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PREPRINT

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by Nelisa Freitas & Johannes Cronjé

How to cite this resource:

Freitas, N., & Cronjé, C. (2022). A trip to the supermarket: Towards authentic learning design in mathematics for underprepared first-years. In T. Jaffer, S. Govender & L. Czerniewicz (Eds.), *Learning Design Voices*. Advance preprint. https://doi.org/10.25375/uct.20509101

A trip to the supermarket: Towards authentic learning design in mathematics for underprepared first-years

By Nelisa Freitas & Johannes Cronjé

Chapter in brief

This chapter describes the design principles and outcomes of a learning intervention to improve the mathematics capabilities related to mental arithmetic and arithmetic/operational skills to solve simple mathematics amongst a group of underprepared first-year Information Technology students at a large university of technology in the Western Cape, South Africa. Although these students had passed mathematics in the South African matriculation examinations, a university placement test showed that their abilities in mathematics lay at Grade 6 school level. They had very little understanding of basic concepts of mathematics as well as a general fear of the subject.

Mathematics proficiency of South African school-leavers is generally poor and unequally distributed. The key drivers resulting in the poor mathematics results include a fear of mathematics, poor teaching and inadequate resources. Authentic learning offers a means by which the mathematics proficiency of school-leavers can be addressed. Contextualisation develops mathematics concepts and authentic problems can be aligned to students' careers. The use of everyday objects allows practical exploration, contributing to realistic mathematics.

In a mixed method, sequential exploratory study, a series of learning events were designed using the Analysis, Design, Develop, Implement, Evaluate (ADDIE) model. Following principles of authentic learning, students were given online learning tasks followed by a field trip to a supermarket, where they were exposed to everyday items of various sizes and proportions. With the aid of worksheets, they learned about proportions and fractions. While only 41,27% of the students passed the pre-test, 71,45% passed the post-test. A qualitative analysis of their interview responses showed an increase in their motivation and confidence to complete the subject.

The chapter concludes with recommendations for the design of authentic learning experiences in mathematics, as well as suggestions for further development and research.

Keywords: mathematics, authentic learning, learning design

Introduction

What do you do when you discover that, although your students passed their school-leaving examination with a university-entrance pass, their knowledge of mathematics is on par with that of *primary* school-leavers when they entered university? You follow the age-old adage: *When the going gets tough, the tough go shopping!*

This chapter tells the story of an intervention designed to teach proportions and fractions to a group of under-prepared, vulnerable first-year students at a South-African university of technology. After describing the context, we consider what causes under-preparedness of South African school-leavers in mathematics. We then present a case study of a series of authentic tasks, among which students were sent to a supermarket to observe different sizes of packaging of the same product and perform a range of calculations in response. In the study informing this work, we measured students' mathematical (and more specifically, arithmetical) capabilities to establish the level at which interventions should be implemented. We then developed and tested the intervention. In this chapter, we extract design guidelines for authentic learning in assisting vulnerable, under-prepared first-year mathematics students based on the results.

International context

An Indonesian study found a high correlation between interest, attitude, habit and performance in mathematics (Hashim et al., 2021). The concept of "attitude" has been refined to encompass patience, confidence and willingness (Yeop et al., 2019) One solution to first-year underpreparedness is to identify students' mathematical background and develop appropriate interventions (Lake et al., 2017). Hands-on activities can also strengthen students' existing mathematical concepts (Banilower et al., 2013) and problem-based learning has been found to significantly improve critical thinking in mathematics (Juandi & Tamur, 2021).

National context

The lamentable state of mathematics education in South Africa is well-documented. Studies such as the Trends in International Mathematics and Science Study (TIMSS) and others in 1995, 1999, 2003, 2007, 2011 and 2015 reported that Grade 8 learners performed at the lowest levels where only a basic knowledge of mathematics had been achieved (Reddy et al., 2016). Three-quarters of South African learners had not acquired even a minimum set of mathematics skills by Grade 8 (DoE, 2006; Reddy et al., 2015; Venkat & Graven, 2008). The South African mathematics curriculum reflects underperformance in mathematics at all levels (Jojo & Mybert, 2015). Although the curriculum is modern and has been benchmarked internationally (Alex & Juan, 2017), in the 2011 TIMSS, South Africa's mathematics performance was in the bottom six of the 63 participating countries (Visser et al., 2015). While the 2015 results show improvement, South Africa is still in the lower order, with the Eastern Cape (which is a feeder area of the university to which this case refers) being the lowest achieving of the nine South African provinces (Alex & Juan, 2017). There is therefore misalignment between students' pre-tertiary mathematical experience and the level of first-year university mathematics they are expected to perform at (Maddock & Maroun, 2018).

Some authors argue that the curriculum misses the fundamental aspects that are needed to empower its recipients. They recommend altering the curriculum to align it with the TIMSS curriculum for mathematics. Such alignment could minimise mismatches in the cognitive domain categories of problem solving and reasoning in numbers, measurement and geometry (Ndlovu & Mji, 2012).

Although students in low-income rural areas without internet connectivity receive mathematics textbooks supplied by the South African government, they and their teachers have no access to other learning materials (Jojo & Mybert, 2015) and the textbooks are not written in the mother tongues of the learners or their teachers (Setati, 2012).

Institutional context

Poor performance of school-leavers may cause the "dumbing down" of mathematics at tertiary institutions (Maddock & Maroun, 2018). This university has a very diverse student population, many of whom are from the neighbouring province at least 500km away. They are typically the first members of their families to attend university and are from vulnerable, low-income families. English is their second or third language. To assist these students, the university Information Technology Department offers a transition programme, the Higher Certificate in Information and Communication Technology. For the mainstream programme, the institution requires a score of 36 on the South African universities' Admissions Proficiency Score scale, while the Higher Certificate requires a score of 28–35. Of all the students enrolled for the Higher Certificate, 8% had studied pure mathematics at high school, 86 % had studied mathematical literacy at high school, 4% of the students studied information technology and engineering subjects at Technical and Vocational Education and Training (TVET) colleges prior to joining the programme, and the remaining 2% had taken a year off after school to do things other than study or work.

The following transcript of a student's response summarises the plight of so many of our students:

> *I lived in Johannesburg with my parents and my younger sister. I was very good in mathematics. I went to private schools and there I had private tutors for mathematics. My father divorced my mother, and we were forced to relocate to Cape Town. We shared a bedroom in my poor grandparents' house. I was admitted in a poor Afrikaans school. I could not speak Afrikaans and mathematics was taught in Afrikaans. By the time I finished Grade 6 I was very bad in mathematics. I carried on that trajectory until I reached Grade 9, I befriended a guy that nobody wanted to be friends with because they said that he was a nerd. He was in Grade 10 and he liked mathematics and I discovered that he was also very good at it. He began to teach me mathematics. I slowly found the love of mathematics, but it was too late. I managed to get a good mark at the end of my Grade 9 final examinations. I was recommended to take pure mathematics at Grade 10 and I did. I passed my matric with a C-. However, there were a lot of applicants that had passed with A+ and B+ at the University of Technology. Therefore, I was placed in the Higher Certificate in Information and Communication Technology intervention programme.*

A total of 147 Higher Certificate students participated in this voluntary intervention described here, which involved using everyday items to teach basic arithmetical concepts.

Reasons for poor performance in mathematics

Poor mathematics performance is attributed to "students' negative attitude toward mathematics, anxiety and fear of mathematics, inadequate qualified teachers, poor teaching methods, inadequate teaching materials, overcrowded classes" (Sa'ad et al., 2014, p. 24).

This section considers the attributes of attitude to and fear of mathematics, poor quality of teaching, and lack of resources.

Attitude to and fear of mathematics

There is a significant negative correlation between mathematics anxiety and mathematics performance. Multi-step mathematical tasks increase anxiety and lower performance, as does assessment that leads to grades (Namkung et al., 2019). Anxiety also hinders self-regulated learning, student engagement and self-efficacy, and negatively impacts performance (Gabriel et al., 2020). Early development of mental arithmetic skills reduces anxiety and helps learners develop mathematical capability (Ramirez et al., 2016).

Poor quality of teaching

Teacher knowledge and instructional practices are key contributors to students' understanding of mathematics. These elements are, however, less prevalent when vulnerable students are educated (Battey, 2013). There is a lack of addressing learner behaviour, framing their mathematics ability, acknowledging student contributions and attending to learners' language and culture (Battey, 2013). Teachers move outside learners' zone of proximal development and learners do not gain relational understanding of the learning content (Siyepu, 2013).

Lack of teacher motivation and unreasonable expectations of the mathematics curricula contribute to poor learner performance. Teachers also struggle with time management and linguistic constraints when learners do mathematics in a language other than their first language (Du Preez, 2018; Maila & Ross, 2018; Waller & Maxwell, 2017).

Lack of resources

"The conservative nature of textbooks, time constraints and the dominant force of poverty remain hindrances in creating mathematics tasks that are issue centric and socially relevant to address concerns of the local community" (Yaro et al., 2020, p. 1) South African textbooks are generally considered inappropriate and lack activities that can help learners develop a relational understanding of mathematical concepts (Siyepu, 2013). The system is plagued with poor internet connectivity, clumsy or absent learning management systems and low technology software (Dube, 2020). Schools in under-resourced areas lack career guidance, parental support and funding (Maila & Ross, 2018). In rural schools, where most of our students come from, the intensity of resource-scarceness is felt even more acutely. Physical distance from school means that students arrive late; students are also often malnourished and come from homes that experience the stresses of unemployment and demonstrate a lack of parental involvement (Owuso-Addo et al., 2021).

The role of learning design in supporting underprepared university students

Against the background of a poor attitude to and fear of mathematics, poor quality of teaching, as well as a lack of resources, learning design guidelines are necessary for developing materials, activities and tasks for underprepared university students.

An effective way of dealing with teachers' lack of content and pedagogical knowledge is to provide fully developed instructional plans (Muthukrishna, 2013). In a Nigerian study, it was found that "developing positive attitude, motivation and proper guidance toward mathematics, using proper methods of teaching the subject, provision of relevant teaching materials, additional classrooms and furniture, provision of libraries and mathematical laboratories were some of the ways of improving performance in mathematics in the study area" (Sa'ad et al., 2014, p. 32). In our case, the field trip to the supermarket was an attempt at motivating students by using relevant authentic materials and, in a sense, the supermarket became our laboratory. The following section will discuss authentic learning design, the use of everyday objects in problem solving, allowing space for the unexpected, as well as flexible tutoring and mentoring (Jackson-Barrett et al., 2019).

Authentic learning

The best learning environment has a dynamic interaction between teachers, learners and tasks that provide an opportunity for learners to develop their own understanding (Siyepu, 2013). Authentic learning tasks improve comprehension, comparison and reflective problem solving (Dolapcioglu & Doğanay, 2020). Research in Canada, Ghana, India and Swaziland found that using local contexts allowed educators to develop authentic, meaningful mathematics tasks that might be called "situated mathematics" (Yaro et al., 2020).

Mathematics tasks are often designed in isolation without showing their authentic usefulness. For aspects of learning to be authentic, they need to originate from outside of the formal teaching environment and they need to use physical, real-world artefacts (Vos, 2018). Unfortunately, lecturers mainly tend to use traditional learning tasks and educators cannot design authentic learning tasks (Sewagegn & Diale, 2020).

Authentic learning (Herrington et al., 2014) places learning objectives at the centre of an open environment with tasks, resources and supports. Tasks have descriptions, details and deliverables. Resources include course content, online resources, primary resources and books, while supports include teacher support, discussion boards and mentoring, with feedback and results in a protected environment. Task resources include case studies, virtual settings and simulations. Resource supports include instructions, tutorials and quizzes, while task supports include guidelines, templates and models. Figure 1 provides an overview of the extended authentic learning design framework developed by Herrington et al. (2014).

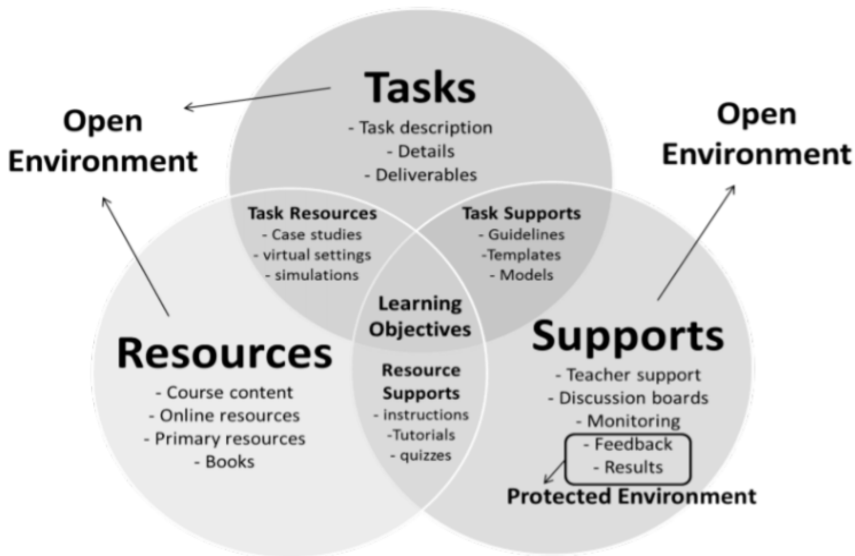

Figure 1: The extended authentic learning design framework (Herrington et al., 2014)

Authentic learning and use of everyday objects

The use of everyday objects when teaching basic arithmetic allows for practical exploration and experimentation, which contributes to realistic mathematics. Realistic mathematics resonates with the work of Vygotsky and Piaget (Das, 2020) and contributes to sense-making through semiotic mediation, when teachers and learners co-create meaning in their interpretation of mathematical problems and the development of solutions (Siyepu, 2013). For example, the use of nutrition-related content such as portion size provides a cross-curricular opportunity to make mathematics highly relevant to learners (Follong et al., 2020).

Problem solving and allowing space for the unexpected

Mathematics tasks can be described on a coordinate system that has two axes: “contrived-authentic” and “clean-messy” (Leung et al., 2020). Paredes et al. (2020) found that along the contrived-authentic continuum, future teachers struggled to create realistic mathematics tasks but they could create open and authentic tasks in the higher cognitive domain. “Messy” contextualisation develops authentic problems that are related to real-world applications connected to students’ future careers. These contextualised problems help students to engage with the material, link concepts and organise mathematical ideas (Valenzuela, 2018).

To develop the creativity and critical thinking skills required in solving mathematical problems, students should be encouraged to use various alternative solutions. A creative problem-solving learning model would include defining, designing, developing and disseminating materials (Sari et al., 2018). In the development of our programme, Kolb’s (2017) "learning cycles” were used in the design, development, implementation and evaluation of the programme. Kolb proposes four cycles: reflective observation, abstract conceptualisation, active experimentation and concrete experience. The sensemaking approach in the experiential learning cycle is grounded in reviewing intelligibility, intuitive knowledge, meaning and natural understanding of students’ usage of level of knowledge, application and/or thinking skills.

Flexible tutoring and mentoring

In multicultural, vulnerable environments, it is essential to create flexible tasks and to allow learners to share what they have learned with others (McLoughlin & Oliver, 2000). Flexibility is obtained by offering students more than one option (Messitidis, 2018) and by encouraging reflective practice (Cornelius et al., 2011).

Mentoring is even more powerful than authentic tasks in enabling creativity and critical thinking (Weng et al. 2021). This may be because of the patterns of interest that mentors spark and the development of student identity (Weng et al., 2021).

The trip to the supermarket

This section presents the case and its results. A mixed method, sequential exploratory design (Creswell, 2013) was implemented to collect, analyse and present numerical and narrative data. The design consisted of three pre-tests, an intervention and a post-test. These were augmented by interviews and focus groups. For ethical reasons, students’ anonymity was guaranteed and participation in the intervention was voluntary with withdrawal allowed at any time. The research took the form of a design experiment using the

Analysis, Design, Development, Implementation, Evaluation (ADDIE) model (Howie & Plomp, 2002; van den Akker et al., 2013).

Analysis

Students' mathematical skills were assessed in three pre-tests. They worked without aiding tools and materials, such as calculators and formula sheets, so that their mental arithmetic skills could be gauged, as well as their foundational arithmetic/operational mathematical skills to solve simple mathematics problems (Ludvigen et al., 2016). The three pre-tests were: (a) a first pre-test – Grade 12 mathematics; (b) a second pre-test – Grade 10 mathematics; and (c) a third pre-test – Grade 6 mathematics. All students failed the first two pre-tests and obtained a mean score of 41,27% in the third. A post-test was conducted in the evaluation phase.

Design, development and implementation

Five activities were designed. The first activity was a visit to a local supermarket. At the supermarket, the students and the lecturer walked around the supermarket picking up, weighing and evaluating different everyday items. Figure 2 illustrates some of the everyday items used to assist students to contextualise different weights and volumes.

Figure 2: Examples of products referred to in the supermarket activity

The supermarket visit was conducted to help students integrate and balance their conceptual understanding of basic mathematics skills regarding proportion. They had to compare the sizes of a 5kg, 1kg, 500g and 250g package of the same product, for instance, and in that way visualise the fractions.

For the second activity, students were given a worksheet requiring them to convert metric units of mass and volume. For example, students were asked to convert 96ml to litres and 100g to kilograms.

In the third activity, students were given a link to a carrot cake recipe that had been audio recorded by the lecturer. This activity was a home-based tutorial activity and the students used household utensils to measure the ingredients stated on the lecturers' audio recording.

For the fourth activity, students were divided into groups that experimented by tossing a coin and guessing on each toss whether the coin would land on a tail or on a head. They recorded their findings and discussed their observations.

For the fifth activity, the research participants played monopoly with dice and cards. Edutainment, a combination of education and entertainment, was used to help the students understand the theory of chance. Our intent was to increase the students' self-expansion, which may lead to self-knowledge and truly widened consciousness (Engeström, 2015).

The intervention was part of a class tutorial module in the first 16 weeks of the academic year, covering basic arithmetic taught to 11- to 12-year-old pupils in the last phase of primary school in South Africa. The first tutorial was based on number theory. The voluntary class tutorials were conducted in a university lecture room that sat 30 students. Two hours 14:00 to 16:00 were allocated to student and lecturer consultation. Students could book time on the lecturer's digital calendar.

Lecture notes, class materials and preparatory tutorials were placed on the university's learning management system. A prerequisite for attending the tutorials was that students studied and completed preparatory exercises at home, allowing for the transformational and transactional acquisition of mathematical knowledge (Meltzer, 2002). When students had difficulties solving problems, they presented it to their groups. If the group failed to solve the problem, the tutor became involved and solved the mathematical problem/s on blackboard with chalk and the students participated.

Evaluation

During the evaluation phase, the student assessment scores were compared. We also evaluated their test scripts, observed the students and conducted one-on-one interviews with purposively selected students (Palinkas et al., 2013). Students were selected based on the scripts that reflected variations in the their computations and methodologies for solving simple foundational arithmetic problems.

Discussion

A comparison of pre-and post-test results showed that the students had improved from a mean score of 41,27% to 71,45%. In this section, we consider the design principles that emerged in this process and support those principles with what the interviews revealed about students' attitudes towards mathematics, pedagogy, and resources.

Attitudes towards mathematics

A key to the success of the intervention was that the students recognised its value. As one student stated:

> *I recognised that the module was my second chance at acquiring mathematical skills.*

They also recognised the importance of taking responsibility for their own learning and confirmed the relationship between confidence and improved skills (Gabriel et al., 2020). One student stated:

> *I booked time with the tutor and I enquired how I could structure my study time. Once I got suggestions, I implemented them. I prepared for all my class tutorials off campus. I spent 30 minutes every day in the beginning and as I gained more confidence, I spent more time and my quantitative skills increased.*

The dynamics between attitude to mathematics and teacher support were clearly illustrated in this student's response:

> *I was an A student in high school. I became very proud because all the students used to come to me for help. Later on, I hated the responsibility and I stopped practising mathematics and I stopped doing my homework. I got bad and one day the teacher asked me to solve a mathematical problem on the board: I said I did not want to. She said I should go and study bookkeeping, and mathematics was not for me. I stopped trying to show her I did not care. When I got to the UoT I was curious to see If I could learn and get back to the level that I start helping other struggling students. I*

> *became good and I enjoyed having other students coming to me to ask questions. I began helping the tutor and this helped me even more because I used to go and ask if I was struggling with some mathematical concepts.*

Teaching and learning

The motivational role of lecturers is evident from these students' responses:

> *Quantitative Techniques class tutorials were a wonderful experience for me, and it made me realise that there are people out there who have my interest at heart and that I only need to read for my own understanding.*

Of particular interest is also the involvement of management:

> *The university professor that was heading the project was very nice and he came to visit us during the class tutorials from time to time.*

Fully developed instructional plans allowed students to plan their time:

> *I was amazed to see that the tutorials were planned well. I had time in between my hectic schedule.*

Students valued authentic tasks and everyday examples:

> *The lecturer took some of us out to have real-life experiences. She used stories that were familiar to us in her examples.*

Addressing the zone of proximal development for this diverse group was difficult:

> *In the beginning I was bored when we went through primary school work. I thought that I knew it all. Then I realised that there were numbering systems that I had never learned, like the binary numbering system. I enjoyed the fact that I could speak to the tutor and say I was bored and she would repeat the reason why we had to go through all the work from Grade 6 to Grade 12.*

But we did get it right in the end:

> *I liked the subject, the teacher the faculty and everything around the module. I was paced at my level. I was not spoonfed, but I felt challenged enough to want to continue attending the classes.*

Resources

The use of technology, peer support and tutors allowed for a flexible approach:

> *I struggled with class non-attendance due to train problems. I missed tutorials. Sometimes when I was late, I would find out that people had moved on, so I had to do catch-up. Just after class, I would approach my classmates and ask for help. My classmates were helpful. I also read the tutorial notes and watched video materials uploaded on Blackboard by the researcher. I also used the tutor/researcher student times every Thursday and this helped me because I had the tutor focusing on me and I had to make preparations for the meetings.*

Conclusions

This section will reflect on the chapter, list the design principles and provide recommendations for further development and further research by filtering our experience of teaching underprepared first-year students through the lens of authentic learning using a field trip, real-life artefacts and a game.

Reflection

The international context of this study lies in the relationship between interest, patience, confidence and willingness of students and their performance in mathematics. Nationally, in South Africa, lack of resources, lack of teacher education and lack of student confidence leads to poor achievement in mathematics, which translates, institutionally, to underpreparedness of first-time entering students.

In this study, the problem was addressed using authentic learning; specifically the elements of tasks, resources and supports, as proposed by Herrington et al. (2014).

The tasks given to the students were taken from everyday life rather than from the IT environment because as first-years in the first 16 weeks of their course they were not familiar with the IT environment. A trip to the supermarket was more authentic. Task resources were freely available, and the case studies involved familiar activities such as shopping, flipping a coin, converting a recipe and playing a board game. There were no digital simulations and real-life settings were given preference over virtual.

Course content was made available online and additional resources were provided in the form of YouTube videos. Resource support took the form of tutorial sessions, online quizzes and formal instructions that occurred during contact sessions.

Teacher support occurred continuously through face-to-face sessions that could be pre-booked. Students were regularly monitored by the tutor and using the learning management system. The lecturer herself was also supported through the professor, as one student mentioned. Task supports took the form of guidelines and notes that were made available through the learning management system. Models took the form of everyday objects from the shelves of the supermarket.

Design principles

The design principles that emerged from the study are listed below as they emerged in terms of attitude, teaching and learning and resources.

Attitude towards mathematics

1. The intervention must be designed in such a way that students recognise both the value of the learning task and the value of the knowledge that is gained through the exercise.
2. Students should be encouraged to take responsibility for their own learning.
3. The difficulty level of learning material must be determined by understanding the relationship between students' confidence and the required skills.
4. Students' attitude to mathematics is dependent on the amount of support they receive from lecturers and tutors.

Teaching and learning

1. Lecturers should play a motivational role in addition to facilitating content.
2. Management should be seen to be actively involved in supporting lecturers and students.
3. Instructional plans should be developed in such a way that students can plan their time.
4. Authentic tasks and everyday examples add value.

5. The learning event should be designed with various points of entry and exit to allow for a diversity in students' zone of proximal development. It may be necessary to develop an easier route, as well as a more challenging route.

Resources

1. A mix of technologies should be used to allow access to under-resourced students.
2. Learning materials should be archived to allow students to catch up on missed classes or tutorials.
3. Peer support should be encouraged so that students can help one another to catch up.
4. Tutorial notes and videos should be made available via the learning management system.
5. Small-group tutorial classes are essential.

Recommendations for further development and research

Further development of authentic tasks for underprepared students should concentrate on open-ended tasks and allow students to provide their own examples of real-life instances of authentic mathematics. Instead of the lecturer taking students to the supermarket, students could be asked to bring their own examples of mathematics in action.

Research should be conducted into developing differentiated tasks to cater for the diverse abilities of students. Given that students may have problems in attending classes regularly, tasks for self-study should be developed parallel to synchronous individual and group tasks. Research should be conducted to determine the optimal balance between self-study and face-to-face classes.

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