Teaching Resource Management with Web-Based Models and Multi-Player Games

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Abstract

An undergraduate level web-based course is described which teaches management of natural resources based on system dynamics principles and methods. The course emphasizes students learning by manipulating animations, investigating models, and playing model-based games. One example is a multi-person web-based fishery game, in which students learn the dynamics of fisheries including the tragedy of the commons. Given evidence that managing such resources is affected not only by the commons problem but also by managers' misconceptions about the dynamics of resource systems, the game was empirically evaluated and is being revised. A pilot test conducted in June of 2012 assessed the potential of collaborative (as well as competitive) learning to help dispel misconceptions about dynamics and improve understanding of resource management principles. The pilot test also investigated the degree to which misconceptions, as well as the commons problem, contribute to management errors. Results suggest that collaboration improved performance and understanding, though participants' difficulty coming to agreement with their partners generated misgivings about collaboration. The pilot test also suggested that lack of understanding of the underlying economics was more important than the commons problem. Several pedagogical improvements to the game are suggested.

Keywords

web-based learning, sustainability, gaming, resource management, collaborative learning

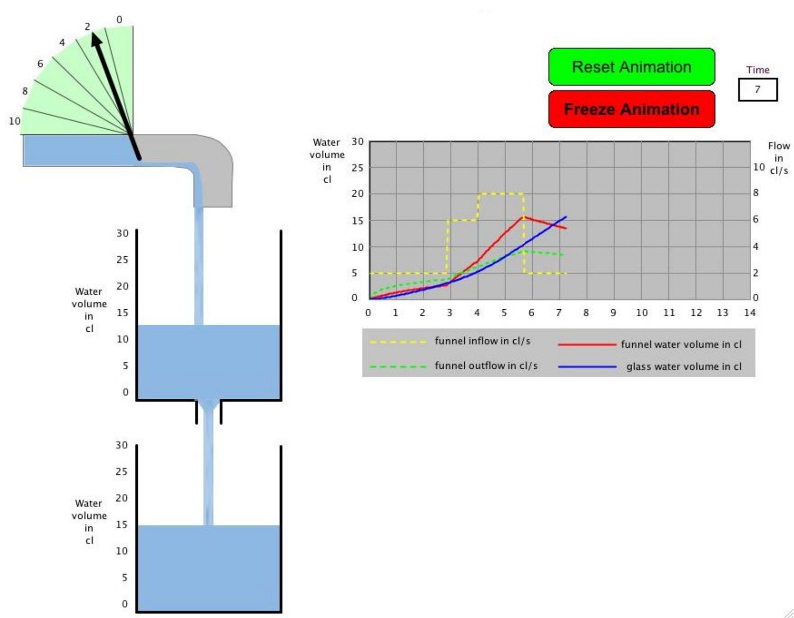
The Resource Management Course

Over the past year at the University of Bergen we have been developing a new undergraduate course on management of natural resources. This fully web-based and primarily asynchronous course will be taught by the third author and is being designed and developed by all three authors. It includes management of renewable resources, local and global management issues, the problems of overshoots and the commons, and policy formulation concerning both local resource management and global issues (availability of food, water, energy consumption, and climate change). The course is based on the principles and methods of system dynamics. It begins with analysis of simple one-stock models and progresses to multiple-stock models with and without competition.

Our primary pedagogical belief is that learning is a result of the things that the learners do, not the things that instructors do. Instructors can create materials and conditions conducive to good student activities, but it is those activities that really give birth to learning. While it is true that listening to a lecture (and hopefully thinking about it) is an activity, and watching a video is an activity, they are the lowest levels of student activity which do not require much cognitive processing. Far more cognitive processing is required and induced by having students do things like solve problems, write analyses, or design models. Although the course is not about model building, its design seeks to facilitate student learning though a variety of on-line problem-solving, analysis, and writing activities based on analogic animations, simulations, and model-based games.

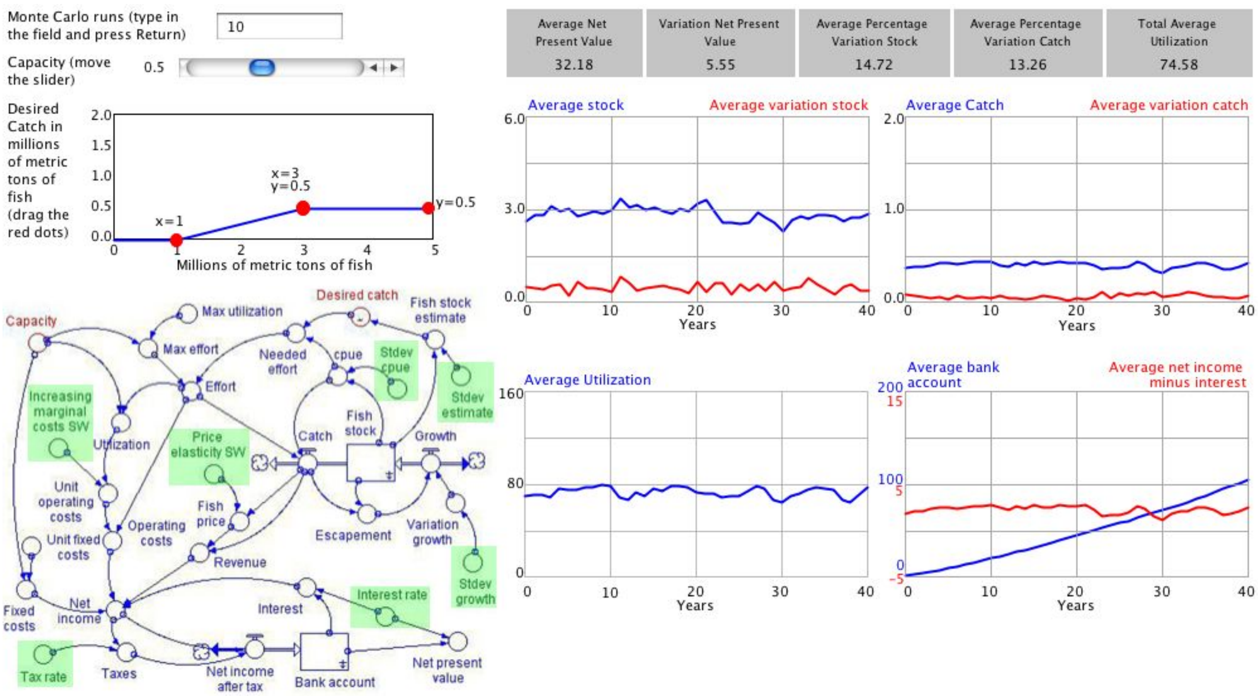
An analogic animation example is shown in Figure 1, in which the analogy of a funnel is used and manipulated by students to learn about flows, stock, delays, and overshoots. For example, the student can be instructed to use the animation (manipulating the flows with the faucet) to fill the glass as quickly as possible to 28 cl. That and other activities with the animation help clarify the nature of overshoots, how delays contribute to them, and how to manage them.

Figure 1: Animation of a faucet, funnel and glass, teaching flows, stocks, delays, and overshoots.



A example of a simulation activity is show in Figure 2. Students are introduced to the system of a non-competitive fishery (only one company has fishing rights to a body of water) and can manipulate various parameters (e.g., the tax rate) and key variables (capacity and desired catch). A system-dynamics model underlies the simulation and model transparency is provided with a causal-loop diagram representing (in a very simplified form) that model. Additionally, Monte-Carlo simulation is utilized so students can investigate the effects of random variation as well as their own choices of the parameters and key variables.

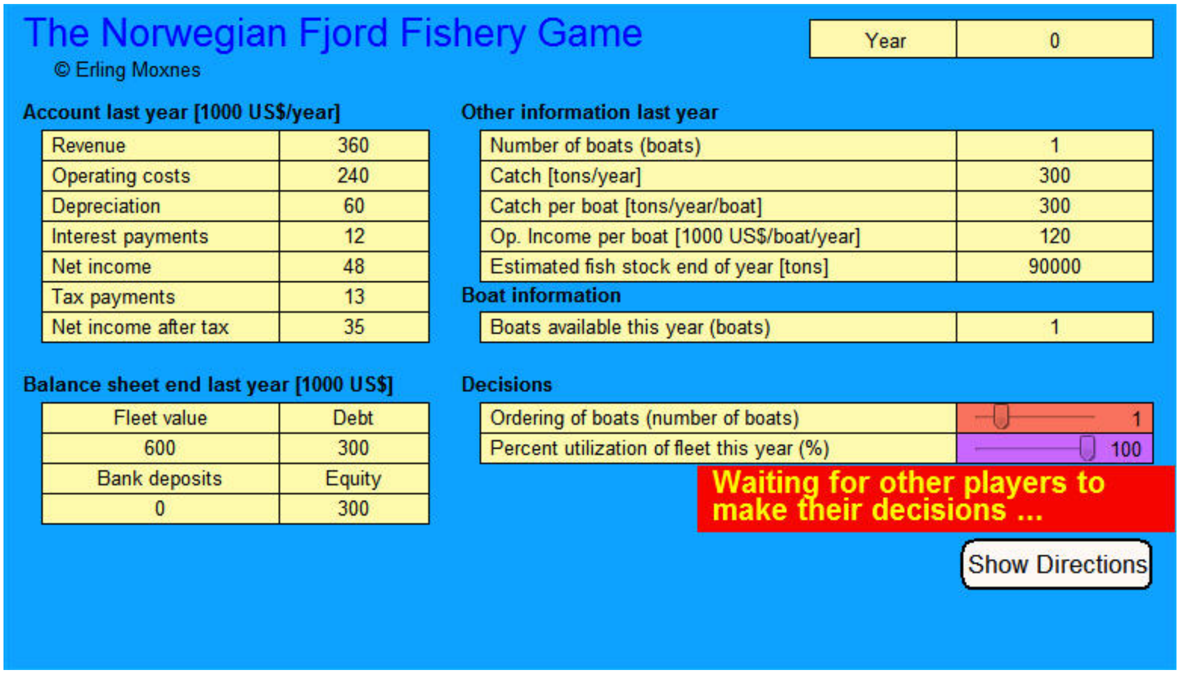
Figure 2: Simulation activity about optimization of a fishery.



Finally, a multi-player game is illustrated in Figure 3. This is the main decision and feedback page in the fishery game. Four to six students (or pairs of students) operate fishing companies sharing the same fjord (a well delineated body of water). For each of thirty years they decide on investments (new boats) and utilization of their boats, and see their decision's results on both economic variables (e.g., company equity) and the natural resource (estimated fish in the fjord).

In addition to working with these animations, simulations, and games, students in the course must analyze various case studies, write analyses and answer questions on a web-based forum, and receive debriefing videos from the instructor. The general course approach is for each section to begin with animations to teach the basic concepts (such as stocks, flows, and delays), and then apply those concepts to real resource management problems such as management of fish, forests, reindeer, and water, including historical case studies based on real-world problems and events. The fishery model underlying the game shown in Figure 3 will be first introduced as a single-player (and single-company) game in the first third of the course, and reintroduced with the multi-player (and multiple-company) game in the middle of the course.

Figure 3: The competitive (multi-player) fishery game.



Currently, we are exploring a variety of pedagogical design decisions, such as whether to have students in the course play the multi-player fishery game, and other management games, as individuals or as teams. That particular design decision is the focus of the remainder of this paper.

Two principles of good course design: evidence-based theory and empirical revision

We believe that good course design has two main features. First, design should be theory and evidence based. That is, one should not simply "throw together" a course based on what one thinks would be a nice idea. Design (not only of the overall course but of each component and activity) should be based on theories with evidence to back them up. But evidence and theory-based design is sufficient only to produce a good first draft of a course, and does not guarantee student learning success. Student success is guaranteed by the process of empirical revision, that is, the iterative process of evaluating a course (or a component of a course), revising it based on the results, evaluating it again, revising it again, and continuing that process until student success meets your expectations. The theoretical and evidence-based design of the competitive fishery game, and after that our initial evaluation of it, are now described.

The difficulty of managing shared resources has historically emphasized the problem of the commons (Hardin, 1968). But when Moxnes (1998a) investigated the understanding of fish populations and economic management of fishing fleets by relative experts (persons in or knowledgeable about the Norwegian fishing industry), he provided evidence that the typical problem of overfishing is not just due to the tragedy of the commons, but is also due to experts' misconceptions about the dynamics of fish populations and fishery economics, resulting in poor business and resource management decisions. Clearly, the dynamics of natural resource populations like fish are complex and difficult to understand, let alone control. Even experts have difficulty, not just due to the competition resulting from the commons problem (i.e., it is economical for the individual to harvest more than what is optimal from society's point of view), but also due to their faulty understanding of the dynamic system.

One goal of the resource management course is to teach students about such complexities of dynamic systems, including problems like the tragedy of the commons. We therefore created a competitive fishery game based on the model employed in Moxnes (1998a). That was originally a one-player (and one fishing company) *Powersim* model. We expanded it into a six-player (and company) simulation-game which students in the web-based course can play simultaneously via the web. But given the evidence that even experts have difficulty with the model, and in an effort to improve the design of that interactive activity, a version of the six-company web-based fishery game was created following up on two recommendations given in the conclusion of Moxnes (1998a). The first was that the dynamics misconception problem should be coupled with the commons problem so as to evaluate their relative contributions to poor decisions. The second was to investigate the potential of collaboration for improving players' understanding and decision making. Especially in technology rich environments, collaboration between learners (e.g., two students representing a single fishing company) extends the somewhat primitive types of communication a computer can provide, with the very rich and reflective communication that can occur between two human players while they are working with a model or playing a model-based game.

In keeping with our contention that course design should be evidence and theory based, let's consider the theoretical rationale for this type of simulation-game, i.e., the misconception issue, the commons problem, and collaborative learning principles. Then, in keeping with our contention that course design should include empirical revision, we describe a pilot experiment to evaluate the fishery game, conducted in June 2012.

Theoretical background

There is growing evidence that people have difficulty managing even simple dynamic systems. It has been demonstrated that students do not understand the simple relationship of animal populations and their primary food sources (Moxnes, 1998b), let alone the less obvious effects of delays (Moxnes & Jensen, 2009) or net flow effects (Moxnes, 1998b; Sweeney & Sterman, 2000; Cronin et al., 2009). Much more surprising was that even experts in a field showed similar difficulties exhibited by beginning students. Moxnes (1998a) had four types of participants play the simple one-person simulation-game based on a model of cod populations in Norwegian fjords and the economics of a single fishing company with sole property rights to fishing in a particular fjord. The experts included actual fishermen (persons owning fishing boats), government policy makers for the fishing industry, and researchers of the fishing industry. Because each participant played a single-company game that included no competition with other companies, the commons problem was eliminated. Yet participants still tended to over-invest in fishing boats, some at the very start of the game and some at later times in the game. The result was over fishing, depletion of the fish population, and suboptimal profits for the companies. A primary explanation of the participants' behavior is that they made investments (purchasing new boats) as if it were a *flow* resource, when in fact they were working with a *stock* resource, which of course does not respond instantaneously and incorporates a significant delay. In his concluding section on future research, Moxnes posed several questions including, "What happens if groups rather than individuals make decisions?" and "What happens if the management problem is coupled with the commons problem?" (page 1247). It is those two questions that we are now investigating in an effort to improve the pedagogy of both the fishery game and the resource management course more generally.

The question of individuals versus groups is a particularly interesting one in light of the considerable research on collaborative learning in the fields of educational psychology, learning science, and instructional design. Based on that literature, we distinguish five modes of learning with regards to number of learners and the roles of the learners: individualized learning (working completely alone), group learning (working in conjunction with others, but towards one's own goals), cooperative learning (working with others and explicitly helping each other, though still towards one's own goals), collaborative learning (working together on a *shared* goal and helping each other to achieve that goal), and competitive learning (working on one's own goals that are at odds with other learners) (Johnson & Johnson, 2004; Resta & Laferrière, 2007). One can of course combine some of those five basic types, in particular one can combine collaborative learning with competitive learning by having teams compete. Within a team there is collaboration while between the teams there is competition. The members of a team typically share two goals, the goal of learning the material and the goal of winning the game. Alessi & Trollip (2001) suggest that team competition possesses both the advantages of collaboration (learners on a team interact and help each other learn and achieve the shared goals) and the advantages of competition (increased intrinsic motivation, which is inherent in most competitive game environments). Additionally, team competition avoids a major problem of individuals competing, namely, teams are more evenly matched than individuals. In a typical learning environment, the weakest learners will frequently lose in competition, which will tend to decrease their motivation to learn and participate. But with well-formed teams of learners (those with a mix of learner ability and achievement levels) all teams tend to experience some winning and some losing. Based upon the well documented behavioral principle of variable reinforcement schedules (Ferster & Skinner, 1957), sometimes winning and sometimes losing is a powerful motivator which gives rise to learning which lasts a long time.

One of our main pedagogical interests, towards improving the effectiveness of the game and of the entire on-line course, is to assess the effect of collaborative interactions. That is, we are not only interested in teams versus individuals competing because of the motivational difference described above, but because of the helping and improved thinking that occurs within a collaborative team. For example, when an individual is at the point of deciding whether to purchase new boats for next year, he or she is (we hypothesize) less likely to consider the reasons for and against new boats than is a pair of players, who are likely to think of and discuss different factors (the company's debt, the fish population, delays). The 'two heads are better than one' phenomenon should encourage deeper and more complete consideration of such factors so that, perhaps, a better decision is made.

The advantage of using a multi-player web-based game are several. First, it incorporates the commons problem, permitting us to investigate the relative contributions of that problem versus mental misconceptions as demonstrated in Moxnes (1998a). Second, it can easily incorporate either individuals competing or small groups (in our case, pairs of learners) competing. The individual versus small group component permits assessment of whether collaboration improves thinking about dynamics. The competitive part incorporates not only the commons problem but also the motivational effects of competition. And combining competition with either individuals or pairs competing allows assessment of the theoretical argument that motivation is improved and maintained more by teams than by individuals.

Based on these principles and theoretical foundations (assessing the contributions of the commons problem versus individual misconceptions of dynamics, assessing individuals' versus groups' thinking about dynamics, and assessing the relative motivational benefits of competition between individuals versus teams) we constructed a web-based six-company version of the original fishery model and game. We now describe the original game (which was designed for research purposes) and then describe the multi-player web-based game (re-designed and modified to serve a more educational purpose).

The *Powersim* Model and Game

For his 1998 research study, Moxnes created a single-company model and interface in an early version of *Powersim*. The model was a standard cohort model of cod with fixed mortality rates, nonlinear stock recruitment and catch per unit effort relationship, and no interaction with other species, the company bank account, the fleet value (all the boats), and an aging chain of boats ranging from brand new to so old that they must be scrapped. The model did not include selling or premature scrapping of boats. The participants' interface allowed them to decide, each year, whether to order new boats, and their percent utilization of their fleet of boats over the year, varying from 0 to 100 percent. They were given updated information each year about their company's accounts, balance sheet, fleet size, and fish catch. (These are the same in the web-based game and are illustrated as part of that game's description in the next section).

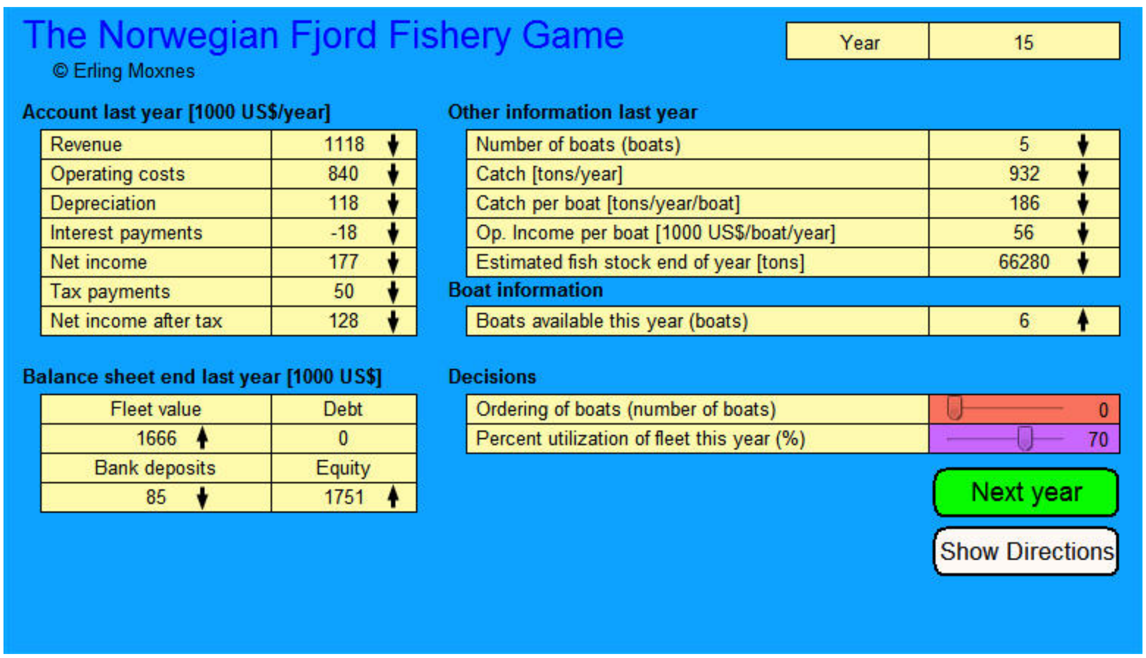
The Web-Based Multi-Player Model and Game

Based on the techniques described in Alessi (2000) and Alessi et al. (2008), the game was programmed in the *LiveCode* programming environment (www.runrev.com). This is an object-oriented higher level language allowing development of desktop programs (for Windows, Macintosh, and Linux), browser-based web programs (though limited to certain versions of the FireFox, Internet Explorer, and Safari browsers) and most recently 'apps' for iOS devices (iPad, iPod, and iPhone) and Android devices (a wide variety of tablets and smart phones). Development within this programming environment facilitates several of our goals, including creation of a multi-player game, delivery via the web, sophisticated data collection (for both research and educational purposes), and delivery in several modes (on desktops, via browsers, and as mobile apps). In *LiveCode*, almost all the variables in the original Powersim model were converted to arrays (for six different fishing companies), several 'common' variables (shared among the six companies) were added, automated players (robots) were added, data collection using a standard MySQL database was incorporated, and some modifications to the interface were made, mostly at the beginning for forming teams and at the end to report results and facilitate a debriefing discussion.

Figures 3 and 4 show the primary game interface. In Figure 3 (shown earlier) the game has just begun, the user has decided to purchase a new (second) boat, and is waiting for other players to make their decisions. Players must move from year to year together, so only after all players have made their decisions and chosen to 'continue' is their data updated. Figure 3 also shows the various company accounts, balance sheet, equipment, and catch. Decisions on purchasing new boats and percent utilization of their boats are made with the red and purple sliders, or typing in the field immediately to the right of the sliders. The players can show or hide all the original directions by pressing the 'show directions' button.

Figure 4 shows a particular player's status after 15 rounds (years) of decision making, about half-way through the game. In addition to the numbers indicating the company's accounts, balance sheet, equipment, and catch, small arrows point either up or down to indicate if those quantities have increased or decreased from the previous year. No arrow indicates there was no change. This particular player has six boats (having recently purchased a new one), and has decreasing values for most variables except for the fleet value, equity, and debt. The player is not purchasing any new boats for next year, and is currently choosing to utilize the fleet at the 70% level.

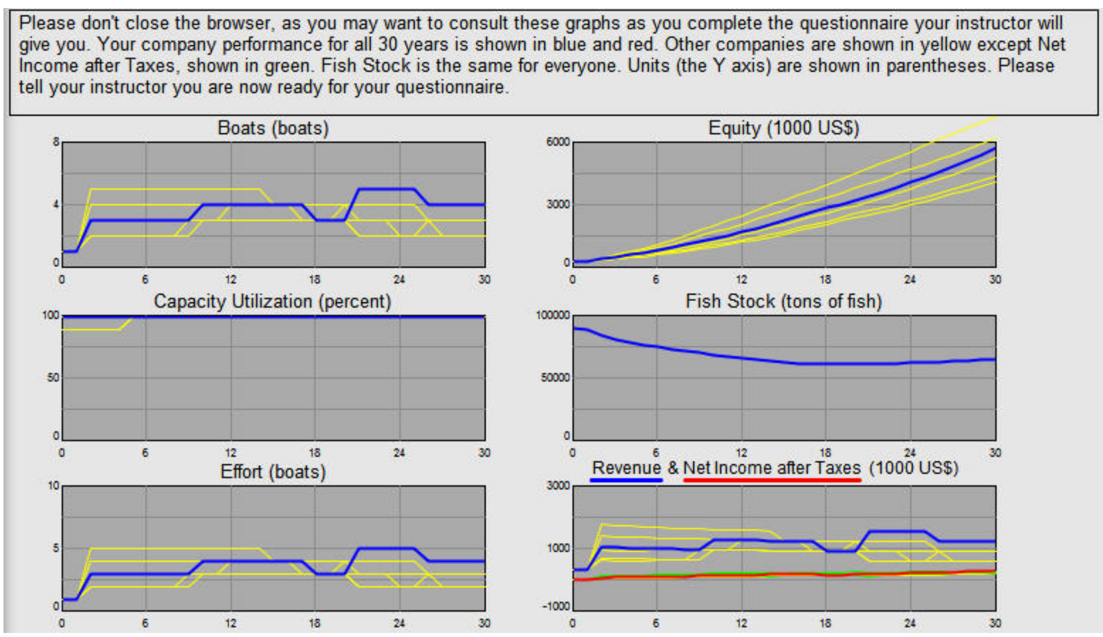
Figure 4: Player interface about half-way through (year 15) the game, with updated data.



This interface, with only the numbers and arrows changing, is displayed from years 0 to 31 (though no decisions are made in year 31). After that final year, Figure 5 is displayed showing not only the player's performance on seven variables (two are combined in a single graph), but how their performance compares to the other players (companies). The player's own performance is shown in blue for Boats, Capacity Utilization, Effort, Equity, Fish Stock, and Revenue, and in red for Net Income after Taxes (to distinguish it from the blue Revenue on the same graph). The performance of the other players is shown in yellow for the first six variables and in green for Net Income after Taxes (again, to distinguish it from the Revenue lines on the same graph). In this illustration, we can see that this player was average in terms of boat purchases until about year 21, when he/she made several purchases and had more boats than anyone else for the rest of the game. Almost everyone was the same for Capacity Utilization (100% or very near to that). This player was again average for Effort until near the end of the game, was average for Equity throughout the game, and was average until the end of the game for both Revenue and Net Income after Taxes. Fish Stock is a common variable and the same for everyone. It decreased quite markedly during the first 15 years (almost in half) but grew slightly during the last 15 years. The purpose of these graphs is to help the learner (or pair of learners) reflect on their decisions and performance, help them to answer questions for our research, and facilitate either on-line or in-class debriefing discussion.

We mentioned earlier that automated players (robots) were added in the multi-player game. The game was designed to model six companies operating in the same region. But it is not always possible or easy to find six players (or six teams of players) and coordinate their synchronous activity. The game was therefore programmed so only four persons (or teams) were needed to play, in which case two companies are played by the computer. If five persons or teams are available, only one company is played by the computer. If six persons or teams are available, the computer does not have to play any company. The automated companies follow simple algorithms for purchasing boats and setting their percent utilization of the fleet. Boats purchased and percent utilization are each set to the median of those values for the real players. Thus, if the real players purchase a lot of boats, so will the automated players, while conservative real players will result in conservative automated players.

Figure 5: Results displayed to the player at the end of the game.



Because the game is played on the web, with players potentially in several countries or continents, there is a ‘game registration and startup’ process. Any player may create a new game (or group of players). Subsequent players will see that game and who is in it, or may form a new game. Of course, it is still incumbent upon potential players, especially those living in different time zones, to do some prior planning either through e-mail or other communication methods, so that when they sign in to play a game, there are other people available and ready to play as well. When at least four players have signed up to play together, the program allows them to start playing, or they can wait for a fifth or sixth player before starting. When they do start, directions are given followed by Year 0, which was illustrated in Figure 3.

Pilot Study of the Multi-Player Fishery Game

Towards the purpose of comparing the pedagogy of playing multi-person games either individually or collaboratively, we conducted a pilot experiment using the multi-player fishery game. The pilot test was conducted with students in a traditional (face-to-face) course on agricultural economics (a type of resource management) taught in the 2012 spring semester.

For the pilot study there were two conditions in which participants played the fishery game, individually or as collaborating pairs. Four students played the game as individuals. That is, each operated their own fishing company and fleet, and the four were operating within the same hypothetical Norwegian fjord, thus sharing a common fish stock. The game allows for as few as four and as many as six companies operated by students, so that an exact number of students is not needed to arrange a round of play. When only four students play (as was the case in the pilot experiment), the remaining two companies are automated. Their decisions (about purchasing and using boats) is a median function of the real players. The instructions for students working as individuals are shown in Appendix A.

Eight other students in the agricultural economics class played the game in pairs. That is, two students operated a fishing company and fleet jointly, with the eight students operating four companies within the same hypothetical Norwegian fjord. Once again, two of the six companies were automated (decisions made by the computer). The two students in each collaborative pair were instructed to discuss, reflect upon, and make joint decisions about boat purchases and percent utilization of their fleets. The instructions for students working in collaborative pairs are shown in Appendix B.

As in previous research (Kopainsky et al., 2010, 2011), we assessed both learners' performance during the game (how well they optimized the key variables of Equity and Fish Stock) and learners' understanding (of the scenario and good decision strategies) using an instrument administered immediately after the game. That instrument, the questionnaire in Appendix C, assessed their understanding of key concepts and relationships, and their opinion about working in teams (for those participants who *did* work in teams). This questionnaire was administered on paper. After the questionnaire, the second author conducted a debriefing discussion about the activity, participants' decisions and performance, and their understanding of the underlying fishery model. To facilitate the discussion and debriefing, the instructor was able to display (on a computer projector) the graphs for any company (as was shown in Figure 5). For that purpose and to assess participants' performance during the game, all decisions and outcomes for each participant were stored in a MySQL database on a web server.

The number of participants in the pilot experiment was far too few to conduct significance tests with adequate statistical power. Nevertheless, we made the following casual observations based on participants' performance during the game, their answers on the questionnaires, the second author's observation of participants during the game, and the second author's debriefing discussion with the participants.

First, students working in collaborative pairs did seem to develop a better understanding (than students working alone) of the scenario and how to manage it. However, the students working in pairs appeared to be less satisfied with the game, because they had difficulty coming to agreement about their decisions. In contrast, students working alone did not have to come to any agreement with anyone, could make their decisions quickly, and given that they performed fairly well, were quite happy with the game. In the debriefing (which included all 12 students), however, the individuals did express the wish that *they* could have discussed the scenario with others, because much of the economics (of running a fishery) was new to them.

Second, all students found the accounting aspects of the game (e.g., variables such as company equity, catch per boat, and net income after taxes) to be very new for them. Discussion of those accounting variables was what paired students liked and individual students wished they could have.

Third, all students performed fairly well in terms optimizing the key variables (company equity and the fish stock). The paired students' mean for equity was slightly greater than that for the individual students, though as was stated earlier, there is almost no statistical power (for any of the key variables) with only four "pair" companies and four "individual" companies. (The appropriate unit of analysis would be a company, whether individual or paired, and *not* an individual student.) Furthermore, all companies' equity was increasing in the final years of the game. The paired students' fish stock was slightly higher than the individual students at the end of the game, and the paired students' fish stock was increasing in the final years, while the individual students' fish stock was decreasing in the final years. Finally, the number of boats owned by the paired students was smaller and more appropriate (according to an optimization algorithm) than the number of boats owned by the individual students. Although, as stated, none of these differences are large and certainly not statistically significant, they do suggest that further research (with greater number of students) might show an advantage for students working in collaborative pairs.

Fourth, these pilot students, being in a class on agricultural economics, are familiar with the tragedy of the commons and were determined not to decimate their fish stocks. This may in part account for why their overall performance in the game was fairly good.

Fifth, and despite the fourth observation, students' responses on the questionnaires demonstrated some misconceptions. For example, most students answered that purchasing new boats would decrease their company's equity. In fact, purchasing boats only decreases equity if the company must borrow money to make the purchases. If the company has sufficient funds, boat purchases have no effect on equity because the newly purchased boats are also part of the company's equity. As another example of a misconception (or perhaps a partial misconception) students indicated that the optimal strategy is to purchase new boats right away at the start of the game. But an optimal strategy would really be to purchase a *small number* of boats right away, and maintain a fairly constant number throughout the duration of the game.

Sixth, some design changes to the game appear to be necessary for pedagogical (learning and motivational) reasons. The game was too long and students were sometimes observed to be just going through the motions. Thirty years, with very similar decisions every year, was not good for maintaining interest and (in the case of paired students) not good for collaborative discussion.

For a learning environment (in contrast to a research experiment environment) we should consider having students make decisions every fifth year or so, rather than every year. The 30-year duration must be maintained, because some long term effects (e.g., retiring of old boats, delays affecting the fish stock) are central to the model. Other design changes relevant to pedagogy include simplifying the economic (business) aspects of the game, and helping the paired students cope with the difficulty of coming to agreement on their decisions.

Conclusion

Interactive multi-person games are likely to be an important component in teaching students about resource management (such as agriculture, fisheries, and forestry). The new web-based course on resource management will have several such games. But key pedagogical design features are anything but certain. Although design of the fishery game began with prior theory and research evidence, our empirical evaluation and revision of it will continue to investigate the impact of collaboration, misconceptions, the commons problem, and other variables. Our preliminary work suggests that collaboration is likely to be beneficial, though it must be better managed, that the game might require economic simplification, and that motivation must be enhanced, such as by decreasing the number of decisions and shortening the game.

Empirical evaluation and revision must be done not only for individual course components such as the fishery game, but of the course as a whole. The third author pilot tested the entire course with a small group of face-to-face students during the Spring 2012 semester. Revisions are now underway based on that evaluation. The course will be taught on-line, for the first time, during the Spring 2013 semester, at which time evaluation of the course and its individual components will continue.

References

Alessi, S.M. (2000). Designing educational support in system-dynamics-based interactive learning environments. *Simulation & Gaming, 31*(2), 178-196.

Alessi, S.M., Kopainsky, B., Davidsen, P., & Pedercini, M. (2008). *A system dynamics-based multi-user domain for improving national development planning*. Paper presented at the Annual Meeting of the American Educational Research Association, March 24-28, 2008, New York City.

Alessi, S.M. & Trollip, S.R. (2001). *Multimedia for learning: Methods and development,* 3rd edition. Boston: Allyn & Bacon.

Cronin, M.A., Gonzalez, C., & Sterman, J.D. (2009). Why don't well-educated adults understand accumulation? A challenge to researchers, educators, and citizens. *Organizational Behavior and Human Decision Processes*, *108*(1), 116-130.

Ferster, C.B. & Skinner, B.F. (1957). *Schedules of reinforcement*. New York: Appleton-Century-Crofts.

Hardin, G. (1968). The tragedy of the commons. *Science*, *162*(3859), 1243-1248.

Johnson, D.W. & Johnson, R.T. (2004). Cooperation and the use of technology. In D.H. Jonassen (Ed.), *Handbook of research on educational communications and technology*, 2nd ed. (pp. 785-811). Mahwah, NJ: Erlbaum.

Kopainsky, B. & Alessi, S.M. (2011). *Measuring knowledge acquisition in dynamic decision making tasks*. Paper presented at the 29th International Conference of the System Dynamics Society, July 24-28, Washington, D.C.

Kopainsky, B., Pirnay-Dummer, P., & Alessi, S.M. (2010). Automated assessment of learners' understanding in complex dynamic systems. Paper presented at the 28th International Conference of the System Dynamics Society, July 25-29, 2010, Seoul, Korea.

Moxnes, E. (1998a). Not only the tragedy of the commons: Misperceptions of bioeconomics. *Management Science*, *44*(9), 1234-1248.

Moxnes E. (1998b). Overexploitation of renewable resources: the role of misperceptions. *Journal of Economic Behavior and Organization*, *37*(1), 107–127.

Moxnes, E. & Jensen, L.C. (2009). Drunker than intended: Misperceptions and information treatments. *Drug and Alcohol Dependence, 105*, 63-70.

Resta, P. & Laferrière, T. (2007). Technology in support of collaborative learning. *Educational Psychology Review*, *19*, 65-83.

Sweeney, L.B. & Sterman, J.D. (2000). Bathtub dynamics: Initial results of a systems thinking inventory. *System Dynamics Review*, *16*(4), 249-286.

Appendix A - Directions given to students in the “individual” condition at the start of playing the game.

DIRECTIONS: You own one of six cod fishery companies operating in a Norwegian fjord. Your goal is to maximize Equity from your company over a 30 year period.

When you start you have a one year old boat. Each year you can order new boats (as few as 0 and as many as 4) and determine the capacity utilization of your fleet (from 0 percent to 100 percent). New boats will be available the year after you order them.

Fish catch is measured in tons. Monetary values are in US$. The market price of fish is 1.20 $/kg and operating costs are .80 $/kg under ideal fishing conditions. If your catch per boat goes down, your operating costs per kg increase.

For calculating equity, you need the following pieces of information:

Equity is defined as the sum of the money your fishery company has in the bank account and the value of all your boats.

The price of a new boat and thus the value of one boat is 600'000 US $. The average lifetime of a boat is 25 years. For tax purposes, however, the average depreciation time of the boat value is 10 years. Thus, the value of a boat depreciates over a period of 10 years.

The money your fishery company has in the bank account is the accumulated cash flow, i.e., the sum of the cash flow in each year over all the years since the start of the game.

For calculating cash flow you need to add depreciation of the value of your boats to your income after tax (i.e., after paying 28% in taxes on your net income) and subtract investment (i.e., the number of boats you have purchased in a year multiplied by their price).

Note that cash flow and thus also the money in the bank account can be negative. In the event that your bank account is negative, you need to pay interest at a rate of 4% per year on your debt. Cash flow can be negative when your net income is negative. Net income is calculated as the revenue from the amount of fish that you catch minus operating costs and minus interest payments on debt.

Because fish in the fjord cannot be counted exactly, there are random variations in the annual estimates of the fish stock available. You are not allowed to order more than 4 boats at a time and you cannot sell boats. Ordering of boats is reset to zero each new year while utilization remains the same, unless you change it.

Each year, you should evaluate the latest information about your company and the fish stock available. You should carefully make a decision about whether to buy new boats and whether to change the percent utilization of your boats for the coming year. Then, use the red and purple sliders (on the game page) or enter new numbers in the red and purple fields and press Enter to change their values. Press the green Next Year button to finalize your choices and proceed to the next year. However, you will not go on to the next year until after all six companies have pressed Next Year. Your company's income and other information will be displayed. Small arrows next to the numbers indicate if they increased or decreased since the previous year. You can reread these directions any time you want (using the Show Directions button) on the main game page.

Appendix B - Directions given to students in the “pair” condition at the start of playing the game. The directions are almost identical to those for the “individual” condition, so the differences are highlighted, although they were not highlighted for the students.

DIRECTIONS: You and your partner own one of six cod fishery companies operating in a Norwegian fjord. Your goal is to maximize Equity from your company over a 30 year period.

When you start you have a one year old boat. Each year you can order new boats (as few as 0 and as many as 4) and determine the capacity utilization of your fleet (from 0 percent to 100 percent). New boats will be available the year after you order them.

Fish catch is measured in tons. Monetary values are in US$. The market price of fish is 1.20 $/kg and operating costs are .80 $/kg under ideal fishing conditions. If your catch per boat goes down, your operating costs per kg increase.

For calculating equity, you need the following pieces of information:

Equity is defined as the sum of the money your fishery company has in the bank account and the value of all your boats.

The price of a new boat and thus the value of one boat is 600'000 US $. The average lifetime of a boat is 25 years. For tax purposes, however, the average depreciation time of the boat value is 10 years. Thus, the value of a boat depreciates over a period of 10 years.

The money your fishery company has in the bank account is the accumulated cash flow, i.e., the sum of the cash flow in each year over all the years since the start of the game.

For calculating cash flow you need to add depreciation of the value of your boats to your income after tax (i.e., after paying 28% in taxes on your net income) and subtract investment (i.e., the number of boats you have purchased in a year multiplied by their price).

Note that cash flow and thus also the money in the bank account can be negative. In the event that your bank account is negative, you need to pay interest at a rate of 4% per year on your debt. Cash flow can be negative when your net income is negative. Net income is calculated as the revenue from the amount of fish that you catch minus operating costs and minus interest payments on debt.

Because fish in the fjord cannot be counted exactly, there are random variations in the annual estimates of the fish stock available. You are not allowed to order more than 4 boats at a time and you cannot sell boats. Ordering of boats is reset to zero each new year while utilization remains the same, unless you change it.

Each year, you and your partner should evaluate the latest information about your company and the fish stock available. You should carefully make a JOINT decision about whether to buy new boats and whether to change the percent utilization of your boats for the coming year. Then, use the red and purple sliders (on the game page) or enter new numbers in the red and purple fields and press Enter to change their values. Press the green Next Year button to finalize your choices and proceed to the next year. However, you will not go on to the next year until after all six companies have pressed Next Year. Your company's income and other information will be displayed. Small arrows next to the numbers will indicate if they increased or decreased since the previous year. You can reread these directions any time you want (using the Show Directions button) on the main game page.

Appendix C - Post game assessment for the Fishery Game. The last two questions (about team collaboration) were only given to students in the team condition.

Thank you for playing the fishery game. Based on experience with playing the game, we would now like to ask you a few questions.

During the game, you could make decisions whether to buy new boats and whether to change the percent utilization of your boats for the coming year. Looking back at the game, which was more important in your eyes, the total number of boats you had or the percent utilization of your boats?

☐ number of boats ☐ percent utilization

Please give a few reasons for your choice:

____

____

How do the number of boats and the percent utilization of boats affect equity?

The number of boats affects equity in the following way: ________________________

____

The percent utilization affects equity in the following way: ______________________

____

Based on your performance and experience, what would a good number of boats be to have on average across time?

Good number of boats: _________________

Please give a few reasons for your choice:

____

____

Based on your performance and experience, what would a good percent utilization be to have on average across time?

Good percent utilization: ________________

Please give a few reasons for your choice:

____

____

Having now played the game, what is a better strategy: Wait a few years before making any investments (i.e., before buying new boats) or invest right away?

☐ wait a few years ☐ invest right away

Please give a few reasons for your choice:

____

____

Having now played the game, under what circumstances and how often do you think one should buy new boats?

____

____

Having now played the game, under what circumstances and how often do you think one should change percentage utilization?

____

____

Please explain your investment decisions, i.e., the reasons you had for purchasing the number of boats you purchased over the 30 simulated years.

____

____

Please explain your utilization decisions, i.e., the reasons you had for choosing and adjusting the percent utilization of your boats over the 30 simulated years.

____

____

Having managed your company together with a partner, do you think you did better or worse than if you had managed your company alone?

☐ <u>better</u> with a partner ☐ <u>worse</u> with a partner

Please tell us how working together with a partner affected your decision making in the game.

____

____

____