Time Series – its place in the secondary school curriculum

Rachel Passmore[1], Maxine Pfannkuch[2]

[1]University of Auckland, Auckland, New Zealand
[2]University of Auckland, Auckland, New Zealand

Abstract
Time Series has been a topic in the New Zealand curriculum since 1996. New Zealand is one of the few countries that include time series specifically in the secondary school curriculum as a topic in its own right. This paper discusses the motivation for its inclusion and examines the changes in the teaching and learning of time series that have occurred since its introduction over 25 years ago. Changes include the integration of data visualisation software into the teaching, learning and assessment of this topic as well as a shift in emphasis to encourage the development of higher levels of reasoning. Challenges and opportunities for teachers and students are identified and pedagogical solutions are presented. Some suggestions for handling COVID-19 affected time series within the limitations of the secondary school curriculum are presented.

Key Words: Time series, secondary school, New Zealand, COVID-19

1. Introduction and Background

During the last 18 months more people than ever before from all over the globe have been regularly exposed to time series graphs; in particular, graphs tracking the number of new COVID-19 cases have frequently appeared in all forms of media. Such graphs have dramatically demonstrated exponential growth in cases resulting from an 'R value' greater than 1, and many people have learned to interpret projections and the assumptions behind them. However, a demand for those with an ability to analyse time series is not new: - numerous disciplines, including economics, biological sciences, medicine, and social sciences, have always had a strong demand for time series expertise. Given the field of time series has such a wide application over so many different disciplines, it is not particularly surprising that in New Zealand, the study of time series was introduced into the final year of secondary school as a topic. It is perhaps more surprising that other countries have not followed suit.

In this paper I will outline the development of the time series topic in the New Zealand curriculum over the last 25 years, and the motivation for this development. An explanation is provided on how software and statistical techniques used prior to COVID-19 have been adapted to permit their continued use in secondary schools despite the massive disruptions observed in many time series and the limitations of what is appropriate at this level.

1.1 Brief History of Time Series in the New Zealand Curriculum

The topic of time series has been offered during the last year of secondary school in New Zealand since 1996. In the early days, the topic was dealt with on a very procedural basis with students undertaking a series of calculations, with little or no engagement with the contextual setting of the time series. In 2013, a major overhaul of the statistics secondary school curriculum took place and members of the New Zealand Statistics Association (NZSA) Education group sought to close the gap between the statistics being practised by professional statisticians and the statistics being taught in schools. This was part of a wider call from eminent researchers for the automation of calculations, production of informative data visualisations and greater engagement with the context of the data within statistics curricula (Cobb, 2007; Moore, 1997; Tukey, 1977). With the introduction of a free software package, *iNZight*, (Wild, n.d.), developed at the University of Auckland, these aspirations could be realised; this technological development enabled the topic of time series to be liberated from the production of tedious calculations and shift towards deeper interpretation of and insight from the data. These changes were also in line with the direction being taken by the statistics curriculum, to promote higher order thinking through the investigation and analysis of real data.

2. The Impact of Curriculum Change

2.1 Outcomes of 2013 Curriculum Change

The impact of the 2013 curriculum change on the teaching and learning of time series was the focus of my Master's thesis (Passmore, 2016). The research involved the development of a framework to categorise the types and levels of reasoning required for time series to determine whether the curriculum change had indeed shifted learning outcomes towards higher levels of thinking. The framework described six hierarchical levels of reasoning associated with time series, ranging from elementary skills such as reading an individual item of data from a time series graph through to critical analysis and interpretation of a statistical model (Passmore, 2018). Student work from before and after the curriculum change was analysed and coded against this framework. Students who sit the time series assessment are given one of three pass grades; results showed that after the curriculum change the mean level of reasoning had increased for each grade, with the biggest increase (17.4%) in level of reasoning found at the highest grade. The new version of the time series topic permitted students to access higher order levels of reasoning, in fact, examples of the highest level of reasoning were only found in student work submitted after the curriculum change.

An exception was an increase in a lower level of reproductive-type reasoning which initially appeared to contradict the overall shift towards higher levels of reasoning. A typical skill that was categorised at a low level of reasoning was a description of the long-term trend. Prior to the curriculum change, teachers often used well-behaved time series, that had been manipulated to reveal clear linear long-term trends and regular seasonal patterns. After the change, teachers were encouraged to use real time series which seldom followed such regular patterns. Thus, the task of describing the long-term trend became a more complicated task. In my research, description of the long-term trend was categorised as a low level of reasoning task, but the adoption of real data revealed a range in complexity within that level, from easy to more complex reproductive- type reasoning (c.f. Assessment pyramid of Verhage & De Lange, 1997).

It was interesting that some teachers interviewed as part of the research perceived the repetitive calculations of moving averages and seasonal effects, which formed the previous time series assessment, as at a higher level of reasoning than interpretation of the outputs from *iNZight*. Such teachers distrusted the software 'black box' and would have reinstated procedural calculations given a choice. In response to the views of such teachers, a change in pedagogical approach was proposed based on strong research evidence (e.g. Arnold et al., 2011). Teachers were encouraged to include 'by-hand' activities for students prior to the introduction of new software, thereby introducing them to the underlying techniques, albeit at a simple level, utilised by the new software before exposure to the actual software. Tutorials which permitted students to examine the effects of different smoothing techniques were developed and showcased in professional development sessions.

The success of the 2013 curriculum change to move learning outcomes towards higher levels of reasoning would not have happened without the development of free software such as *iNZight*. Any transition to new software within the secondary school environment is often treated with caution and to shift a whole cohort of teachers to a new software package usually takes a considerable number of years. It is a quite remarkable testament to the appropriateness and ease of use of the software, that during the two years of my research all participants had moved from EXCEL to either *iNZight* or *NZGrapher* (Wills, n.d.). A key factor in this rapid transition was the inclusion of outputs from the software packages in official documents such as exemplars posted by the national qualifications' authority and the provision of accessible professional development.

Although the 2013 curriculum change did transform the time series taught at secondary school, it was disappointing that the full potential of the new software was not exploited. One data visualisation option, easily created using *iNZight,* permits the comparison of several related time series on the same screen. Such a visualisation can assist students to identify similarities and differences and to speculate on links between the series, promoting a deeper understanding of the time series under investigation.

2.2 Statistical methods employed to analyse time series

The two main techniques employed by *iNZight* are Holt-Winters for prediction and the seasonal trend LOWESS for series decomposition. Such techniques were new to secondary school teachers in New Zealand, as few studied time series as part of their study or training. Professional development and extensive resources were provided for teachers to upskill them in this area. It was never proposed that these techniques should be taught as part of the curriculum, but it was deemed important for teachers to have some understanding of the techniques that the new technology used. Given the investment that teachers had made to integrate the new technology into all aspects of their teaching, learning and assessment, many were keen to continue using such tools despite the disruption caused to so many time series by the impact of COVID-19. The challenge was to develop some mechanism by which teachers could continue to use *iNZight* yet still allow them to analyse time series, dramatically impacted by COVID-19, in a meaningful way.

A common time series used by teachers, visitor numbers to NZ, demonstrates the problem of using the software when time series have been disrupted (Figure 1). The model used data up to January 2020 to make predictions (shown in pink), but the black line showed that the predictions were inaccurate and meaningless. The Holt Winters model used to produce the predictions assumed that previous patterns and trends would continue when obviously they did not.

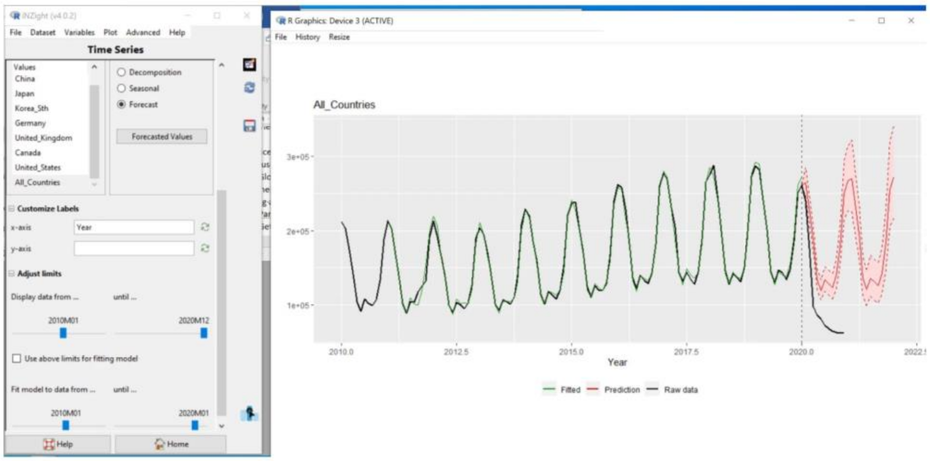

Figure 1: Forecasting visitor numbers after January 2020 using the data from 2010-January 2020 (Wild & Passmore, 2021)

Other time series such as the fruit and vegetable component of the NZ consumer price index (CPI) up until December 2020, (Figure 2) did not experience similar disruptions and the projection of past trends and patterns did produce accurate and meaningful predictions. Teachers were recommended to use such time series for assessment purposes whenever possible.

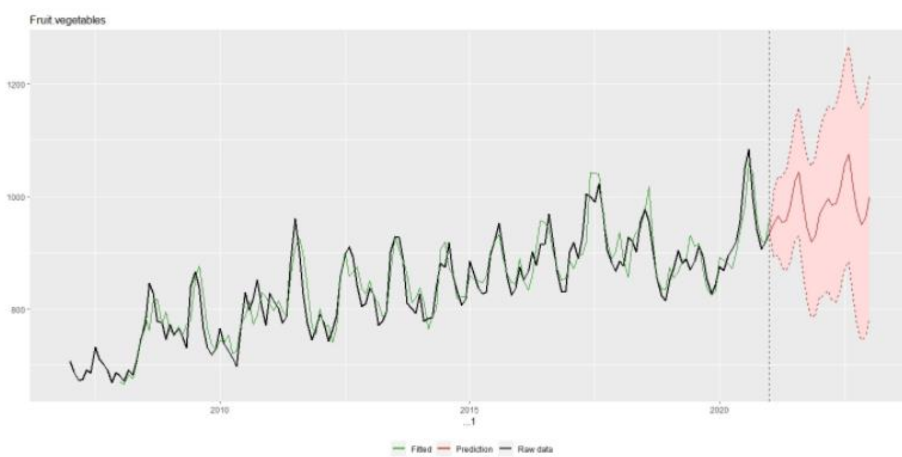

Figure 2: Forecasting average fruit and vegetable price index values using data up until December 2020 (Wild & Passmore, 2021)

3. Modelling Disruptions in Time Series

3.1 Disruptions in time series

Disruptions to time series are a relatively common event for time series modellers to contend with. Disruptions may be caused by price changes, policy changes, definition changes and environmental changes as well as pandemics. Recovery from such disruptions can be handled in several ways, depending on what information about the disruption is available. For example, if a time series has been disrupted by a price change, there may have been other price changes in the past, so estimates of the impact of a price change can be made and the time taken for levels to recover can be made and predictions adjusted accordingly. The four most common patterns for a disruption are:

1. Permanent shift to the level of the time series, either up or down.
2. A 'blip', either up or down, perhaps caused by a one-off event; time series resumes pre-blip level and patterns afterwards.
3. Permanent shift to the level of the time series that does not happen all at once.
4. Sudden shift to the level of the time series which gradually over time reverts to its pre-sudden shift level.

Intervention analysis is often employed to cope with such disruptions and can be modelled using an Autoregressive Integrated Moving Average Model (ARIMA) although other models are possible too. Such techniques are beyond the knowledge of most New Zealand secondary school teachers and far beyond expectations for secondary school students. In response to requests from New Zealand teachers, the NZSA Education Group were asked to suggest options that teachers could use in their teaching and learning activities, which would allow students to still use *iNZight* but with modified predictions based on different recovery assumptions (Wild & Passmore, 2021).

3.2 Adjustment of predictions following disruption in time series

Suggestions were restricted to skills that were within the capabilities of secondary school students and included the following suggestions for each type of disruption.

Permanent shift to level of time series. Remove data post shift and predict from the last pre-shift data point. Make an assumption about the size of the shift and reduce/increase projections by that amount. This type of disruption can thus be handled by employing *iNZight* in the usual way, but then adjusting projections by the estimated size of the shift. At secondary school level, this does not have to be a sophisticated estimate; any reasonable justification for the size of the estimate should be sufficient.

Blip caused by one off event. Remove the unusual value from the data set and replace with an interpolated value, then calculate projections using *iNZight* in the usual way.

Permanent shift that happens over time, such as a gradual decline. This could be modelled by adding an additional variable in the model that decreases over time. For this type of disruption two assumptions need to be made; the size of the shift, and the length of time taken for the shift in mean level to occur. This is outside the scope of secondary school students in terms of assessment but could be utilised in stimulating teaching and learning activities. For example, students could adjust projections by applying a linear or non-linear decay element.

Sudden shift that gradually recovers to pre-disruption levels. This could be modelled by adding an additional variable in the model that increases over time until pre-disruption levels are regained. This type of disruption again provides several teaching and learning opportunities including discussion around what happens to the seasonal component after such a shift (largely disappears, but assumptions required as to when the seasonal component might resume and whether it would be the same as before the disruption). If the visitor number time series is used (Figure 1), students could make assumptions around when travel bubbles with certain countries might open up, and then using past proportions of visitors from these countries, adjust projections accordingly. Once a travel bubble opens, assumptions also need to be made about how quickly, if ever pre-COVID-19 levels might resume. Depending on the assumptions made, projections calculated using pre-COVID-19 data can be adjusted, thus allowing students and their teachers to continue using *iNZight.*

4. **Conclusion**

Teaching the topic of time series at secondary school level provides an excellent opportunity for students to engage with a wide range of contexts and to develop their statistical reasoning to a high level. Study at this level helps prepare students for further study of time series, and for a wide range of employment opportunities which also demand such skills. The opportunity has only been possible in New Zealand because of an innovative statistics curriculum change that was implemented in tandem with the integration of new technology. Critical to the shift has been an extensive professional development programme for teachers, as well as the integration of the new technology in all aspects of teaching, learning and assessment of time series.

Time series as a topic, if integrated with technology, can produce a rich learning area for secondary school students and as such I feel its inclusion in the secondary school curriculum is entirely justified. Disruptions to time series caused by COVID-19 although problematic since usual tools for their management were beyond the scope of secondary school students, can be viewed as a source of excellent learning opportunities if handled as suggested in this paper. Further improvements to the topic of time series are still possible to ensure that the full benefits of shifting to new technology can be realised.

References

Arnold, P., Pfannkuch, M., Wild, C., Regan, M., & Budgett, S. (2011). Enhancing students' inferential reasoning: From hands on to movies. *Journal of Statistics Education*, 19(2), 1-32.

Cobb, G. (2007). The Introductory Statistics Course: A Ptolemaic curriculum? *Technology Innovations in Statistics Education, 1*(1), 1-15.

Moore, D. (1997). New pedagogy and new content: The case of statistics. *International Statistical Review, 65*(2), 123-165.

Passmore, R. (2016). The impact of curriculum change on the teaching and learning of time series. Master's Thesis, The University of Auckland. http://hdl.handle.net/2292/29102

Passmore, R. (2018). Time series - Its place in the secondary school curriculum. In M.A. Sorto, A.White & L.Guyot (Eds). *Looking back, looking forward. Proceedings of the Tenth International Conference on Teaching Statistics (ICOTS 10).* Kyoto, Japan: International Statistical Institute. https://iase-web.org/icots/10/proceedings/pdfs/ICOTS10 2H3.pdf

Tukey, J. (1977). *Exploratory Data Analysis.* Addison-Wesley.

Verhage, H., & De Lange, J. (1997). Mathematics education and assessment. *Pythagoras*, 14-20.

Wild, C. (n.d.). *iNZight*. https://inzight.nz/index.php

Wild, C., & Passmore, R. (2021). *Teaching Time Series in our covid affected era*. https://new.censusatschool.org.nz/resource/teaching-time-series-in-covid-era/

Wills, J. (n.d.). *NZGrapher*. https://grapher.jake4maths.com/