T

he shift in science education towards the aim of developing broader scientific literacy is well underway. It is recognised that there is a need to integrate learning across the science, technology, engineering and mathematics (STEM) domains in order to achieve this aim. There is also a need to equip our students with the skills necessary for the future and—for some—the eventual progression into these fields as technical or knowledge workers (PCAST, 2010; Honey, Pearson & Schweingruber, 2014).

Many argue we are faced with the looming approach of a time when such integration is inevitable given the inexorable changes in this VUCA world. What is much less clear is how we will get there (for example, English, 2016). Part of the difficulty is that integration is multi-faceted. It can merely be between subjects (e.g., biology and chemistry) or across the domains of science, engineering, technology, mathematics and beyond; there can be varying degrees of integration—interdisciplinary, multidisciplinary or transdisciplinary, in increasing order of interconnectedness (Drake, 2000). Another difficulty in schools is in finding appropriate contexts in which to craft learning experiences that naturally blend and encompass various disciplines. These issues potentially affect the value derived from such integration in schools.

Finding an Approach

In a transdisciplinary approach to learning, students learn and apply knowledge and skills to the task at hand, without discerning or distinguishing the disciplinary providence of that knowledge. This is by now, a familiar paradigm for educators, albeit better known in various guises as project- or problem-based learning, and the development of life skills and competencies. The difficulty in achieving true transdisciplinary integration in lessons begins with finding a context in which each domain has a key role to play, where learners have to find out, analyse, or apply knowledge or skills from that domain, whilst engaged in those lessons.

Design-based inquiry (DBI) is a lesser-known member of the inquiry-based pedagogies. DBI is characterised by a design-and-make approach to fulfi l a specific task or objective. This can be couched as a challenge or goal, such as “build a paper airplane that can fly the furthest distance”. Additional or subsidiary challenges can also be given, such as longest time aloft, or accuracy in hitting a target. This type of activity thus affords a context in which broad-based knowledge of science, engineering, technology and mathematics can be applied in pursuit of the set challenge.

One key issue is that DBI activities tend to involve only the physical sciences, with very few that involve chemical or biological sciences, and none that incorporate all three. Leaving aside STEM integration for a moment, there are paltry examples of an integrated approach to the learning of science as a holistic discipline, or where all three of the natural sciences are seamlessly amalgamated. The learning of science in school is almost always segregated into its sub-disciplines. It’s either a life science topic, or a physical science topic.

The Microbial Fuel Cell

The microbial fuel cell (MFC) is a device that produces electricity through the biochemical life processes of microbes. It is capable of sustainably doing so, as long as there is a food source for the microbes, and typical applications for MFCs involve bacteria feeding on organic waste, such as sewage to generate municipal power. This incidentally affords a student-friendly introduction to the MFC as an environmentally-sustainable alternative energy source. Using the MFC as the context in science lessons with a DBI challenge in which secondary school students work in small groups to design and build their own improvised MFCs has been developed and found to be effective in achieving learning outcomes (Tan, Lee, Sam, & Lee, 2013; Tan, Toh, Teo, & Lee, 2017). Most of the students were in Secondary Two.

The MFC has a multitude of design parameters that influence its power output. For a start, we can simply focus on voltage output as a simple measure of the cell. Thus, building a working MFC is a basic task, but “building the MFC with the highest voltage” would be the DBI challenge. This friendly inter-group challenge serves well as motivation for students to seek ways to improve their MFC design in iterative cycles. Other measures such as current output, longevity of the cell, and the ability to.

 approaChing STEM Integration

By Timothy Tan

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power simple devices, such as LEDs and tiny motors serve as increasing levels of challenge.

School Science Reimagined

Learning about the MFC inherently involves acquiring and applying knowledge from across biological, chemical and physical subject areas, most of which are already standard topics in school science. A substantial proportion involves topical areas that are already familiar transdisciplinary fields, such as the biochemistry of respiration and the electrochemistry of fuel cells. Unlike the typical learning of science, each discipline in isolation, each topic ordered by thematic similarity, this type of problem-based science lesson centres learning in the task or goal at hand, with what needs to be learnt brought up in an as-needed and a just-in-time basis. This is perhaps the core idea in finding an approach to reengineering school science in order to integrate STEM in a way that is not only pedagogically appropriate, but also serves to prepare students for the future workplace.

This of course, would involve a sea change in the teaching and learning of science—not one to be taken lightly nor hastily. But the MFC programme does offer opportunities to tackle current shortcomings in more manageable portions. The MFC programme can help in the near-term to address long-standing problems with school science practical work. For example, it is an inherently hands-on programme, but it also excels as one which forces a minds-on engagement as well. Building a functional MFC requires the application of scientific knowledge. A pour-it-all-in approach will not work, nor would random trial-and-error. Furthermore, in investigating the parameters that influence voltage output, experimentation has to be sequential and iterative; the results of one experiment informs and guides the conduct of the next, and ultimately underpins the design decisions students have to make.

Traditional school science practices have been carefully crafted to direct students to observe or measure the change in one dependent variable, as one independent variable is manipulated, while everything else remains unchanged controlled variables. The real world rarely ever works that way. Being an actual device that students have to grapple with hands-on, they also come up against real-world interactions. Just as one example, changing the concentration of one reagent, not only influences the reactions that reagent is involved in, but changes parameters such as the salinity and osmolality of the MFC, thus influencing the biological functions of the microbes within, with concomitant changes to the microbes’ ability to provide the energy needed. With the MFC, such complex interactions result in a system where there is no “model answer”, and in trying to build your own improvised MFC, there are no ready references on the internet.

Thus, learners are presented with a situation in which they have to invoke their own critical and inventive thinking, work collaboratively in conducting authentic experiments to investigate various properties of the MFC, actually measure the effect of individual design decisions made, and then use all that to engineer a winning MFC that outperforms the rest. And that they do, with the best designs so far from secondary two students producing a voltage approximately 75 per cent higher than the reference MFC design.

Issues and Challenges

The MFC programme described above presents a multitude of issues for school science. While it may incorporate the desired transdisciplinary STEM integration with inquiry-driven approaches to broad-based learning, it is this very nature that gives rise to significant difficulties in teacher-readiness, curriculum integration, assessment and so on.

The author has conducted teacher professional development workshops for over a decade on the MFC, and many teachers find the material challenging, baffled by the simplicity of the paradigm, but facing the complexity of explaining the MFC in the light of their own extant, but sometimes distant, knowledge. As nearly all teachers are subject specialists by training and/or practice, and the need to apply integrated science knowledge from across disciplines tends to perplex and unsettle. On the other hand, the school students were far less intimidated by the material and approach the programme with enthusiasm and were much less concerned with the disciplinary boundaries they were blithely traversing.

At present, these issues and more have limited the programme to be employed as a niche enrichment programme for higher-progress students. However, it is hoped that it provides a working model to serve as a basis for future approaches to, and a small step towards, integrating STEM in schools.

References


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