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Title **Playing with rusty nails:
'Conceptual tinkering' for 'next' practice**

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*For details on the
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Abstract An important issue for the Educational Design Research (EDeR) community to continue to deal with is the scalable and sustainable implementation of its methods, findings and designs beyond the bounds of specific projects. Those engaged in EDeR specifically seek out concurrent problems of theory and problems of practice, but this should not be seen as sufficient for ensuring their work has impact beyond their current project. Just as with other forms of research, EDeR practitioners must still reach out to and connect with educational institutions and teachers who are dealing with many competing demands. This position paper offers a largely theoretical contribution to the discussion of the problem of implementation. It will introduce the concept of conceptual tinkering as an approach to engaging teachers in the skillsets and, more importantly, the mindsets of EDeR as an approach to educational improvement. Sketches and prototypes of tools to enable conceptual tinkering will be discussed.

Keywords design based implementation research
teacher professional learning
tinkering
play

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Playing with rusty nails: 'Conceptual tinkering' for 'next' practice

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1.0 Introduction

Educational Design Research (EDeR) or Design Based Research (DBR) positions itself as highly aligned with the immediate needs of teacher practice. Using the problems of educational practice as its departure point, EDeR seeks out researchable spaces in which problems of theory and problems of practice both lay. To address these problems it adopts an inquiry stance driven by an iterative design process involving a collaboration of 'designers' who are typically teachers in some capacity, and researchers. One easily overlooked limitation of this close alignment of research and practice is that it is easy to assume that the alignment of intent will automatically address the challenges of scalable and sustainable implementation of any findings from any design-research project. Unfortunately this does not seem to be the case with scholars such as Fishman, Penuel, Hegedus, and Roschelle (2011) demonstrating that even when innovations are shown to be useful and useable through design research, teachers often simply do not continue to use them after the research project is completed, and few take them on.

While the appearance of poor post-project implementation of EDeR designs may in part be due to the lack of mature projects in this still nascent genre (McKenney & Reeves, 2013), it may also be because many applied educational projects with or without a design orientation are carried out in exceptionally favourable conditions. This means that many projects are able to indicate potential for impact on practice but may lack evidence of genuine impact, and has resulted in some arguing the importance of Design Based Implementation Research (DBIR, Penuel & Fishman, 2012; Penuel, Fishman, Cheng, & Sabelli, 2011), which extends EDeR to critically examine the scaling up process. In this paper we will argue that engaging teachers in a process we will describe as 'conceptual tinkering' is an important part of scaling and sustaining the innovation of EDeR, which we will henceforth refer to as the 'challenges of implementation'.

We will begin this paper with the proposition that the challenges of implementation cannot be met simply by improving educational design as a thing that is separate to those who will implement it. The desire at a policy level to 'teacher proof' curriculum seems to have grown in recent years, but here we will assume that good educational design will consider the teachers who translate curriculum into practice as an essential element of the educational design.

This proposition will be reified, somewhat, through a brief discussion of the conflict Australian teachers now find between

an increasing emphasis on and interest in inquiry approaches to professional learning, stemming particularly from the research field, and the demands of the 'standards' approach that has been applied to teacher governance in Australia as in many other settings. This policy discussion will be reconnected to matters of design through reference to a recent debate between Janssen, Westbroek, and Doyle (2015) and Bereiter (2014, 2015) in the *Journal of the Learning Sciences* concerning the merits of heuristics vis-à-vis principled practice knowledge. While coming down on the side of Bereiter, we will suggest that the cloud of issues raised in our discussion might be best approached through lenses such as cultural historical activity theory and various forms of practice theory and their dialectic technique of taking practicality and knowledge building to be different threads of the same fibres. The working theory we offer here is that unlike the reproduction of 'best' practice, innovation or 'next' practice may require slow and 'playful' forms of thinking.

We will return to this theoretical ensemble at the end of the paper as we discuss our own experiences of conceptual tinkering. Before this, the paper will take a practical turn and argue that a deliberate practice of conceptual tinkering may improve the way teachers engage with innovative educational design, and what the 'tools' that enable conceptual tinkering might look like. The authors' broader work is in science, technology, engineering and mathematics (STEM) education and our concept of conceptual play is heavily influenced by the tinkering movement within that field. Tinkering steps beyond the boundaries of classic educational inquiry within the STEM disciplines and emphasises creative and open-ended design processes in which the learner can work in an improvisational way. Be it a glue gun, or a 3D printer, the freedom of tinkering is simultaneously enabled and constrained by tools. Conceptual tinkering, we suggest, offers teachers a similar approach to improving practice through creative, open-ended innovation, but good tools are needed to enable it.

2.0 Professionalism in the neoliberal era: Teacher development or teacher proofing?

It is essential to the implementation of EDeR that teachers engage in some level of inquiry. This is clearly the case within a design-research project, but it is also true afterwards if the project is to be scaled or sustained. EDeR is, by definition, responsive to the practice context, and typically carried out through a process of collaborative iterative design informed by ongoing inquiry. As such, teacher inquiry is an important piece in the implementation challenge.

Despite its growth as a form of teacher professional learning, a recent scoping review on teacher collaborative inquiry (DeLuca et al., 2015) found that the epistemological and theoretical foundations for teacher inquiry remain relatively underdeveloped. This does seem to ignore relevant theorisation under different titles such as 'action research' (see for example Kemmis, 2005, 2010). Nevertheless, it does suggest that for the benefits of inquiry approaches to be realised, there is a need to continue to

develop both better frameworks and better explanations for the value of the approach. This is particularly so in the current era where neoliberal modes of governance have framed teacher professionalism in a very different way (Connell, 2009).

A feature of the neoliberal approach to governance is that it seeks to assure quality by identifying parts of a system that can be measured, and measuring them intensely. The basic logic is that if the chosen measures improve then the system as a whole must also improve (Power, 2009). The chosen measures become a proxy for the entire system. The logic is flawed and it has long been recognised that what might actually happen is that the shifts in the system that are made to improve the measures may actually corrupt (Campbell, 1976) and even pervert (Lingard & Sellar, 2013) the system rather than improve it. Regardless of the flaws, however, the logic is in the ascendancy and is applied to teacher professional learning through instruments such as mandatory teacher professional development shaped against pre-defined, competency-based, professional standards. The critique of the neoliberal governance of teachers is now well developed (see for example Ball, 2003; 2016; Sachs, 2003; Singh, Heimans, & Glasswell, 2014) and will not be repeated at length here. For the purposes of understanding the design problem faced in implementing educational innovation, however, we will briefly discuss how the neoliberal understanding of governance as implemented through measures such as competency-based standards actually mitigates against implementation.

Following a trend that has been global, but which has particularly played out in the English-speaking world, Australia has increasingly turned to forms of neoliberal governance of institutions, teachers and students in the search of systemic improvement to education. The principal tool applied to teachers has been the adoption of a set of competency-based national standards that teachers are expected to demonstrate in order to maintain their registration as a schoolteacher. Proponents of the approach see this as a quality assurance measure, and also something that provides a language for the discussion of quality teaching practice at the level of the school, the profession, and the wider community.

As noted, there has also been much criticism of this approach with scholars noting that while the standards adopted in many places do, in themselves, seem a reasonable description of practice, they are implemented as part of a package using the policy technologies of the market, managerialism and performativity (Ball, 2003). It is the last of these, performativity, which we see as particularly problematic for the implementation of innovation. Performativity is a mode of regulation that employs judgements, comparisons and displays as a means of control through real and symbolic incentive and sanction. Employed through a registration system, the sanction can be as symbolic as a 'teacher of the year' prize, and as real as de-registration. Such a system relies on comparison and so automatically mitigates against innovation. Within this technology, even a standard explicitly calling for innovation is only able to recognise innovation that looks the same as the innovations others are making!

Some scholars have tended to accept that standards frameworks are a reality of the current policy era and chosen instead to engage with how standards could be used to promote an expansive vision of teacher professionalism. Sachs (2003), for example, has called on teachers to take an 'activist' approach and reclaim the moral authority over what constitutes quality teaching, a process which necessitates ongoing teacher inquiry. We would argue that EDeR supports the activist approach to professionalism that Sachs' suggests, but before we move on, we will first discuss the more direct limitations of Australia's standards with respect to innovation.

2.1 A limited standard

The standards for teachers adopted in Australia, we contend, are limited in ambition and present teaching practice as one of technical implementation, leaving little room for knowledge generation as a recognised part of teacher practice. This stands in stark contrast to many representations of practice to be found in the literature (Hargreaves & Fullan, 2012; Kemmis, 2009), which feature knowledge buildings, and particularly collaborative knowledge building, as an essential part of teacher professionalism. The closest the Australian standards come to requiring professional knowledge building, however, is for teachers at the most advanced or 'lead' level to:

Conduct regular reviews of teaching and learning programs using multiple sources of evidence including: student assessment data, curriculum documents, teaching practices and feedback from parents/carers, students and colleagues (Australian Institute for Teaching and School Leadership, 2011, Standard 3.6).

Certainly there is a commitment to evidence-based improvement of practice here, but that practice is presented as static. At no point is professional knowledge presented as problematic, contested, or in need of inquiry. Even at this most advanced level, teachers are constructed as the consumers of data, but not as makers of knowledge. Knowledge, and practice for that matter, are presented as fixed and certain:

Use teaching strategies based on knowledge of students' physical, social and intellectual development (Australian Institute for Teaching and School Leadership, 2011, Standard 1.1).

Where knowledge creation, through research, is mentioned it is unambiguously presented as work for someone else:

Lead initiatives within the school to evaluate and improve knowledge of content and teaching strategies and demonstrate exemplary teaching of subjects using effective, research-based learning and teaching programs (Australian Institute for Teaching and School Leadership, 2011, Standard 2.1).

We hope the reader will forgive our indulgence in critiquing our own national context and understand that the point of this brief

analysis of the Australian standards is to show that a technocratic vision of professionalism can easily be entrenched within such framework documents. The technical vision is, perhaps, of our times as has been argued by others (see for example Connell, 2009; Moore, 2004), but it is a vision that will be difficult to shift now that they are enshrined in this governance structure. Rather than calling for a (re)turn to old models, though, we see this as all the more reason to assert the potential of approaches such as EDeR, and to develop the skills and dispositions to realise that potential.

2.2 Debating the means to support innovation

The debate between Janssen et al. (2015) and Bereiter (2015) over the distinctions between and comparative benefits of Principled Practice Knowledge (PPK) and 'practicality' provides a useful place to start thinking about what design approaches offer practicing teachers. As conceived by Bereiter (2014) PPK is 'explanatorily coherent practical knowledge' (p. 5). In contrast to basic scientific research, it does not attempt to provide a comprehensive account of some aspect of nature. The search for PPK, however, does seek to go beyond the immediate needs of practice and provide coherent (design) principles sufficient to allow the field of practice to advance. It pushes beyond best practice, evidence-based practice and reflective practice, which are all ways of making optimum use of 'know how that already explicitly or implicitly exists' (p. 7) to support the invention of new technologies, strategies and organising concepts; but it does not push so far beyond as to be unusable by current practitioners. While not bearing the title PPK, Bereiter suggests many examples of this type of knowledge production can now be found in the learning sciences literature beginning with the edited volume that perhaps started the discipline (Bransford, Brown, & Cocking, 1999) and including the seminal collection Cambridge handbook of the learning sciences (Sawyer, 2006).

Responding to the proposal of PPK as a way of closing the theory-practice gap, Janssen et al. (2015) have drawn on their own work in practicality studies (see for example Janssen, Westbroek, & Driel, 2014) to suggest that, as described, PPK may still not be practical enough for teachers. They argue that the work of learning scientists, while starting with practical problems rather than theory, is still often carried out under ideal conditions such as with the production of exemplary teaching materials and teachers' guides and the support of the researchers. The complexity of transferring even this engaged research to day-to-day practice, they contend, is typically underestimated. This argument is relevant to all inquiry approaches, as is the practicality theory (Doyle & Ponder, 1977) that forms the basis to Janssen et al.'s critique which posits that teachers see practicality in terms of instrumentality, congruence and cost. The practicality argument is that educational innovation is only likely to be adopted when teachers see clear and recognisable procedures; where the innovation is not in conflict with the various and simultaneous goals of practice such as covering content, maintaining

positive relationships and making judgements of individual performance; and where the perceived benefit outweighs the costs in terms of time, knowledge and resources. Hence, they argue, even when learning scientists and the teachers they are working with produce knowledge that supports innovation, it is likely that a reluctance to implement innovation will be common.

Janssen et al. go on to argue for the use of 'fast and frugal heuristics' instead, pointing to work from research on decision making that has shown that in order to deal with time resource constraints when making decisions in both daily life and professional practice, that people tend to rely on heuristics, procedures that allow a person to ignore information in order to make quick and generally more accurate decisions (for a review of this work see Gigerenzer & Gaissmaier, 2011). An example of a heuristic they argue is practically useful to teachers adopting guided inquiry in science is 'start with the function of the biological system as a whole and reformulate this in a design problem' (p.83).

While finding the broad arguments of Janssen et al. persuasive, Bereiter (2015) felt it over-claimed and responded by problematising the issue of specificity observing:

My impression is that the accepted levels of specificity in commercial... programs are sufficient for parts of the curriculum that are smooth sailing but typically fall short of the levels necessary for dealing with the hard stuff. And the hard stuff includes such fundamentals as the ability to recognize written words by sounding them out, a workable understanding of the dual character of fractions as both numbers and operations, and practically everything having to do with syntax and its punctuation. Thus, adhering to established norms of specificity tends to perpetuate weak spots in instructional practice (Bereiter, 2015, p. 189).

Bereiter goes on to suggest that, while heuristics may indeed be a good way to get from principled knowledge to actual classroom action, they should also be the subject of learning sciences research. He makes this claim arguing that the justifications for some heuristics offered by Janssen et al. - such as 'creating common and shared experiences' - are based on overly general pedagogical principals and so do not provide useful insight for innovation. As such, understanding why a heuristic works, and also when it does not work, may provide a more fruitful way to advance practice.

2.3 Activity theory and 'practice'

To a large degree, the debate summarised above is one of detail and the different researchers are really not that far apart. Clearly the practice field of teaching needs research that supports both 'best' practice and rapid decision-making and also 'next' practice through slower, deliberative thinking. There are certainly advantages to the building of best practice, not least of which is the building of professional judgement through practice and developing the ability to discern and recognise pertinent

features of an educational context (Hargreaves & Fullan, 2012; Hostetler, 2016). Teaching, as practiced in most places, is a very busy profession and there is a need to provide quality supports for that rapid practice. On the other hand, human fast thinking appears to work by adding new information to existing patterns and so resists new patterns emerging (Kahneman, 2011). The effect of this is a conservative disposition with practices and a resistance to innovation. A further limitation is that working entirely from existing configurations leads to a tendency to universalise our assumptions across different contexts of practice, meaning that these entrenched practices provide poor support for observing the unique saliences of each situation (Hutchins, 1995).

A theoretical basis for working with these tensions is cultural historical activity theory (CHAT) or the various forms of practice theory. These theoretical approaches position activity or practice that is mediated by society as the principal unit for analysis and, in so doing, link concerns normally examined independently. When taking this approach, the distinctions being made in the practicality - PPK debate might be seen as separate threads each contributing to the same fibre (Roth & Lee, 2007), and might be represented as practicality|PPK. In this sense, we would argue that practicality is clearly important but cannot be isolated, and cannot be understood without reference to purpose, which we would see as the primary 'principle' of PPK. In other words, both the practicality and purpose of teaching presuppose each other, and each contributes to the activity of teaching (Valsiner, 1998). The circular formation of this theoretical cloud has been well explored over the last half century by sociologists such as Bourdieu (1977), Schatzki (1996) and Giddens (1979) who have each contributed to theories of 'practice' in which practices both make and are made by practitioners.

Cultural-historical theories of practice have been explored extensively within educational policy studies, although the application of Schatzki's approach by Kemmis and various colleagues is perhaps most relevant here (see for example Edwards-Groves & Kemmis, 2016; Kemmis & Mutton, 2012) in its exploration of the architecture of teacher practices and the 'ecologies' or relationships between those practices. This work has shown that changing the practice knowledge of individuals is not enough to cause change, but that the practice architectures – the cultural-discursive, material-economic and social-political arrangements – must also change. Within this framework, our belief is that conceptual tinkering is a method to change the cultural-discursive, and possibly the social-political arrangements in the implementation of innovation. It is an approach in stark contrast to the hyper-rational approaches of our neo-liberal era to teacher improvement, however, which has valorised practicality over and above purpose. To simply valorise PPK, though, would make no more sense if, as Janssen et al suggest, it cannot be practically implemented. In the next section we will instead describe efforts to use design processes to instead pursue practicality|PPK.

3.0 Co-designing tools for conceptual tinkering

The work in this paper emerged from a project on the use of emergent technologies in education being carried out within a teacher education program. The teacher educators and early-career teachers in the program were co-designers in the project and are co-authors of this paper. The project is small, and while 'play' has been a feature of design work our centre has carried out in the higher education context, finding ways to apply play to conceptual tinkering to the more regulated space of teacher education was new to us. As such, this paper is from the early stages of a design-research project and the ideas are offered here as sketches and prototypes, with a view to extending the discussion of play and tinkering within educational design research. The sketches are offered as constituting a 'particular instance of the possible' (Bourdieu & Wacquant, 1992, p. 233). Further, they are offered with the invitation to others to test them in other settings such that the invariants might be identified from the particulars of each case (Vygotsky, 1971).

The project began with a literature review on the educational use of additive manufacturing also known as 3D printing. Apart from some innovative work on spatial reasoning (Horowitz & Schultz, 2014), and approaches making an increased use of collaboration (Leonard, Kohlhagen, & Murray, 2015), it was difficult to find examples of 3D printing being used for educational purposes in ways that could not be achieved with traditional manufacturing methods such as wood or metal, or even with plasticine. When we asked 'what is educationally different about the designs?' the answer was often 'very little'. Seeing the same limitations in our own initial designs, we identified a need and opportunity to develop new skillsets, mindsets and toolsets (Covey, 2005) to be able to see the salient features of our design task.

The idea of 'conceptual tinkering' came from this design thinking process. The process already included the practice of slow thinking around the most salient needs of users as a first step. It seemed reasonable then that new tools and ways of working might also emerge from tinkering or 'playing' with the conceptual space around the project. We link tinkering and 'play' here in the sense argued by (Csikszentmihalyi, 1981) in which play occurs when normal cultural limits are exceeded. We are not referring to children's play per se. The cultural limits we refer to are those of the 'transmission' understanding of teaching that emphasises the presentation of learning goals in a ready or pre-made form. This orientation is evident in the discussion of the professional standards above and focuses teaching actions on the efficient transfer of learning as specified in a syllabus. In the tinkering we propose, in contrast, teaching actions are first oriented to formation of learning activity (Davydov, 1990). Through play at the design stage, learning goals are actively transformed making the structure of problems in conceptual space visible and highlighting what has to be acquired in order to solve the class of problems that will be presented (Lompsher, 1999).

To prototype the new tools in a playful way we moved away from the central design task, where we felt unable to 'play' and

chose to explore this idea of conceptual tinkering around a common science investigation or 'prac' used in schools that all involved knew well, but which we were not going to use in the current project. This prac involved the observation of non-galvanised nails in contact with salt water, boiled fresh water, oil and crystals of calcium chloride (common table salt). In this prac some nails rust quickly, some over several days, and some do not. While near universally used as a demonstration in secondary schools, students still struggle to grasp the chemistry it demonstrates. To make our work with the prac a little clearer, we will first briefly explain the chemistry, and then the educational challenge in designing the activity.

3.1 Rust

Observing nails rust is akin to the watching of proverbial paint as it dries, but it is a standard of secondary science as it allows the demonstration of a number of chemical principles beyond the basics of A reacts with B producing C. Most commonly the observation of rusting is used to demonstrate that the reaction between iron and oxygen is an oxidation-reduction (redox) reaction in which iron is oxidised into iron cations (Fe^{2+} , then Fe^{3+} through a reaction with H^+ ions) and the reduction of oxygen to form hydroxide ions (OH^-). The non-intuitive part of this reaction is that while it starts with iron (Fe) and oxygen (O), and finishes with iron (III) oxide (Fe_2O_3), the reaction requires water to provide the H^+ and OH^- ions, and it will all proceed faster if the conductivity of the water is increased by adding an electrolyte such as common salt, which dissolves to Na^+ and Cl^- .

The educational difficulty with this activity is that while observing that nails rust less quickly in deionised water and more quickly in salty water is a neat demonstration of the role of observer ions in the solution to those who already understand the concepts, it does not necessarily make this somewhat complex process any more obvious to those still learning what is going on. Indeed the actual chemistry is counter-intuitive as the more obvious conclusion to be made from the demonstration is that the added salt must be part of the rust that is formed. The observation that there is a limited reaction between the iron and salt crystals may similarly suggest that water must also be part of the rust that is produced (which is partially true in the sense that the iron oxide salt known as rust is typically in hydrated form, but this is actually a further complication in the chemistry). So what is a fairly straightforward practical classroom activity – put nails into test tubes with deionised and salty water respectively – is actually intended to demonstrate what to the learner is quite complex chemistry. Chemistry complex enough that it may not be fully understood by many science teachers trained in other science disciplines. One does not have to mark too many exams on this issue to realise how many students fail to grasp the scientific principles that activities such as this are intended to 'teach', and so to realise that some 'slow' thinking could be useful.

3.1 Prototype tool 1: SOLO

The first tool for conceptual tinkering we turned to was the Structure of Observed Learning Outcomes or SOLO Taxonomy (Biggs & Collis, 1982), an approach to understanding the quality rather than amount of learning. It argues that there is a qualitative difference between prestructural learning in which the learner simply does not grasp a new task or concept; unistructural learning in which the learner picks up only one or a few aspects of a new task or concept; multistructural learning in which understanding of several aspects are evident but they are unrelated; and relational learning in which the different aspects come together. The highest quality of learning in the SOLO taxonomy is extended abstract in which the learner is able to apply the new skills or knowledge in previously untaught or novel settings. When considered through the SOLO lens, much student assessment in science education could be considered multistructural at best and more often than not, a simple counting of the different aspects of a new task or concept that a student has mastered. Our first task was to use the SOLO framework to push our thinking on rusty nails beyond this established pattern of assessment through 'volume of learning' with the results of the activity summarised in Table 1.

The analysis in Table 1 is not ground breaking and many researchers and teaching practitioners have routinely reached similar understandings. The purpose of reproducing it here is not to offer new insight into this particular activity, but to point to the utility of practicing making the salient features of a task literally visible, and also doing that work in a collaborative way. Collaboration made the professional learning expansive (Engeström, 1987, 2001) in the sense that it allowed each of us to build insights into the activity that were not available to us as individuals. SOLO provided a structure to tinker and play with the concepts involved and to develop a clearer understanding of the purpose of the activity before beginning to design the implementation of the task. The time resource required was not insignificant, but shared across the group it was not unreasonable.

3.2 Conjecture mapping

A second tool we prototyped was Conjecture Mapping (Sandoval, 2004, 2014). This approach assists in decision-making and making an educational design visible. It is used to set out how high level hypotheses translate into the design of curriculum, resources and activities; and then to connect these design features to actual learning. This is achieved by identifying the mediating processes educational designs are intended to elicit. Sandoval refers to the move from design to mediating process as 'design conjecture', and to the move from design to learning outcome as 'theoretical conjecture'.

One of the maps produced by our team for the rusting nails activity can be found at Figure 1. It is an example of the type of analysis advocated by CHAT researchers in that it pays attention to the collective, artefact-mediated, object-oriented system

Table 1. SOLO analysis of rusting nails activity

SOLO level	What students will say, make and do
Prestructural	These students will not be able to define rust using any scientifically relevant terms. Further, they will not understand Will not know what causes rust or what effect it has on metal, and they will not be able to link rust to other known information or situations. They may however, be able to identify situations in which rust can occur, but without providing evidence-based explanations linking these situations.
Unistructural	Will show evidence of a having seen rust and their subsequent ability to identify it. Or they may be able to explain that it affects metal in some way. These students will be able to identify one similarity and one difference between two different situations in which rust may occur, one situation in which rust may occur, and one reason for associated cause and effect. They may make limited links between rust and other familiar situations and will make a limited generalisation about rust (for example, rust always involves metal). These students may be able to suggest a possible reason why an outcome associated with rust may or may not occur, for example, whether reducing oxygen in water will affect the rate of rust occurrence.
Multistructural	Will demonstrate (to varying degrees) an understanding of what rust is, where rust can be found, what kinds of metals are affected, factors that may accelerate or reduce rust rates, the order of events that cause rust to occur, and what the result is. These students will be able to identify multiple situations where rust may occur and identify similarities between them. They will be able to link their understanding of rust to other situations, make a limited generalisation about rust, and provide evidence-based explanations. Students at the multistructural level will also be able to suggest several reasons why an outcome in a rust experiment may or may not occur.
Relational	Will show (to varying degrees) an understanding of oxidation, including that rust occurs differently in different environments and why, and describe other relevant situations where rust may occur and how their specific conditions relate to rust accumulation (for example, coastal conditions). Students will be able to explain similarities in these environments. They will be able to compare and contrast different situations in which rust occurs and why, and they can explain the reasons behind why and how different factors affect rust. They will be able to make evidence-based and justifiable generalisations about rust and be able to explain in detail whether rust may or may not occur in a given experiment.
Abstract extended	Will identify students who understand all the steps in the rust process and can explain their significance. These students can compare and contrast different situations in which rust occurs, identify why this is the case, and accurately generalise this to other situations. These responses will provide evidence-based and justified generalisations about rust, including around the likely occurrence of rust in a given experiment. They will also be able to predict the likely outcome in such situations and make analogies about rust and other situations. These responses may also connect rust knowledge to construction, engineering, economics or other real world industries without being specifically taught these connections, and responses would show evidence of the ability to predict the occurrence of rust in novel situations.

Design Conjectures relating to Activity 1

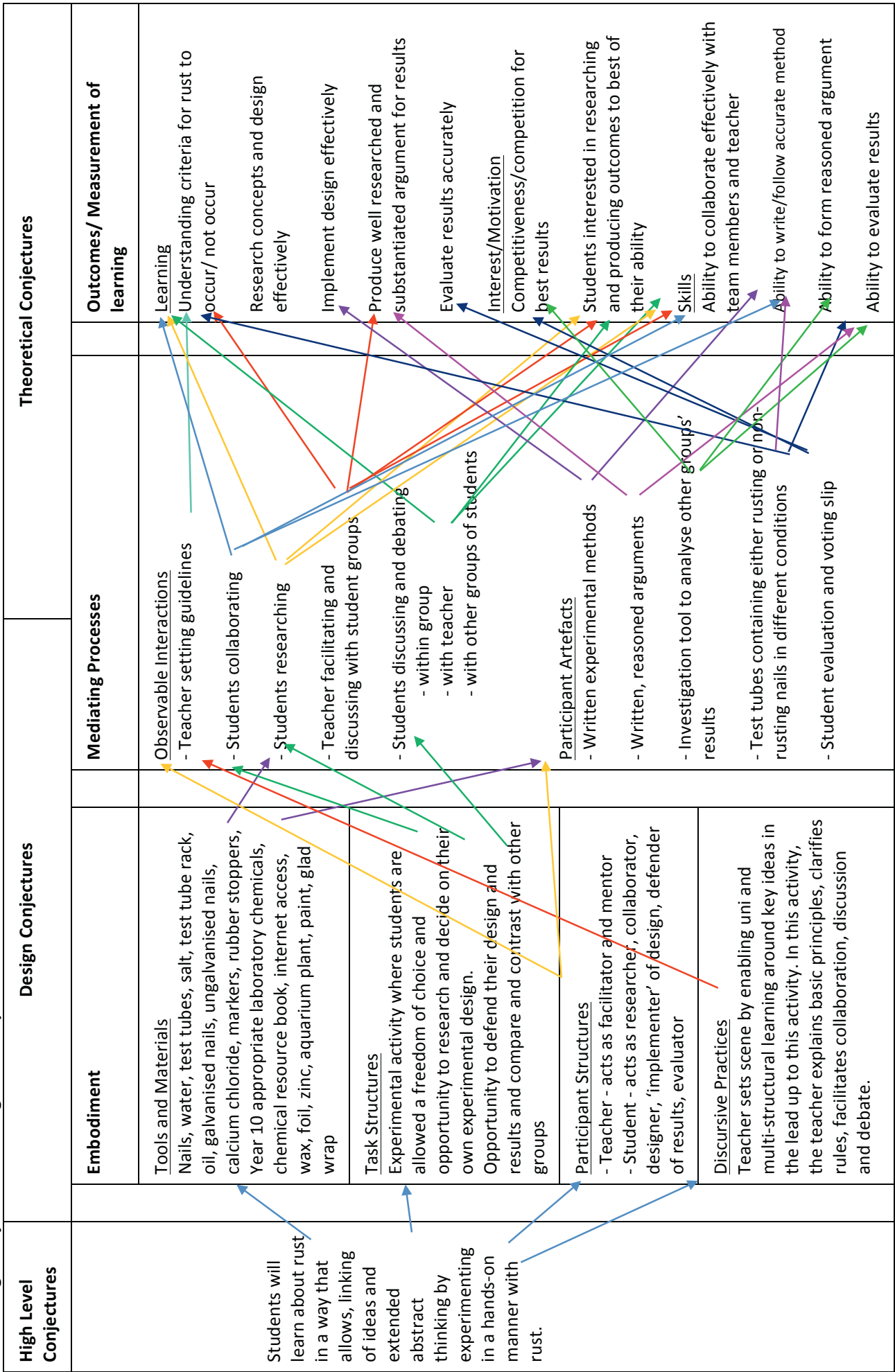


Figure 1: One of the maps produced by our team

itself (Engeström, 2001). The process essentially produces a logic model centred on the student interaction with the designed elements as opposed to the conceptual logic of the activity, the saliency of which may only be available to those with greater expertise. Where the SOLO activity served to increase sensitivity to the range of learning outcomes possible through the rusting nails activity, conjecture mapping similarly served to increase sensitivity to the various interactions possible with the different elements of the designed learning environment including interactions with the objects; other people including teachers and peers; and the artefacts produced by the learners during the activity. Again this was not ground breaking analysis, but it served to provide practice for the sorts of mindsets, skillsets and toolsets that were needed for the larger design-research project.

4.0 Reflecting on actions and operations

Our final piece of tinkering was to return our attention to the original project centring on 3D printing and apply our new tools in that context. After completing the next iteration of that project the early-career teachers who were now leading the design work conducted their own focus group and developed a collective reflective account of their use of tinkering in the design process. Following the pattern of design-research, our intent was to understand both the practical and theoretical dimensions of the use of our tinkering tools as part of an iterative redesign of the process. In this section we summarise some of that theoretical discussion, with a particular focus on the types of thinking identified by the activity theorist Leont'ev (1978), namely actions and operations.

As proposed by Leont'ev, actions are conscious, productive and creative processes that are directed towards a specific object or goal. Actions are supported by operations whose purpose is to automate cognitive processes within the conditions set by the field of the action. Operations, though, are neither conscious nor goal-directed and are only effective when they become unconsciously directed towards the action. The working theory we will set out through the following discussion is that conceptual tinkering assists in redirecting operations. In this way, while the products of the tinkering serve to make what is salient visible, the more significant change may be an unconscious but enacted sense of what is salient. This unconscious process may be a form of the 'judgment' that Hostetler (2016) has championed recently in his defense of teacher belief in intuition. First though, our actions:

Firstly, our vision for the assignment was to create 2 practical, achievable activities which would utilise a 3D printer in a unique way and complement the curriculum.

In naming 'practical' as an objective and also seeking a real purpose in complementing the curriculum, the students here display a real sense of practicality|PPK.

We feel that, as a group, the many discussions we had to come up with such ideas delved deeply into extended ab-

struct thinking as we planned, designed and redesigned activities, addressed challenges, thought about the design thinking involved and settled on two activities and associated assessment options. Although such discussions are not in our final assessment piece, if we had not delved into these discussions, our assignment would have only reached a relational level of understanding through the development of activities which did not (to such an extent) utilise the potential for 3D printers appropriate to the given scenario.

Here we see an awareness of the impact of the tools used and explained using the language of the SOLO taxonomy. The students were aware that their normal practice would not have engaged the project at the same level – and it could be argued that they would have designed activities similar to those found in the literature review that were of arguably trivial educational value.

We really wanted to ensure that the activities we produced had the ability to be taken in different directions depending on the students' design thinking and ensured that we developed assessment items that would encourage that level of thinking.

We also think that extended abstract understanding was shown through our design of previously unconceived 3D printing activities and in the associated assessment tasks. Further, we decided to include the section on some of the challenges that arose. We felt that the inclusion of this section gave a snapshot of the higher order thinking that we went through to reach the final activities and also felt that this could be of use to future researchers and teachers who are developing activities associated with 3D printers. We also included the conjecture map, which in itself is more relational, however, the inclusion of research on some misconceptions and some key possible detours showed deeper thinking and an awareness of the challenges which may become apparent when working through the activities within a design thinking space.

This was actually a development on Sandoval's model, which came out of our co-design work and discussions. Playing with the mapping metaphor it became apparent that we could readily map a range of possible 'detours'. The map is presented in Figure 2.

A relational response would not have delved into such misconceptions and detours and would not have included the section on challenges. Fewer links would have been made between the activities and previously studied relevant educational theory. We aimed to ensure that we drew upon our learning from the Big History Project and the SOLO task, noting that many science activities and programs do not encourage either design thinking, connections to real science or assessment or include activities which encourage extended abstract understanding. We also wanted to include our knowledge of conjecture mapping and UbD, among others. We believe that the linking of all these ideas

in a cohesive and logical manner also showed extended abstract understanding, rather than just an assortment of ideas which did not draw the activities together under a common theme of student oriented, quality learning.

In this concluding section of the reflection a return to practicality can be seen. We are referring to an assignment at university, but could equally be talking about teaching practice in a school.

5.0 Thoughts for future design

This paper has reported on an early attempt to find tools that support a process we have described as conceptual tinkering as a way to build principled practice knowledge as part of an EDeR project, and proposes that 'playful' approaches to design ought to be an ongoing concern in this journal. To conclude the paper and start a longer discussion, we offer the following final thoughts from early in this design-research project – a set of researchable ideas rather than truth claims.

The work of Leon'tev tells us that the human mind draws on operational knowledge first; we do fast and 'easy' thinking whenever we can. The difficulty this creates in educational design work is a tendency to not recognise the conceptual complexity we are dealing with. A 'good' prac is one in which the students see the right nails rusting, even if they don't understand the chemistry in any meaningful sense. This is a curriculum design issue that has been well recognised:

Many approaches to curriculum design make it difficult for students to organize knowledge meaningfully. Often there is only superficial coverage of facts before moving on to the next topic; there is little time to develop important, organizing ideas (Bransford et al., 1999, p. 42).

The playful use of conceptual maps and the SOLO taxonomy as outlined in this paper, on the other hand, allowed the identification of conceptual understandings that varied from those we held ourselves, and forced us to take actions to address those variations.

Our experience was that the tinkering process was practical in terms of congruence with existing teacher practice – it was tinkering, not reinvention. Defining the problem is a fundamental step in the design thinking process. In most applications of design thinking this is at best understood as a process to understand the user and their needs. This paper has shown that conceptual tinkering can expand the problem space of the activity enabling a more nuanced and relational definition of the problem to be solved. Through the practice of conceptual tinkering outlined here we saw those involved in the project expand their curriculum design work from 'an assortment of ideas which did not draw the activities together' to a 'common theme of student oriented, quality learning'.

This, we believe was a change from Leont'ev's operations to actions. It led to change, but not to radical change. A standard operational approach to science curriculum design is to piece

together a string of ideas that demonstrate in some way the topic of study. Better design creates a narrative around these teaching and learning items, but the purpose tends to be tied to the concept rather than the learner. Our curriculum design-play, on the other hand, brought our attention – our actions - equally to the ‘ways of thinking and practicing in a subject’ (McCune & Hounsell) and built its narrative around an explicit pathway from existing to new ways of thinking. Tinkering gave us the cognitive space to think slowly.

The final practicality issue of cost is more troubling. The project described here engaged the design-research team collectively in many hours of tinkering or other ‘play’ that led to better design work that was more responsive to user (learner) need, but it did not produce many deliverables relative to the time expended. We would contend that the value created in the process is worth this cost, but we recognise that time-poor teachers in practice are less likely to agree.

There is certainly a need for further iterations of this type of research to find if the types of processes built here become more efficient with repeated use, and to find if there are ways to better scaffold this type of professional practice, with collaborative work through communities of practice, and the establishment of better communication of design-research work carried out by and for teacher-professionals - seeming a potential way forward. In the end though, we are designing for ‘slow thinking’, and the more important work may be to demonstrate that the cost is worth the benefit.

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