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Physical separation techniques in water purification: an inquiry-based laboratory learning experience

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Abstract:
This article outlines a structured investigative activity for students in lower secondary school. It was developed for the Australian Mathematics and Science Partnership Programme, a government initiative intended to promote the employment of more hands-on investigations in secondary science within Australian schools. The investigation focuses on water purification and is intended to develop conceptual knowledge of this topic and also high-level skills such as experimental design, particularly in relation to identifying and controlling variables. The investigation is outlined in detail and was trialed with practicing science teachers, school students and preservice secondary teachers. All of these groups provided feedback in various forms that indicated the investigation was valuable, relevant, interesting and allowed students to take some responsibility for their own inquiry learning.

Keywords: inquiry, investigation, scaffolding, water purification

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Background and introduction

This activity is presented in the context of Australian lower secondary science. Concerns about the declining numbers of students in Australia progressing beyond compulsory science in upper secondary school have been expressed for some decades, yet those declines are still occurring (Kennedy, Lyons, & Quinn, 2014). Government funding was provided through the Office of the Chief Scientist (Australian Mathematics and Science Partnership Programme, AMSPP) to various bodies in 2014 (Ministers for the Department of Education and Training Media Centre., 2014) to develop hands-on investigative activities for lower secondary science in the hope of increasing engagement with science and the number of students proceeding to senior science. This article outlines one suite of investigative activities that spanned the different subdisciplines of science, with a focus on chemistry, at the lower secondary level. The activity was developed with AMSPP support, and undertaken by both teachers and students in a series of in-service teacher professional learning workshops run as part of the AMSPP. The learning sequence relates to water purification and has been designed to be easy to organize and complete and allows students to access progressively increasing levels of inquiry, while providing students with opportunity to develop a range of scientific understandings, skills and generic capabilities.

This article has two interlinked aims. The first is to provide a detailed descriptive account of a sequence of inquiry-based activities suitable for Year 8 Chemistry, and links to extensive resources that teachers can adopt and adapt as they see fit. The second aim is to report some data from a limited number of in-service and preservice teachers and students who undertook the sequence of activities to provide some evidence as to how it was received.

Frances Quinn is the corresponding author.

Inquiry in science

For decades it has been argued (e.g. Bybee, 2006; Goodrum, 2006; Goodrum & Rennie, 2007; Tytler, 2007) that successfully engaging students in meaningful science requires a focus on scientific inquiry. In common with other educational jurisdictions, the *Australian Curriculum: Science* aims for students to develop "an understanding of the nature of scientific inquiry and the ability to use a range of scientific inquiry methods...". Various resources (e.g. *Science by Doing*) have been developed to integrate inquiry into secondary school science, and an "inquiry slider" that categorizes different elements of inquiry along the spectrum from demonstrated to open inquiry has been developed (Cornish, Yeung, Kable, Orgill, & Sharma, 2019). Inquiry approaches that are genuinely student-centred place particular demands on teachers, who may be concerned about how much class time inquiring can consume, "covering" the syllabus (Trautmann, MaKinster, & Avery, 2004), as well as managing behaviour, and differentiation (Pablico, Moustapha, & Lawson, 2017). Inquiry approaches require a teacher to navigate a range of student expectations (Trautmann et al. 2004), as well as ideas, problems, understandings and requests for equipment, to some extent "on the fly", without the time advantages afforded by more teacher-centred approaches. Moreover, some researchers (e.g. Kirschner, Sweller, & Clark, 2006) have claimed that inquiry learning is ineffective because of insufficient student guidance.

It has been argued (Hmelo-Silver, Duncan, & Chinn, 2007) that the key to successful inquiry is appropriate scaffolding. In line with these researchers, our conceptualisation of inquiry learning is an appropriately *scaffolded* process of investigation which helps learners to engage with the disciplinary practices of science and construct scientific understandings, as well as to develop other generic capabilities such as collaboration. In addition, providing scaffolds that offer different levels of staged support as a tool can reduce some students' reliance on their teacher, thus allowing the teacher to spend more time managing the practicalities of supporting the participation of all students and maintaining productive and enjoyable learning.

The learning sequence

The sequence was designed to help Year 8 students (aged about 14 years) achieve the following aspects of the *Australian Curriculum in Science* (ACARA, 2018):

- Science as a Human Endeavour: Science knowledge can develop through collaboration across the disciplines of science and the contributions of people from a range of cultures
- Use and Influence of Science: People use science understanding and skills in their occupations and these have influenced the development of practices in areas of human activity
- Science Inquiry Skills:
  - Collaboratively and individually plan and conduct a range of investigation types, including fieldwork and experiments, ensuring safety and ethical guidelines are followed
  - Measure and control variables, select equipment appropriate to the task and collect data with accuracy using a range of techniques
  - Summarise data, from students' own investigations and secondary sources, and use scientific understanding to identify relationships and draw conclusions based on evidence
- Chemical World: Mixtures, including solutions, contain a combination of pure substances that can be separated

While the learning sequence may not always cover all of the points listed above depending on how teachers present it, it is particularly effective in helping students design experiments and control variables. The article focuses particularly on this skill. Other elements of the syllabus that may be foregrounded are sustainability and literacy.

To achieve the intended outcomes the learning sequence begins with a discussion of the properties of water and a clarification of terminology such as solutes, solvent and the resulting mixture, a solution. It is explained that because many things dissolve in water it is easily polluted, but water is naturally cleaned when it trickles through sand and gravel (a process known as filtration) and when it evaporates. In order for water to be safe for human consumption, and to be pleasing to drink in terms of odour, colour and taste, it needs to be purified. Many types of scientists including civil, chemical and environmental engineers, chemists, health scientists and biologists work together to enhance and develop water treatment systems.

The diagram below (Figure 1) provides a visualization of the various scientists involved in water purification and can be used as stimulus for discussion with students.

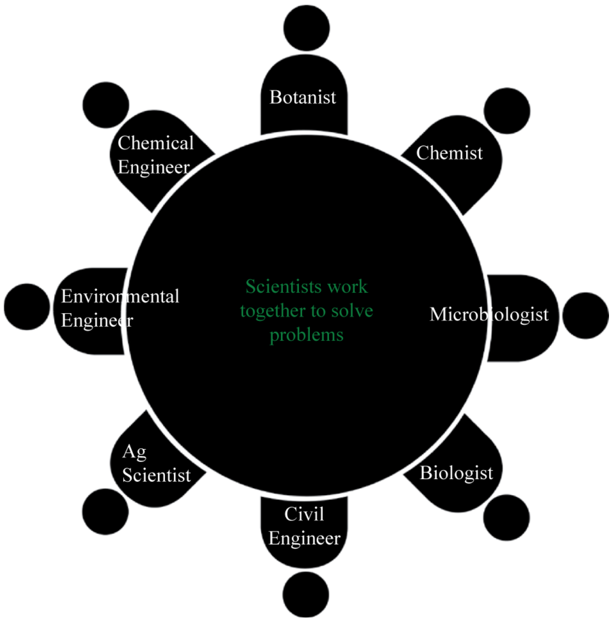

Figure 1: How scientists work together. Figure 1 was created by Katherine Harris.

The process of water purification on a macroscopic scale is then discussed with the students using the flow diagram in Figure 2, and the students then focus on steps 6 and 7, "coagulation" and "flocculation", which involve the removal of suspended solids using substances called flocculants. This leads into a series of investigations where students compare different manufactured and plant-derived flocculants, and design experiments to test the effectiveness of these. The procedures for these investigations are presented below in a narrative style.

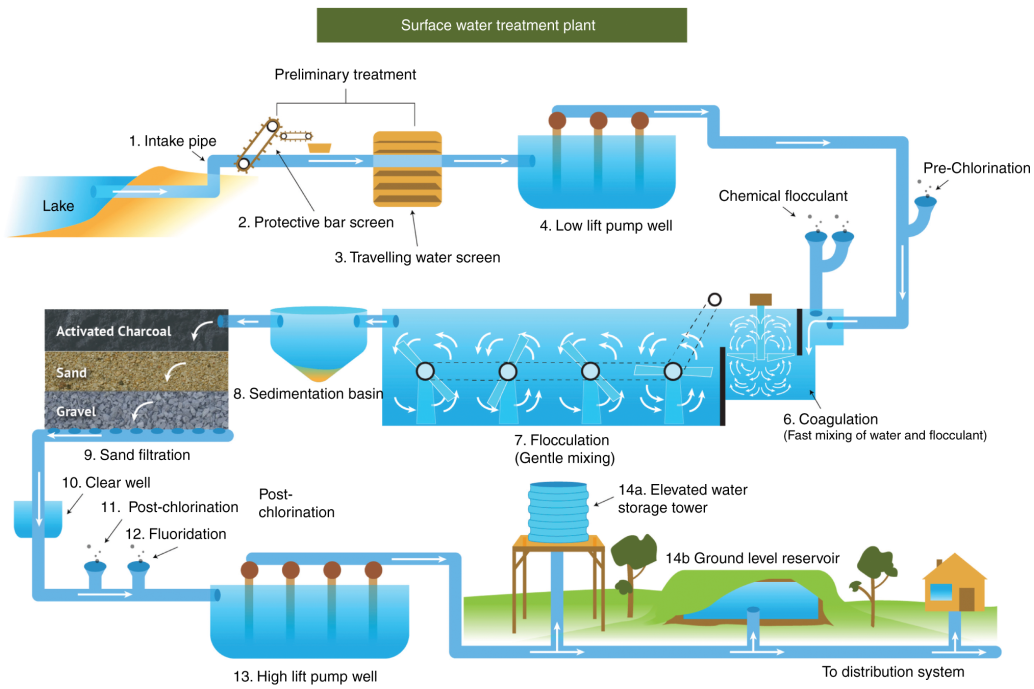

Figure 2: The physical separation techniques used in the treatment of surface water at a water treatment plant. Figure 2 was designed by Katherine Harris and created by University of New England.

Investigations

Following the initial discussions of Figure 2, the sequence of investigations comprised four progressively more complex, open and student-centered inquiries, each building on the findings of the previous one in the sequence. In line with our conception of inquiry and in accordance with suggestions of Hmelo-Silver et al. (2007), we developed multiple written scaffolds ("helping hands" sheets) to support students through each of the investigations (incorporated in the Teachers' Notes, see later in this article). The amount of guidance was staged to span students' likely Zones of Proximal Development (ZPD) (Vygotsky 1978). The ZPD is the difference between a given student's independent problem-solving capabilities and their potential problem-solving capabilities when supported with guidance by people or tools (such as scaffolds). These "helping hands" sheets contained literacy supports such as a glossary and a report writing scaffold, and science inquiry skills scaffolds such as a planning template, flow charts and hints for developing a method and a materials list. The students could access the scaffolds when and as they liked during the investigations, or not at all, depending on their own group's need or desire for support.

All investigations were conducted in cooperative learning groups of four, adopting (with the additional role of reporter) the roles of manager, speaker and director utilised in the cooperative learning approach of *Primary Connections* (Australian Academy of Science, 2016) which promotes personal and social capability, manages student movement and noise in the laboratory and enhances organization and safety. In particular, allocating these roles helped to minimise student traffic around the lab (as only the manager could collect equipment), particularly useful when students are carrying glassware containing liquids. During the workshops the students and worked together with their classroom teachers.

Investigations 2–4 required participants to explicitly plan their experiments on paper and discuss this with the facilitator prior to carrying it out, in order to promote students' skills in this aspect of science inquiry, and to locate, discuss and incorporate any potential areas of improvement, including any safety issues. Students write up their investigations in the form of a written scientific report, to incorporate and foster development of generic and scientific literacies.

Investigation 1

How does a flocculant work in "cleaning" water?

In this first investigation students are provided with some dam water in a clear plastic cup and initially record observations of the water using their senses of sight, touch and smell (not taste!) over a period of 3 min. They then add 1 mL of the flocculant aluminium sulfate solution to the cup and stir using a paddle pop stick and watch the cup for 4 min, recording their observations about the water in the cup over this time. Finally, they write a brief conclusion about how they think flocculants "clean" water.

Investigation 2

Flocculants – making sure they work

In the second investigation the students engage in a student-directed inquiry process to determine if stirring helps a flocculent work more effectively and they also carry out a comparison of the efficacy of different manufactured flocculants. These investigations require students to design and carry out their own controlled experiments (in primary schools often known as "fair tests"), where they need to decide on the independent and dependent variables. As well as dam water and paddle pop sticks, students are provided with:

– 10 mL of aluminium sulfate flocculant solution

– 10 mL of a polymer-based flocculant solution (readily available commercially as swimming pool cleaners)

Investigation 3

Using a natural flocculant made from the seeds of the *Moringa oleifera* tree to "clean" dam water

Students are provided with information (history and context) about *Moringa oleifera* (Figure 3) seeds as a natural flocculant (see Appendix 1), which they read and discuss prior to designing and carrying out an experiment to purify a sample of muddy dam water (recently shaken up) using *M. oleifera* seeds. Each group is provided with up to three seeds and various equipment they can choose from such as mortar and pestle for grinding up the seeds if so desired. Upon completing the investigation groups are asked to prepare a poster explaining their approach and outlining their findings, illustrated using digital photographs if possible. The groups then present their posters to the rest of the class.

Figure 3: *Moringa oleifera* tree and seed pods. Photograph by Katherine Harris.

Note: *Moringa oleifera* seeds can often be obtained from local trees, depending on location. They can also be purchased online but the buyer needs to be very careful that the product meets all biosecurity requirements for the jurisdiction into which it is being imported.

Investigation 4

Using a variety of physical separation techniques to "clean" a sample of muddy dam water

In this final investigation, students use the skills and knowledge developed in the previous activities to "clean" a sample of muddy dam water. This involves simulating Steps 6, 7, 8 and 9 (used in the water treatment plant shown in Figure 2), by developing and following a logical sequence of steps (algorithm) to achieve their aim of cleaning the water. The treatment plant takes in "surface water" and so it is unlikely to be as "stirred-up" as our dam water sample. For this reason, they may need to add a sedimentation step and a decantation step to the beginning of their purification process. They need to make observations after carrying out each step in their purification process, identifying any contaminants that may have been removed in the process.

An elaboration to this investigation may be undertaken to test whether the purification steps remove microscopic organisms that often occur in unpurified water. Students can add a drop of water to an agar plate, which can be incubated (with appropriate safety guidelines) for 30 h at 33 degrees Celsius to see if anything grows.

Investigation resources

The teacher and student handbooks detailing this learning sequence and including the "inquiry slider" of Cornish et al. (2019) are available for free download as follows:

Teacher & Student Notes: https://asell.org/page-5/.

In addition, two annotated video clips of approximately 28 min are available showing four students undertaking the activities outlined above. For a link to these video clips, please email cfellows@une.edu.au. The intended learning outcomes of these activities should be applicable (with locally relevant modification) to a range of educational contexts.

Research findings

The remainder of this article reports on research findings associated with two trials of this suite of investigations:

1. One local workshop (Workshop 1) with 11 middle-school aged students (aged between 13 and 15) and six in-service science teachers. All of the student participants were selected by their teachers from their year 8 or 9 classes and had previous experience of completing some investigations in science, although this was generally limited.

2. One workshop (Workshop 2) with three pre-service secondary teachers who were completing their formal teaching qualification in secondary science at a local university. These students were interviewed to get some sense of how engaging and informative they found the activity and also how effective they perceived it would be with lower secondary students, based on their classroom experience to date.

The sample size of students and teachers, and the time that the teachers and students were able to contribute to participating in the trial was constrained by their ordinary school commitments. Accordingly, there are limitations to the breadth and depth of data presented in this section, but these do provide some evidence of how the sequence of activities as received.

Teachers and secondary school students

In workshop 1, support for students was provided throughout the process by the facilitator moving from group to group, monitoring and discussing progress and answering queries. If difficulties were being experienced, questions and hints and referral to the “helping hands” sheets (as appropriate) were used to help students to move to the next step. We found that the students tended to rely on the default option of asking the teachers for help, rather than leaving the group to go to the front of the room to collect scaffolds as needed. This indicates that scaffolding inquiry using aids such as these needs to be carefully and explicitly built-in over time to regular classroom activity so that this expectation becomes part of the student inquiry routine. Issues for students that might need to be addressed include physical accessibility and perceived stigma, which depending on context and class size, may be addressed by issuing each group with its own set of scaffolds, or having the teacher distribute them at need based on discussions. It is important that the students know what areas the scaffolds cover in enough detail to be able to decide which scaffold might be useful at given stages in the inquiry.

The students’ plans for investigation 2 were quite detailed, however in the context of our workshop became somewhat rushed and abbreviated for the later investigations particularly towards the end of the day. In addition, the time it took for different groups to complete their plans varied considerably, adding to the challenge of marrying student-centred work with scheduled lesson times of 45 min to an hour. A recommendation we would make based on this experience is to spread out the series of investigations over several lessons (dependent on school context) with negotiated goals for achieving certain steps including dedicated planning time.

In this workshop, looking at the students’ written and drawn plans was particularly useful in quickly gauging student progress and understanding.

Following the workshop, the students completed a survey in which they rated the first two parts of the investigation, with the final two parts not rated due to time constraints on the day. Four criteria of perceived value, relevance, interest and the extent to which the activities allowed independent (inquiry-based) learning were rated on a five-point Likert scale (“very poor”, “poor”, “average”, “good”, “excellent”) for the following items:

1. Overall, I found this investigation a valuable learning experience
2. I see the relevance of this investigation to my science studies.
3. I found the investigation interesting.
4. I took responsibility for my own learning when doing this investigation.

The survey findings are presented in Figure 4. Although this represents a small sample of respondents from a single workshop, the findings are still encouraging with a majority of students reporting excellent for all of the criteria.

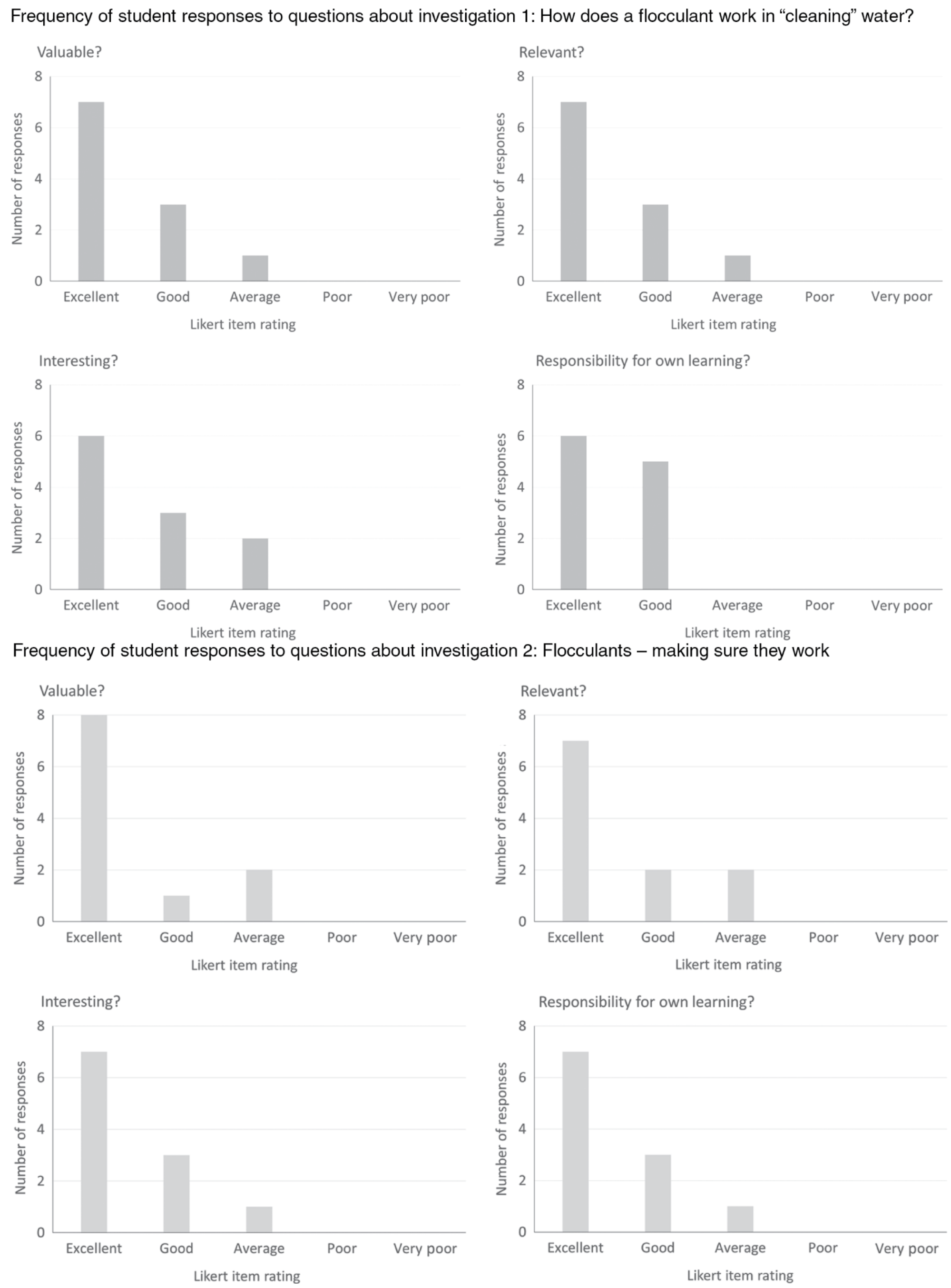

Figure 4: Student feedback from an individual workshop comprising Investigations 1 and 2, containing 11 students. Figure 4 was created by the authors.

The six teachers who attended the same workshop provided free-response feedback on the activity. All said that they would use the investigation with their students. Most teachers claimed to like the structure and the way the activity was designed to provide autonomy, for example:

> The different experiments were structured to have a step-up effect that reduced the guidance at each level.

Two teachers specifically mentioned the use of support ("helping hands" sheets) that helped with differentiation and therefore made the activity more accessible. Good differentiation is often one of the most challenging issues that face teachers doing laboratory activities, (Pablico et al. 2017), so it was encouraging that these teachers noted this.

Pre-service teachers

On conducting workshop 2 it became apparent that all of the pre-service teachers had done some work on water purification during their school careers and one student, John, had actually observed a lesson on water purification during a recent teaching practicum, but none had conducted or observed a practical investigation involving this process.

> **John**: So, on the prac, it was more just theory, they didn't have the chemicals, they didn't use chemicals. They just looked at videos and read articles about how it worked...

Despite having covered the topic of water purification previously all three pre-service students stated they had learnt something new from the investigation.

> **Janet**: Well, we learned about flocculants, so they kind of coagulate the particles in the water to increase their density I suppose and sink them to the bottom so you have clean water left.
>
> **Interviewer**: Have you come across that term, flocculants, before?
>
> **Janet**: No, I've never actually

All three pre-service teachers commented that the activity had been very engaging, because they were conducting first-hand investigations which were novel, relevant, and yielded easily observable and rapid results:

> **John**: I found it very engaging because I've never done this before, so you're seeing it in action, you can see the sediments clumping together very quickly, and so it's quite exciting watching the differences and having three different beakers, with water in them and then each one changing.
>
> **Alice**: I found it really enjoyable actually. I found it really interesting to see the differences in how each substance contributed to the purification and we did have an experiment at the end where we added all sort of different substances to see which one worked the best and to see if maybe we could come up with something new that wasn't maybe tested. But yes, it was really good to be able to visualise what was happening rather than just like the theory.
>
> **Janet**: Yes, I found it engaging, I really enjoyed being able to see first-hand the particles sinking to the bottom and being able to compare which one was the clearest and things like that, I found that I really enjoyed being able to see it and do it first-hand like we were actually causing that to happen.

The pre-service teachers were also asked about the types of skills the investigation might help their own students to develop. Janet mentioned social skills related to the cooperative groupwork involved in the activities as well as the skill of planning or designing a scientific investigation:

> ...there are cooperative group work skills like communication and interpersonal skills, also, learning how to design their own experiments; because it's scaffolding there, as they go along in the experiment, they're getting less and less scaffolded and they actually have to put in more thinking and effort to create their own experiment...

This was echoed by John:

> One of the biggest skills would be "plan investigations" because the way the activity is set out; like the first part was set up for us but the second one we had to plan ourselves, we had all the tools around us but we had to decide how to plan investigations to test a theory or an idea that was given to us; and then we did the same again to test the seeds, to test its effectiveness.

Janet noted that the activity was effective for teaching about experimentation in which students have to identify which variables to control, one of the most important skills in experimental science.

> ...so they have to learn about variables and things like that...they have to understand what a control is, the independent and the dependent...I think it's really good to show the control...like depending on what kind of control you need but I think it's very good to have that there for comparison, like showing that you are comparing to a control.

Conclusion

This article has presented an investigation on water purification, a topic that has relevance globally. The investigation is designed not only to develop conceptual knowledge of the topic but just as importantly to develop significant scientific skills particularly experimental design in the area of controlled experimentation. The "helping hands" scaffolding was an integral part of the activities that facilitated student access to the inquiry process and allowed the teachers more time to manage the overall classroom dynamic and interact with students as required. Feedback from participants, although limited in scope, consistently indicated that the activity was valuable, relevant, interesting and allowed them to take responsibility for their own learning.

Appendix 1

Moringa oleifera seeds as a natural flocculant – current research

Written by Katherine Harris UNE

Background

The United Nations Millennium Development Goal Target 7.C was to "Half, by 2015, the proportion of the population without *sustainable* access to safe drinking water and *sanitation*". Between 1990 and 2015, 2.6 billion people worldwide gained access to safe drinking water in their communities and the United Nations' goal was met ahead of time (United Nations 2017).

Although there have been significant improvements in access to safe drinking water there is still much work to be done with 663 million people still relying on untreated drinking water in their communities and 502,000 *diarrhoeal disease* deaths per year estimated to be a result of *exposure* to contaminated drinking water (World Health Organisation (Media Centre), 2016).

One of the key problems with *implementing* water treatment processes in developing countries is the large cost and difficulty in buying and transporting flocculants. For centuries natural materials have been used to purify water. Research suggests that the idea of using *Moringa oleifera* seeds to purify water first originated in the country of Sudan where the women would clean the muddy water from the Nile River.

Moringa oleifera is a native tree from the sub-Himalayan regions of India. It is able to be grown anywhere along the *tropical belt of the earth* and grows well in Queensland, Australia where it can be readily found in parks and gardens and is locally known as the "drumstick" tree. The tree is extremely fast growing and produces seeds within a year of planting. The leaves, flowers, seeds and roots are a nutritious food source and the oil from the seeds has many uses.

In addition to the *Moringa* tree being an exceptionally nutritious food source, a protein found within the seeds is able to combine with suspended materials in the water to clarify it and another identified protein in the seeds is capable of destroying the bacterial cell membrane of bacteria (Shebek et al., 2015).

Recently scientists around the world and right here in Australia have been investigating the use of *Moringa* seeds as natural flocculants (Jerri, Adolfsen, McCullough, Velegol, & Velegol, 2011; Mustapha, 2013; Swales, J. PennState, 2017). Dr Vikashni Nand from the Australian National University has been working, in partnership with the University of the South Pacific, on investigating the use of *M. oleifera* seeds and other local seeds as a natural flocculant to purify water in three developing countries in the South Pacific Islands (Sanchez-Martin, Beltran-Heredia, & Peres, 2012). A botanist from the University in Zaria, Nigeria has teamed up with scientists from Pennsylvania State University to research whether the season in which *M. oleifera* seeds are harvested influences the ability of the seeds to clarify the water and remove bacteria from the water (Swales, J. PennState, 2017). Recently, researchers have found that when the crushed seeds are mixed by stirring with sand the active positively charged protein in the seeds irreversibly binds to the sand. This "sticky killer sand" can be recycled over and over again to purify water (Jerri et al. 2011).

Imagine the possibilities for developing countries if this tree can be grown locally as a food source and used as a means to purify a communities' water (Sanchez-Martin et al., 2012; Subramanium, Nand, Matakite, & Kanayathu, 2011).

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