status" with balance (annual income) and accumulated balance (accumulated income) of the farmer is shown, as well as the "current hydrological conditions", from which the current year's farming decisions can be based on. The student can also see when all the farmers have made their decisions at the bottom (either "submitted" or "irrigating"). Two game scenarios are shown in Table 1: the columns (from left to right) show the game scenario (Game 1, cooperative vs. Game 2, non-cooperative); the year (1-10) for the given round; the groundwater level at the start of each year (GW level); the farming decisions taken: how many fields are irrigated with groundwater (Irrigation GW); and river water (Irrigation River); and number of rainfed fields. The outcomes for each year follow including the income (net revenue and costs) for each year; the accumulated income for the round; and finally the accumulated income for the entire village.

After playing the game several times, patterns related to the amount of communication and information shared usually emerge (Seibert and Vis, 2012; Pierce and Madani, 2013). In a non-cooperative setting, where no information is shared (farmers are not allowed to discuss and don't see each others input), villages typically perform worse, whereas when full cooperation occurs, and each farmer knows who the other is, there is less selfishness, more cooperation between farmers, and this high amount of cooperation usually results in a high income for the village. This can be seen in Table 1 where two game scenarios are shown for farmer Susan from Raintown village. In Game 1 (top), a cooperative game, where players know who each farmer is, farmer Susan tends to irrigate moderately with both groundwater and river water over all years, reaches a high individual accumulated income, and her village wins with the highest accumulated village income (other villages not shown). Compared to Game 1, in Game 2 (bottom), a non-cooperative game, where players don't know who the other farmers are, farmer Susan tends to irrigate more heavily, reaches a moderate income, and has a lower overall income. The resulting groundwater (GW) level is much lower in Game 2 at the end of the round in year 10, where GW Level = 23, compared to 19 in Game 1, reflecting the overall tendency for players to act more selfishly in the non-cooperative game setting. Similar patterns were also found to emerge by others, e.g., Pierce and Madani (2013) who played *Irrigania* as part of a larger study to better understand decision making related to common pool resources. They showed that the most important factors to promote sustainable resource use were communication and cooperation, followed by trust, information disclosure and social learning.

When uncertainty is introduced in the weather in the *Irrigania* setting (i.e., random amount of rainfall), decisions become more difficult and differences between farmers in their risk taking also tends to emerge. Between the different water resources, there is also learning as players improve the more they play simply by better understanding the longer term effects of overuse in groundwater, compared to river water which, in the game, has no year-to-year memory. In a recent study on sharing common resources amoung farmers in Tanzania, Lecoutere et al. (2015), showed that gender and social status were also found to play a role; during times of water scarcity, high-status women shared fairly, whereas rich and powerful men were less worried about being greedy. Low social status (both men and women) tended to distribute water equally when it was abundant but were more selfish when water was scarce. These different outcomes and aspects that emerge when *Irrigania* is played with different scenarios and groups of players, make *Irrigania* a useful tool to both explore and understand the complexities of water resource sharing.

2.1. A survey of using *Irrigania*

To evaluate the effectiveness of *Irrigania* in teaching about water resource sharing, we carried out a survey, with an online questionnaire sent out to users (teachers) who had registered to use *Irrigania* (since 2012; 18 in total). We asked these users 15 questions in total and received feedback from 9 users (see Table A1, Appendix). We asked users questions ranging from basic information on how they have used the game in their classrooms, or as an outreach tool, and how they have incorporated playing the game into their curriculum. We then asked for details on the educational level of their class, the type of course it was used in and how many students played. As responses, teachers have used *Irrigania* mainly at university level, for both bachelor and graduate courses, with one exception of using it for a high school geography course with 30 students. It has mainly been used in courses with a water resources focus (including departments of hydrology, environmental engineering, and natural resources management). One group however, in the department of psychology, played it with students to better understand environmental decision making. Group sizes ranged from 20 students to 110.

This was followed by more detailed questions on the specifics of play (how many times they played with the same group, and with different groups, and duration of play). Although some groups played it only one time, most played it frequently, and some have incorporated it into their regular class curriculum. Most groups played it once during the semester in a block of 2-4 hours, but several also played it over several weeks, with up to one full semester for play.

Following the first set of questions, we asked more targeted questions to gauge the effectiveness of *Irrigania* in engaging students (whether the game held students' interest for the duration of play and how enthusiastic students were when playing the game). Teachers' responses depended strongly on the level of study. For bachelor classes that used it, most said that the game held the enthusiasm of the students for the full period, and that the students were quite enthusiastic about playing it. For the graduate level courses however, many said that a 3-hour period was sufficient, since after this amount of time, the students understood the mechanics of the game and some lost interest somewhat. For the high school students however, they wanted more graphics and visualizations to make it more interesting, and teachers commented that this would have likely held their attention for longer periods.

Questions to evaluate the effectiveness as a teaching tool were then asked, including how well *Irrigania* taught about collaboration and conflicts with regard to shared water resources and whether there was improved understanding of shared resources like surface/river and groundwater. All teachers (regardless of level) said that *Irrigania* was moderately (4 replies) to very successful (5 replies), when asked 'how successful' (not; moderately; very) in teaching about collaboration and conflicts with regard to shared water resources. When asked about whether they thought there was an improved understanding of shared resources like surface/river and groundwater, all answered that there was increased learning about shared water resources, but that a discussion session afterwards was key to solidifying the concepts learnt, especially for the high school and early level bachelor students.

Since *Irrigania* is based on game theory, but is also simple in its rules, it can be a good way to teach about game theoretical considerations related to water resource sharing (Seibert and Vis, 2012). As a follow-up after game play, we asked whether any interesting patterns had evolved and how much discussion the teachers incorporated into the process of playing the game (e.g., whether they had discussions on the topics before and/or after play). We then asked a few questions related to game theory including whether game theoretical considerations related to water resource sharing were discussed (before and/or after playing) and whether *Irrigania* was successful in teaching students (or other players) about the tragedy of the commons. Almost all teachers discussed game theoretical considerations related to water resource sharing briefly before play, but also in a final discussion after play, and this also helped to solidify learning concepts related to game theory. Almost all teachers also found that students understood, by the end of the session play, that cooperative behavior and communication were both key to succeeding. All teachers said that *Irrigania* was successful in teaching students about the tragedy of the commons and supporting discussion of these concepts (all answered 'yes' to this).

Additional questions were asked on whether the teacher had used other educational games, and differences they found in teaching aspects in these games compared to *Irrigania*. Four teachers used other games in the classrooms, and all said that in comparison, *Irrigania* was very easy to use and required little preparation before using it in the class, which made it appealing. In a final question, we asked for general feedback that teachers thought would be useful for evaluating *Irrigania* as an innovative tool for learning about water resource sharing and suggestions for improving the game. Several suggestions were given, e.g., for younger students (high school) it was suggested that it should be more game-like and visually engaging. University level students however seemed to find it engaging enough, but also suggested that a spatial interface be developed where villages could be represented visually. It was also suggested that more game settings would make it more interesting, allowing students to explore more scenarios and play longer, for e.g., by setting different amounts of water from different sources and having rewards or punishments for level of sharing. Two teachers recommended that a more flexible groundwater level evaluation be implemented by allowing the game to be played with different amounts of available water to start. Another commented that allowing the results to easily be exported would be an advantage for follow-up discussion and analysis of game play.

Overall, the feedback from the survey was positive, and all teachers felt that *Irrigania* was a good tool for teaching about both shared water resources, and game theory. The results highlight that the use of *Irrigania* for different levels of teaching is quite different, and that it seems to be best suited to higher bachelor level to master level courses where students were the most engaged, it held their interest for longer, and teachers had less comments for improvements for these groups.

Additional analysis was carried out considering user data collected since July 2013, when user histories began to be saved; this excluded data collected during our own use of *Irrigana*. This data included how often users played *Irrigania* (number of games played), how long their rounds were (average game length), and over what period of time they played. The number of games played varied from only one game (users 8,9) to 26 games played (user 10), with most users playing games with 10 years (the default setting), although user 10 played consistently shorter games, with an average of five years. For the game length, many users played over one day, but users 1 and 12 played over a 2 month period, and user 10 (with 26 games played), playing over the full period (July 2013 - present). This agrees with some of the user feedback from the online questionnaire, where many teachers had used it once during the semester in a block of 2-4 hours, and several also played it over several weeks, with up to one full semester for play.

3 Developing water games in the classroom

An 'Integrative Project' course within the master's program at the Department of Geography at the University of Zurich, is a six credit point course, corresponding to 180 working hours for the students, running over two semesters. This course has the aim of putting theory learned in the classroom into practice, and is led by different teachers or research groups within the geography department each year. In the "Integrative Project" course on "Water Games" (fall term 2014 and spring term 2015) five students, four female and one male, from the MSc program in geography participated. All students had German as a mother language and the class was taught partly in German and partly in English. In the following, we first present the course as well as the design and development of two games by students that participated in the course, followed by an evaluation of learning outcomes from the course.

A first goal of the course was for the students to carry out a survey of existing water-related games, including both computer and board games. These games were then played and both positive and negative aspects of each game were discussed, followed by an analysis of what makes a good game. Students also had a couple of lectures, with one on project management followed by two lectures on game theory, given by invited game theory experts, introducing students to game theory (which *Irrigania* is based on). The second part of the course focused on the development of their own games, first through brainstorming ideas for new games, and then forming groups. The students then developed two different games: a board game, *Wiapuna* (Figure 2, and a computer based game, *Habitat Ganges* (Figure 3) over a period of 6 months. Game development began with initial 'idea boards' (Figure 4) where students brainstormed possible game ideas, discussing aspects of each in class, and further in working group sessions, to narrow down their ideas. Most ideas built upon already existing games that the students had reviewed and played in the first part of the course. The games were then developed over three months of group work with students organizing their own group time together (including summer). During game development, students also tested (played) the games with a couple of smaller groups of their intended target audiences, to get feedback and make improvements. In a final three hour class, the games were played by the students in the class and other geographers in the department. Overall, the players enjoyed the games and comments for improvements or changes were discussed amongst the players.

Wiapuna: Wiapuna was developed as a multiplayer board game (Figure 2) for both family play or play in schools or as an outreach tool, for ages 10 and older. It is based on the topic of water resource scarcity, and could be incorporated into regular geography curriculum to supplement and enhance regular lectures. In Wiapuna, players build and develop settlements around four central wells (Figure 5), where water is supplied by buying water pipes, and shared between neighbors using the same well. Natural resources (copper, gravel, wood and food, Figure 5 right) are used to buy infrastructure. Water supply through wells is slowly depleted as more and larger houses are built around each well. New efficiency measures need to be implemented to reduce the amount of water use (e.g., through buying drip irrigation, harvesting rainwater for agriculture, and increasing efficiency in household appliances). An element of uncertainty is introduced into the game with natural events that include global and regional heavy rainfall, water poisoning, floods, droughts, tornados or storms. The board design is based on the well known *Settlers of Catan* board game, where players are also awarded points as their settlements grow, and like *Settlers*, is won by the first player to reach a certain number of points. Game play is approximately 70-100 min long, and thus could be incorporated into the regular curriculum, where several sessions could be devoted to game play.

Habitat Ganges: Habitat Ganges is an online game (Figure 3) about the sustainable use and sharing of water resources along the Ganges. This game is aimed at German speaking geography students in secondary schools, ideally for groups of 16-24 students. Time needed is approximately 90 mins, which could be played in a classroom where 2 x 45 min sessions could be planned for play (approx. 15 rounds). The focus of the game is on the development of sustainable water use for communities (the cities of Kanpur, Varanasi, Calcutta and the district of Chamoli), and the consequences for the river, the communities relying on it, and the environment, caused by poor river management. Students developed the game based on the sustainability triangle, described by Heins (1994), as a way to show that sustainability needs to be approached by considering ecological, economical, and social aspects equally and all together, in an integrative way. They applied this to the idea of river management and the interaction between upstream and downstream use. The overall objective of the game is to create a sustainable river environment between the different communities (played in teams), with each community's action affecting the others, as in the case of a real river with upstream-downstream consequences for each community. The game is played by buying and trading resources (with the different resources shown in the field; Figure 5; Table 2), in an attempt to optimize the economy, life quality, and water quality of the Ganges (Table 2 "Effects"), starting with a certain budget. The game is won by achieving the highest overall score from these three indicators, while also taking into account the total population and remaining budget.

3.1 Evaluation of "Water Games" course

Based on feedback we received after the course from the students, one of the main comments that most of the students had about this course, was that the time (two full semesters), was not enough to get introduced to different games, get into groups, and finally develop, test and produce their own games. In the end, the rush to complete a final project, and actually produce a game (especially the board game which required a lot of technical expertise to produce) that could be played during the final session (and used later on as a teaching or outreach tool), meant that the game testing phase was very limited. Since the course was really aimed at getting students to apply theory to practice, there is a goal to produce a product at the end that can be used for either teaching or as a communication tool. This problem in time management likely resulted out of a combination of this (not having much experience in turning theory into a practical product in their studies), and having difficulty getting started with the project (deciding on a group and idea and getting going). The latter could have been improved by giving students more time at the beginning of the course to discuss ideas. The introductory sessions/lectures could have been shorter, and possibly more direction while developing ideas and forming the groups given.

Students commented that the lecture on game theory was maybe the least useful part of the course, although they found it interesting, several said that what they learned in the lectures was too theoretical and not useful for them to immediately apply in their game development. Following the lectures, the next part of the course, where students reviewed existing games, worked rather well, and the students all gave positive input about this part and said it was critical for them in developing their own game ideas. This was also clear in the development of the final games, since both of the games were based on existing games that they had reviewed during this part of the course. After this, when students were given time to get into groups, discuss ideas and get down to work, proved to be challenging – some students had quite strong ideas about how they wanted to proceed, and what type of game they wanted to develop (based on their skills, interests and review of what makes a good game), without wanting to discuss too much with other students. This was however to be a group activity, and reaching a consensus was rather important for the game development to get started. In the end it was decided that the two games would be developed, and that one of the students would contribute to both groups. Once this decision was made, game development went reasonably smoothly, and students spent many hours discussing and testing the intricacies and complexities of water resources sharing. In each step of game development, all the possibilities resulting from of each player's next move had to be evaluated, and through this process, many scenarios were thought through to the final outcome. This process meant that students learned about water resources sharing in great detail and that soft skills learning, including critical thinking, problem solving and team work, was reinforced. Several students who didn't have a background in either physical geography or hydrology also participated in the course and although their learning curve for the material was very steep, had an excellent grasp of the topic after having developed their games.

The overall impression of the course from students was that they had put a lot of work into the course (for the given number of credit points received) – the group project was intense, requiring them to meet and work together frequently. The deadline for the final games to be submitted was also extended into summer and the next fall semester, but they nevertheless scrambled to get the games finished over the summer holiday. As mentioned, this course was meant to emphasize practical aspects of what students learn during their master's curriculum, and students found the transition from theory to practice to be a more challenging step. Although they also had a course on project management, most of them felt that they couldn't apply the information learnt to their actual project. Indeed, working through the theory of project management, is not likely useful without a concrete project to apply those theories to. This lecture could have maybe come later in the course, after they had formed groups, and finalized their project ideas, and then finally apply some of the project management principles to their planning. Given these minor glitches, the students were quite satisfied with having taken the course, and produced their games, and it was definitely a very new (learning) experience for everyone. A next step is to now to get others to play the games, either incorporating the games into teaching curriculum for the age appropriate levels, or possibly during hydrology/water focused outreach events as a communication and teaching tool.

4 Discussion and Conclusions

In this paper, we have presented a short evaluation of how both playing games and developing games can be effective ways to learn and communicate about water resource sharing. Using *Irrigania*, a multi-player, web-based game, we presented results from a survey carried out to evaluate the effectiveness of its use in the classroom to teach about water resource sharing. Our survey showed that *Irrigania* is an effective tool for learning about: i) water resource sharing, and that both cooperation and communication are key factors for sustainable water use; ii) different shared resources including surface/river and groundwater and differences between them; and iii) tragedy of the commons and support discussion of these somewhat theoretical and sometimes difficult concepts for students to grasp. Overall, teachers found *Irrigania* to be an effective and also easy tool to incorporate into curriculum, ideally for upper level bachelor to master level students, studying either water resources or decision making.

Learning activated through both playing and developing serious games in the classroom can provide crucial skills for future professionals to solve complex water resource problems. The complex learning through game play and game development emphasizes problem-solving, communication and collaboration, and critical reflection on wicked problems (Hummel et al., 2010), of which water resource management is one. In a review of learning outcomes of playing serious games, Wouters et al., (2009) found that serious game play improve the acquisition of knowledge and cognitive skills, and that they seem to be promising in accomplishing attitudinal change, likely an important aspect for future water resource professionals as they transition from an educational setting to the workplace, bringing new perspectives with them. In a study on using serious games in acquiring water resource management skills, Hummel et al. (2010) found that the aspect of collaboration within serious games (in the classroom setting) can improve learning about certain problem situations applied in the workplace, according to new modes of more active and experiential learning. The focus on cooperation and communication in *Irrigania,* through its multi-player character and simple game set-up, where communication between farmers is decided before game play, thus also likely lead to improved learning of water resource sharing concepts.

An evaluation of a course on developing water games, based on our experience and student feedback, found that designing and developing their own water games was a positive learning experience for students, although they found it somewhat difficult putting theory into practice to produce their final games. Developing their own games was an active learning exercise, emphasizing what Ruben (1999) describes as "social, collaborative, and peer based" learning. During game development, students had to think through and discuss the intricacies and complexity of water resource sharing, as they enacted players' moves and water resource outcomes, and then had to reevaluate game variables. Through this process, fundamental learning about water resources took place, emphasizing soft skills, including critical thinking, problem solving, collaborative (team) learning and time management. Several studies that have looked at the effects of collaborative learning in serious game development (Corrigan et al., 2015; Prensky, 2003; Mansour and El-Said, 2008), found that the development of serious games (within the workplace (Corrigan et al., 2015)) play a role in fostering the development and improvement of various soft skills, such as communication, collaboration or negotiation and enhance overall collaborative learning, similar to learning outcomes from playing serious games. Corrigan et al. (2015) further suggest that "we are at the beginning of a fundamental shift in the way both learning and working is happening in organisations", and that these novel, active learning tools, including both playing and developing serious games, can add a critical collaborative dimension to decision making that cannot be learned otherwise. Our course was a first step in testing serious game development in the classroom and further insight into the learning outcomes as well as carry-on effects into the workplace would be an interesting research question which could shed light on whether just playing games (emphasizing the fun factor), might be enough to achieve similar learning effects as the full process of game development.

Tracy Ewen 8/22/2016 6:50 PM
Deleted: Further using these water games as either a teaching or communication tool, will encourage students to think about water resource sharing in a more critical and insightful way.

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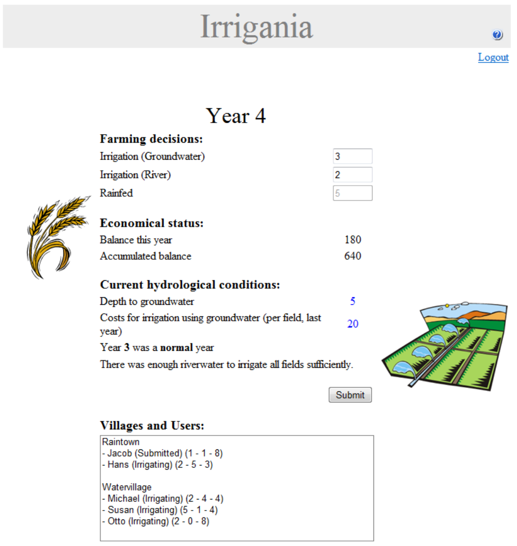

Figure 1: The student (farmer) web-interface during a game of *Irrigania* showing the "Farming decisions" taken for Year 4, the "Economical status" based on Years 1-3, and "Current hydrological conditions" to base the current year's decisions on.

5

Figure 2: Playing the board game *Wiapuna* in the final class.

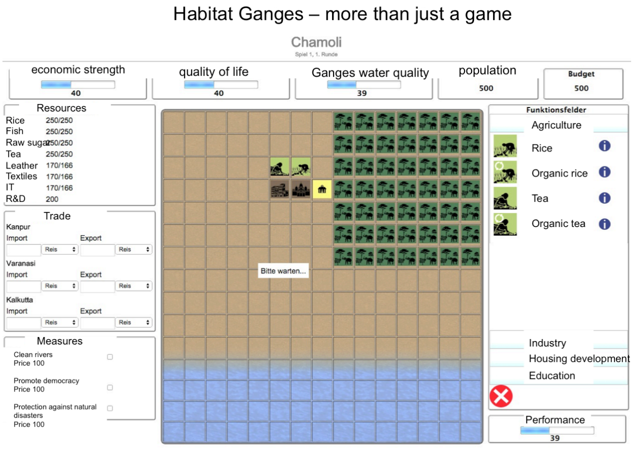

Figure 3: A screen-shot of *Habitat Ganges* - more than just a game (Lebensraum Ganges - Mehr als ein Spiel). Shown is the game interface for the district of Chamoli, translated from the German. Note that the resources here can be related to those shown in the resource price list in Table 2.

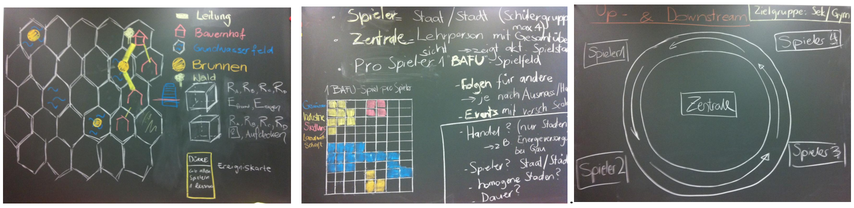

Figure 4: Initial stages of game development with idea boards. Board 1 (left): shows a hypothetical game board with options for introducing a pipeline (Leitung); farmyard (Bauernhof); groundwater source (Grundwasser Feld); well (Brunnen), forest (Wald); drought (Dürre) -> event card' (Ereigniskarte). Board 2 (middle): game board development based on the FOEN, 2015 game. Board 3 (right): hypothetical game idea for computer game based on the idea of upstream downstream river use and influence on each player (Spieler).

Figure 5: Board set-up for Wiapuna centered around four wells (left). Settlements are developed on different land use tiles (right), corresponding to the natural resource cards (copper (Kupfer), gravel (Kies), wood (Holz), food (Nahrung), marsh (Sumpf) and desert (Wüste)) that are used to buy infrastructure and energy efficiency measures.

Game 1: Cooperative	**Year**	**GW Level**	**Irrigation GW**	**Irrigation River**	**Rainfed**	**Income**	**Accum. Income**	**Accum Income Village**
Village: Raintown	**1**	7.25	2	3	5	525.00	525.00	
Farmer: Susan	**2**	9.25	2	2	6	453.54	978.54	
	3	11.25	3	3	4	548.31	1526.85	
	4	11.75	3	2	5	442.81	1969.67	
	5	12.25	2	1	7	378.88	2348.54	
	6	13.5	3	4	3	530.92	2879.46	
	7	15.25	2	1	7	309.88	3189.33	
	8	17.75	3	2	5	239.81	3429.15	
	9	18.25	2	3	5	294.88	3724.02	
	10	19	3	4	3	272.00	3996.02	**16745.02**
Game 2: Non-cooperative	**Year**	**GW Level**	**Irrigation GW**	**Irrigation River**	**Rainfed**	**Income**	**Accum. Income**	**Accum. Income Village**
Village: Raintown	**1**	6.5	4	4	2	650.00	650.00	
Farmer: Susan	**2**	8	4	4	2	663.33	1313.33	
	3	10.25	4	4	2	669.75	1983.08	
	4	12.25	5	4	1	601.35	2584.44	
	5	14.75	5	4	1	517.19	3101.63	
	6	17	6	6	-2	424.00	3525.63	

	7	19.75	4	5	1	142.75	3668.38	
	8	23	5	5	0	-325.00	3343.38	
	9	22.5	1	5	4	236.42	3579.79	
	10	23	1	5	4	271.67	3851.46	**11012.46**

Table 1: Two Irrigania game scenarios played with international students during a course at CABI (Centre for Agriculture and Biosciences International), Delemont, Switzerland: Game 1 (top), a cooperative game, and Game 2 (bottom), a non-cooperative game, for farmer Susan in Raintown village. Farmer Susan tends to irrigate more heavily in Game 2, acting more selfishly, ending up with a lower individual income and a lower accumulated income for her village, as compared to Game 1 where the other farmers in Raintown are known to her.

Resource	Price/year	Yield/year		Effects		
		Resource	Budget	Economy	Quality of life	Ganges water quality
Agriculture/Fisheries						
Tee plantation	60	30	20	+	0	-
Rice field	60	30	20	+++	0	--
Sugar cane plantation	60	30	20	+++	0	--
Fishery	60	30	20	+++	0	--
Industry						
Textile factory	80	50	60	+++++	+	---
Leather factory	80	50	60	+++++	0	-----
IT firm	90	60	70	++++++	+	---

Table 2: Each community in Habitat Ganges is given a sheet of paper indicating the list of prices for each resource (in arbitrary monetary units) together with the qualitative outcome (+/-) for each of the indicators (economy, life quality, and water quality) needed to win the game (here only "Agriculture/Fisheries and Industry" are shown for Calcutta resource prices, as an example).

Appendix: Table A1: Irrigania Survey. The Irrigania survey questions (16, left column) sent out to 18 Irrigania users. A total of 9 users responded. Responses are shown for each question, and comments when given.

Irrigania survey: use in the classroom and for outreach events	**Responses**	**Comments**
1. Have you used Irrigania in a classroom setting? [Yes/No]	Yes, 8 No, 1	
2. If yes, what educational level was it used for?	High school, 1 University, bachelor level, 4 University, graduate level (masters/PhD), 3	
3. What was the name of your course and what department/institute is it in?	Risk Analysis, School of Environmental Engineering, (Greece); Geography, Secondary 2 (high school; US); Geography, Oregon State University (US); Natural Resources Management and Integrated Water Resources Management (Italy); Engineering Systems Design (Singapore); Behavioral psychology, Dept. Psychology (US); Hydrology, Geography; Water resources, Environmental Engineering	not all responded; country provided in brackets where given
4. If you have used Irrigania to teach about water concepts outside of a classroom setting, please let us know what kind of event it was, e.g., an outreach event or during a meeting.		no responses
If you've played Irrigania with students and/or other groups of players, please answer the questions below:		
5. How many students (or other players) played Irrigania?	group size (number of replies) 1-10 (2) 11-20 (2) 21-50 (2) 50-80 (1) > 80 (1)	
6a. How many times have you played Irrigania with the same group of students (or other players)?	0 (2) 1 (2) 3 (2) 3 games/same day (1) > 10 (1)	
6b. How many times have you played Irrigania with different groups of students (or other players)?	0 (2) 1 (2) 2 (3) > 5 (1)	
7. How long did the students (or other players) play Irrigania?	1 hour (1) 2 hours (2) 3 hours (2) over one week (2) over one semester (1)	
8. Did the game hold their enthusiasm for this length of time, or could the session have been shorter/longer?	longer (3) - yes, the students were excited by Irrigania and wanted to play longer - yes, ideally it should be played for more than 2 hours, e.g., 3-4 hours. shorter (2) - It is a wonderful game but the lack of visuals and graphics made it a little less engaging for the students, who are easily distracted and bored with things. - The session could have been a bit shorter as the students' enthusiasm decreased after they understood the mechanisms of the game.	

9. How interested/enthusiastic were the students (or other players) about the game?	very interested (3) very interested initially, but lost interest after ~1 hour (2) very interested in the game competition (2) very interested in setting up different strategies and testing them, e.g., cooperative vs. non-cooperative (1)
10. How well in general did Irrigania teach about collaboration and conflicts with regard to shared water resources? [Very/Moderately/Not very successful]	very successful (5) moderately successful (3) not very successful (0)
11. Do you think there was improved understanding of shared resources like surface/river and groundwater?	yes (8) Yes, but most didn't get that far. Yes, but it is important to recall and consolidate these concepts in a debrief session.
12. Did you notice any interesting patterns that evolved when playing the game in a class?	- Cooperative behavior was improved among players - Yes. In the first rounds students were taking decisions a bit randomly. After this (testing phase), decisions started to be more rational and related to the objectives of the game.
13. Did you discuss game theoretical considerations related to water resource sharing? Before or after playing (each round)?	Before (3) After (2) Before and after (3)
14. Do you think Irrigania was successful in teaching students (or other players) about the tragedy of the commons?	yes (6) yes, more or less (2)
15. Have you used other educational games? If so, which ones? What differences did you find in teaching aspects compared to irrigania?	No (4) Catchment Detox http://www.abc.net.au/science/catchmentdetox/files/home.htm
Please give any other information that might be useful in evaluating Irrigania as an innovative tool for learning about water resource sharing.	- Allow for more flexible groundwater levels - It has the potential to be a powerful educational tool, but it might need to be more engaging and more game-like. - It will be very useful for older children/young adults - Allow for more game settings, e.g., allow for different amounts of available water, rewards - Improve the user experience, include a nice interface with spatial representation of the villages. - Would be great if the results could be directly exported in some formats (e.g., Excel).