Introducing Young Children to Complex Systems through Modelling

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In recent years, educators have been calling for an increased focus on complex systems across the school years. One approach to achieving this is through modelling, where children think mathematically about relevant relationships, patterns, and regularities in dealing with authentic problems. This paper reports on the different mathematical models created by three classes of fourth-grade children (9-year-olds) in working a problem that addressed the complex system of team sports. Consideration is given to the problem elements and interactions the children explored, together with the ways in which they operated on and transformed the given data.

We are surrounded by complex systems. Governments, financial corporations, school and university systems, ecosystems, the World Wide Web, the human body, and our own families are all examples of complex systems. In the 21st century, such systems are becoming increasingly important in the everyday lives of both children and adults. For all citizens, an appreciation and understanding of the world as interlocked complex systems is critical for making effective decisions about our lives as both individuals and as community members (Jakobsson & Working Group 1 Collaborators: www.necsi.org/events/cxedk16_1.html, accessed Feb., 2006; Lesh, 2006).

Complex systems have become increasingly difficult to define. Over a decade ago Horgan (1995) published an article titled, *From Complexity to Perplexity*, in which he highlighted the struggle of researchers to find a unified definition. Nevertheless, in basic terms, complex systems comprise sets of interconnected elements whose collective behaviour arises in an often counterintuitive and surprising way from the properties of the elements and their interconnections (Jakobsson et al., 2006). When dealing with complex systems, people need to understand that they are not only dealing with the realities of the systems themselves, but they are also dealing with models of those systems (Jakobsson et al., 2006; Lesh, 2006). For example, the financial decisions made by governments and corporations are based on economic models designed to convey the likely consequences of their decisions. Citizens must thus contend with the actual consequences of these model-based decisions.

In recent years, educators have expressed concerns that students display limited or no understanding of complex systems and are thus advocating for an increased focus on such systems across the P–12 curriculum (e.g., Hmelo-Silver & Azevedo, 2006; Jacobson & Wilensky, 2006; Lesh, 2006).In particular, activities involving complex systems need to be integrated within the existing school curriculum and need to begin in the early school years (Jacobson & Wilensky, 2006; English & Waters, 2005).One approach to achieving this goal is through modelling, where children think mathematically about relevant relationships, patterns, and regularities in dealing with authentic problems (English, in press; Lesh & Doerr, 2003; Lesh & Zawojewski, in press). In this paper I report on the different mathematical models created by three classes of fourth-grade children (9-year-olds) in working the final of three modeling problems implemented across the school year. The problem involved the selection of swimmers for the men's 100 metre freestyle event for the 2006 Commonwealth Games. Selecting sporting teams is an appealing and meaningful problem activity for children and provides a rich opportunity for children to learn, think about, and apply basic ideas of complex systems (Bar-Yam, 2004). Consideration is given here to the problem elements and interactions that the children explored, together with the ways in which they operated on and transformed the given data.

Mathematical Modelling

Mathematical models and modelling have been variously defined (e.g., Greer, 1997). The perspective adopted here is that models are "systems of elements, operations, relationships, and rules that can be used to describe, explain, or predict the behavior of some other familiar system" (Doerr & English, 2003, p.112). From this perspective, modelling problems are realistically complex situations where the problem solver engages in mathematical thinking beyond the traditional school experience and where the products to be generated often include complex artefacts or conceptual tools that are needed for some purpose, or to accomplish some goal (Lesh & Zawojewski, in press). In contrast to typical school problems, modelling problems do not present the key mathematical ideas "up front" for children. Rather, the important mathematical constructs are embedded within the problem context and are elicited by the children as they work the problem. The problems allow for various approaches to solution and can be solved at different levels of sophistication, enabling all children to have access to the important mathematical content.

The modelling problems developed as part of my research are multidimensional: they include background information and "readiness questions" on the theme of the problem, detailed problem criteria, tables of data, and supporting illustrations. The multifaceted models that the children are asked to construct not only represent their end-products but also reveal a great deal about the thinking processes they used in creating them. Because children's models should be applicable to other related situations, my research has engaged children in solving sets of related problems that facilitate model application and adaptation (e.g., English & Watters, 2005; Doerr & English, 2003).

Another important feature of the problems is that they require the children to explain and justify their models, and present group reports to their class peers. The children thus have to ensure that what they produce is informative, "user-friendly," and clearly and convincingly conveys the intended ideas and processes. Because the children solve the problems in small groups, each group member has a shared responsibility to ensure that their final product does meet these criteria.

Design and Methodology

A multilevel collaborative design (English, 2003), which employs the structure of the multitiered teaching experiments of Lesh and Kelly (2000), was adopted for this study. Collaboration of this nature focuses on the developing knowledge of participants at different levels of learning, including the classroom teachers whose participation is an essential factor. At the first level of collaboration (the focus of this paper), children work in small groups to solve the modelling problems. At the second level, their teachers work collaboratively with the researchers in preparing and implementing the activities. At the third level, the researchers observe, interpret, and document the growth of all participants. Multilevel collaboration is most suitable for studies of the present type, as it caters for complex learning environments undergoing change, where the developmental processes and the interactions among participants are of primary interest (Salomon, Perkins & Globerson, 1991).

Participants

Three classes of fourth-grade children (9 years) and their teachers participated in the first year (2005) of this study (in 2006 the children and their fifth-grade teachers are participating in a new set of modelling problems). The classes represented the entire cohort of fourth graders from a private prep-12 college situated in a regional suburb of Queensland. The school principal and college mathematics head provided strong support for the project's implementation.

Procedures and Activities

In January, 2005, the fourth- and fifth-grade teachers participated in two half-day workshops on mathematical modelling problems and their implementation in the classroom. Meetings during first term, 2005, were held with the fourth-grade teachers to plan preliminary modelling activities, which were implemented early in term 2.These activities included interpreting and using visual representations (e.g., simple tables of data, basic diagrams), conventionalising representations (i.e., using simple notations and inscriptions), explaining and justifying mathematical ideas, constructing simple mathematical arguments, conveying mathematical findings in explanatory text, and operating as a mathematical team member. Three comprehensive modelling problems, one for each of the remaining terms, were designed in collaboration with the teachers and implemented across four 60-70 minute sessions per term.Planning and debriefing meetings were held with the teachers prior to and following the implementation of each problem. The last problem, the *Friendly Games*, is the focus of this paper. This problem served as a model adaptation activity where the children extended and adapted the ideas and processes they had developed on the first two problems (these problems involved [a] determining the best light conditions for growing beans and [b] determining winners of a paper airplane contest, given their times in the air and distances travelled in a straight path).

For the Friendly Games problem, we presented the children with an initial readiness activity containing background information on the history of the Commonwealth Games and a table of data displaying the men's 100 metre freestyle world records from 1956 to 2000. The children answered a number of questions about the information and the table of data given. In the second session, we presented the modelling problem comprising the data displayed in Table 1 and the following problem details:

> The Australian Commonwealth Games Committee is having difficulty selecting the most suited swimmers for competing in the Men's 100m Freestyle event. They have collected data on the top nine male swimmers for the 100m Freestyle event.Table 2 (Table 1 in this paper) shows each of the swimmer's times over the last 11 competitions. As part of the Commonwealth Games Committee you need to use these data to develop a method to select the two most suited men for this event. Write a report to the Commonwealth Games Committee telling them who you selected for the Australian team and why.You need to explain the method you used to select your swimmers. The selectors will then be able to use your method to select the most suitable swimmers for all the other swimming events.

The children worked the problem in groups of three of four over the next two sessions. The children were not given any directions on how to tackle the problem. In the fourth session, the children presented group reports on their models to their peers, who, in turn, asked questions about the models and gave constructive feedback.

Data Collection and Analysis

In each classroom, one group of children was video-taped and another group audio-taped in each session. The children's group reports and their responses to their peers' comments were also video-taped. Other data sources included classroom field notes and all of the children's artefacts (including their written and oral reports). The video- and audio-taped data were transcribed for analysis. All of the transcripts were reviewed several times to identify the ways in which the children interpreted and re-interpreted the problem, their decisions on which elements to address, the interactions they explored among the elements, the operations they applied to the data, and how they transformed selected data.

Results

In reporting some of the results of the children's model development, consideration is given first to the problem elements and interactions the children explored. Next, a selection of models generated across the classes is presented.

Identification of Problem Elements and Interactions

The following elements and interactions were considered by the children, although not all groups addressed all of these.

The swimmers' times. In identifying and comparing the swimmers' times, the children frequently discussed the relationship between the number of seconds and the 'best time.' As one child asked, "The lower the better, or the higher the better?"

The DNCs ('did not compete'). This element generated a good deal of discussion, with some children choosing to ignore it while others considered it a significant factor in their model development. Issues that arose included how the number of DNCs impacted on the overall time totals of individual swimmers and how the number and recency of the DNCs impacted on a swimmer's potential performance.

The PBs ('personal best times'). Some groups ignored this element, especially as some of the PBs listed (which were obtained from the website indicated in Table 1) were higher than some of the individual race times. Issues that arose in the children's discussions included the recency of a swimmer's PB ("they didn't happen so recently;" "we don't know when the personal best time was done") and thus its relevance to future team selection, and the extent of variation of swimmers' times from their PBs.

The recency of events. This element was addressed from a few perspectives. How recently a swimmer scored a best time was considered by some children to be an important factor in team selection: the more recently a best time was recorded, the better the indication of future performance.Hence, some children decided to ignore the 2003 and 2004 events.

The status/level of events. A swimmer's best time in relation to the level of the swimming event in which it was recorded was addressed by a couple of groups. For example, a best time achieved in the 2002 Commonwealth Games would be considered more significant than a best time scored in the 2003 Telstra Australian Championships.

Children's personal knowledge. In the early phases of working the problem, children's knowledge of the swimmers' history and their public image sometimes came to the fore. For example, Ian Thorpe was clearly favoured as a team member as was Michael Klim. As one child said, “Oh I vote Michael Klim and Ian Thorpe.” A group member retorted, “We are not voting; this is not a game.” The children had to push aside their personal biases and focus on the given data.

A Selection of Models Generated

The children generated a range of models in solving the problem. Included are the following, which were gleaned from the children’s group work and their final reports to peers.

Model no. 1. Children aggregated all the times for each swimmer, ignoring the DNCs “because we had no idea why they did not compete.” PBs were not taken into account as “they didn’t happen so recently.” The two swimmers with lowest times were chosen, namely, Michael Klim and Cameron Prosser (other children were aware of the difficulties with this approach, as evident in those who calculated mean times).

Model no. 2. Only the most recent events were considered, namely, those of 2005. The two swimmers who had scored the best times in these events were selected, namely, Michael Klim and Andrew Mewing.

Model no. 3. Children chose the swimmers with the least number of DNCs and, from this group, selected three swimmers with the lowest times.In selecting the two best swimmers, the children considered the PBs of the three swimmers and chose the two lowest PBs (“We were looking for the less time, because the quickest and fastest.”). Eamon Sullivan and Andrew Mewing were selected.

Model no. 4. As a first step, children eliminated those swimmers who had scored times that were 50 seconds and over. Next, for each of the events listed, the children circled the fastest time. The swimmers with the greatest and second greatest number of circled times were chosen, namely, Ian Thorpe and Michael Klim. One group noted, “You can use this method on all the swimming events, because we tried it on all the races and it worked.”

Model no. 5. One group explained their model as follows: Step 1 - We circled the three best times for each swimmer, not including their personal best times. We added their three best times together. Step 2 - We crossed off Ian Thorpe because he hasn’t swum for more than a year. Step 3 - We next crossed off all the swimmers that had all of their three best times over fifty seconds. Step 4 — We looked at the lowest times and chose the two best swimmers.They were Ashley Callus and Michael Klim.

Model no. 6. In each race, children awarded one point to the swimmers who came first and one point to those who came second. They totalled each swimmer’s scores and calculated the mean (“We divided it by the number of events they played in”). In identifying Ian Thorpe and Michael Klim as their choices, the children explained, “We were going to chose Ashley Callus, but he didn’t get many good records on his races.”

Model no. 7. One group stated that they selected the two swimmers, Ian Thorpe and Michael Klim, by “investigating the averages.” The group explained, “It turned out that Ian Thorpe had the best average and Michael Klim had the second best. The averages calculate the time the swimmer would approximately get in the Commonwealth Games; that is why the averages are important.”

Model no. 8. One group explained that they decided on the two best swimmers in two ways: First, the children calculated the mean time for each swimmer. Second, the group considered each swimmer in turn, commencing with the swimmer’s 2002 Commonwealth Games time and finding the difference between it and the next event (2003 Telstra

Australian Championships). This process was repeated for each successive event. If there was an improvement, the children added the difference between the two times (ignoring the decimal point); if there was a decline, the difference was subtracted from the running total.The group reported as follows: "Dear Commonwealth Games Committee, we have chosen two of the best swimmers for the Commonwealth Games. Those swimmers are Michael Klim and Andrew Mewing. We have decided by two ways. The first way was doing the mean. The mean is when you add all the numbers in the section of numbers and divide it by the numbers you add. We did not count the DNC. The second way was we started from the Commonwealth Games (and progressed) to the FINA World Championships. For example, we added the score when they get quicker and subtracted points if they were slower in the next race. For DNC we gave it a zero. If you calculate it, you will find that it is Michael Klim and Andrew Mewing."

We were rather surprised by the children's calculation of the mean, as this had not been covered in the classroom curriculum. In one classroom, the teacher engaged a group of children in the following discussions:

Teacher: Why were the averages important? And how did you work out averages?

James: We worked it out by adding up all the scores, adding up all the times, and then dividing it by how many events they had competed in.

In trying to probe further the children's understanding:

Teacher: ….you told me you divided the first by three because…

Luke: That's how many times the person actually swam.

Teacher: Did all swimmers do three races?

Luke: No.

Teacher: If somebody swam in four races what did you do then?

Luke: You had to divide it by four because it's not really fair if … someone competes three times and the other person competes like eight times because eight times could get a higher amount.

Discussion and Concluding Points

Increasingly, citizens need to deal effectively with the vast range of complex systems in their world. School curricula need to incorporate experiences that equip children with the rudiments of understanding and working with complex systems. Mathematical modelling is a powerful vehicle for doing so. The present modelling problem involving the selection of team members for the 2006 Commonwealth Games is an ideal activity for children to learn, think about, and apply basic ideas of complex systems.

In developing their models, the children identified a range of elements and considered interactions among these elements. For example, the DNCs were ignored by some children but were considered by others to be key factors. The interaction between the number of DNCs and a swimmer's overall time total was addressed by several groups of children.

In contrast to traditional problem solving, the models developed by the children provided valuable insights into the range of mathematisation processes they employed.These processes included eliminating data, ranking and aggregating data, assigning scores, calculating and ranking means, and aggregating differences between successive sets of data.Importantly, the children developed these processes themselves during the course of problem solution.

Although not addressed here, it is worth commenting on the opportunities for critical reflection provided by modelling activities of the present type. In responding to the models presented in the class group reports, the children displayed a range of questions. Among the more sophisticated were the following: “How did you justify your answer?” “What was one thing you learnt?” “Would you use that strategy in another problem?” “Do you think there are other ways to do it to come up with a different answer?” “What was the hardest and most easiest part [sic] about your strategy?” and “Before you worked your answer out, before you worked it out, what was your estimate or prediction?”

In sum, introducing children to complex systems through mathematical modelling enables them to deal meaningfully with comprehensive, real-world problem situations that capture their interest and commitment to solution. Team sports represent one such avenue for exposing children to the intricacies of complex systems.

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Table 1

*Men's 100m Freestyle Results Recorded by Australian Competitors (seconds)**

Competition	Ashley Callus	Michael Klim	Eamon Sullivan	Ian Thorpe	Andrew Mewing	Antony Matkovich	Patrick Murphy	Casey Flouch	Cameron Prosser
2005 FINA World Championships	DNC	49.32	DNC	DNC	49.99	DNC	DNC	DNC	DNC
2005 Telstra Grand Prix	DNC	50.04	51.64	DNC	50.95	DNC	50.96	DNC	51.28
2005 Telstra Trials	50.24	49.02	50.05	DNC	49.72	50.25	50.38	51.30	51.43
2004 Telstra FINA World Cup	DNC	DNC	49.82	DNC	48.96	49.69	DNC	49.08	DNC
2004 Athens Olympics	50.56	DNC	DNC	48.56	DNC	DNC	DNC	DNC	DNC
2004 Telstra Grand Prix	DNC	50.44	50.35	49.23	51.09	52.17	51.20	50.91	51.28
2004 Telstra Olympics Team Trials	49.31	49.78	50.06	48.83	49.98	50.15	50.48	50.51	51.57
2003 Telstra FINA World Cup	47.93	DNC	50.24	49.36	DNC	49.50	49.46	49.11	50.55
2003 Telstra Australian Championships	49.07	DNC	51.86	49.07	50.52	50.58	50.95	50.20	DNC
2002 Commonwealth Games	49.45	DNC	DNC	48.73	DNC	DNC	DNC	DNC	DNC
Personal Best Times	48.92	48.18	50.06	48.71	49.72	50.15	50.29	50.20	49.38

DNC: Did not compete.

** Best time across heat, semi final, and final*