Colloquia: GIREP/MPTL 2014

Teacher change in implementing a research-developed representation construction pedagogy

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Summary. — The Representations in Learning Science (RiLS) project developed a representation construction approach to teaching and learning in science, which has successfully demonstrated enhanced student learning through sustained engagement with ideas, and enhancement of teachers' pedagogical knowledge and understandings of how knowledge in science is developed and communicated. The current Constructing Representations in Science Pedagogy (CRISP) project aims at wider scale implementation of the representation construction approach. This paper explores a range of issues that confronted four Year-8 teachers in implementing this research-developed approach, such as: preparedness of the teacher in terms of epistemological positioning and positioning as a learner, significant support for planning and modelling by the university expert, and a team ethos where teachers share ideas and plan jointly. The Year-8 teachers implemented a representation construction approach to the teaching of the topic of astronomy. The Interconnected Model of Teacher Growth (IMTG) (Clarke and Hollingworth, *Teach. Educ.*, **18** (2001) 947) was used to analyse the teachers' experience in planning and delivering the teaching sequence. This model was found to be flexible in identifying the experiences of teachers in different situations and useful in identifying issues for implementation of a research-developed pedagogy.

1. – Introduction

There is a growing consensus that quality learning must involve richer and more sustained reasoning and engagement with the mediating tools of the discipline in ways that entail the acquisition of a subject-specific set of purpose-designed literacies (Lemke, 2004). Students use the multi-modal representational tools of science to generate, coordinate and critique evidence (Ford and Forman, 2006), involving models and model-based

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reasoning (Lehrer and Schauble, 2006). A recent Australian Research Council (ARC) funded project, Representations in Learning Science (RiLS), successfully developed a theoretically sophisticated but practical, representation construction approach to teaching and learning that links student learning and engagement with the epistemic (knowledge production) practices of science (Tytler, Hubber, Prain and Waldrip, 2013). This approach involves challenging students to generate and negotiate the representations (text, graphs, models, diagrams) that constitute the discursive practices of science, rather than focusing on the text-based, definitional versions of concepts. The representation construction approach is based on sequences of representational challenges which involve students constructing representations to actively explore and make claims about phenomena. It thus represents a more active view of knowledge than traditional structural approaches and encourages visual as well as the traditional text-based literacies. RiLS has successfully demonstrated enhanced outcomes for students, in terms of sustained engagement with ideas, and quality learning, and for teachers' enhanced pedagogical knowledge and understanding of how knowledge in science is developed and communicated (Hubber, 2013, 2010; Hubber, Tytler, and Haslam, 2010).

The set of principles (Tytler *et al.*, 2003, p. 34) developed by the RiLS project that underpin the representation construction approach are broadly described as

1. *Teaching sequences are based on sequences of representational challenges*: Students construct representations to actively explore and make claims about phenomena.

2. *Representations are explicitly discussed*: The teacher plays multiple roles, scaffolding the discussion to critique and support student representation construction in a shared classroom process. Students build their meta-representational competency (diSessa, 2004) through these discussions.

3. *Meaningful learning involves representational/perceptual mapping*: Students experience strong perceptual/experiential contexts, encouraging constant two-way mapping/reasoning between observable features of objects, potential inferences, and representations.

4. *Formative and summative assessment is ongoing*: Students and teachers are involved in a continuous, embedded process of assessing the adequacy, and their coordination, in explanatory accounts.

These principles formed the basis of the current Constructing Representations in Science Pedagogy (CRISP) project which aims at wider scale implementation of the representation construction approach. In introducing the approach to new teachers the CRISP researchers aim to identify key enablers, and blockers, that facilitate quality teacher learning and adaptation of the representation construction approach. This paper explores the issues that faced four Year-8 teachers from a Melbourne metropolitan private school who were initially introduced to the representational construction approach and then implemented the approach in a four-week teaching sequence in the topic of astronomy.

The professional growth of a teacher that leads to a change of practice should be considered as a result of a complex process (Clarke and Hollingsworth, 2002). To explicate the underlying processes that mediate teacher change Clarke and Hollingsworth (2002) developed the Interconnected Model of Professional Growth (IMPG) (see fig. 1). The IMPG identifies four domains in which change can take place:
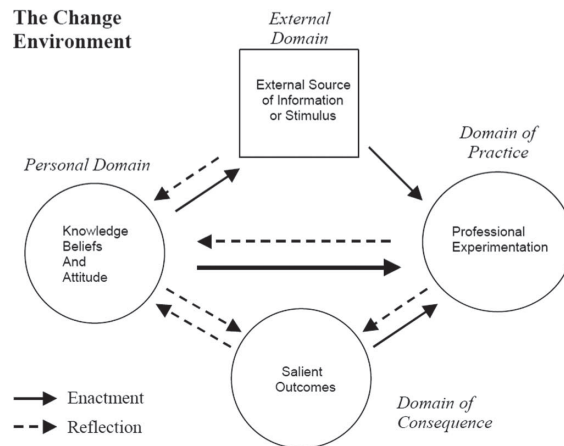
Fig. 1. – The Interconnected Model of Professional Growth.

- personal domain—a teacher's knowledge, skills, attitudes and beliefs;

- domain of practice—all forms of professional experimentation;

- domain of consequence—outcomes of new practices for the teachers themselves and their students; and

- external domain—sources of information and/or stimuli and support to develop new practices.

The first three listed domains form a part of the teacher's professional life whilst the fourth, external, domain is outside the professional day-to-day world of the teacher. Change may occur in any domain, and is mediated through the processes of enactment and reflection. According to Clarke and Hollingsworth (2002), the processes of enactment and reflection can be described in terms of paths connecting the various domains, which mirror the learning processes taking place (see fig. 1). The IMPG is used in this study as a lens for identifying change in the Year-8 teachers in addition to exploring the issues they faced in implementing a research-developed pedagogy, the representation construction approach.

2. – Background: change environment and external domain

Any change in the professional growth represented in the IMPG occurs within the constraints and affordances of the change environment. Salsa[1] College is an all-boys Catholic secondary school with student enrolment around 950. There were four teachers (Alice, Suzie, Kate and Jaz) who taught five Year-8 classes (28–30 students) the topic of astronomy. One class was special entry (high academic achievement) taught by Alice; two classes were taught by Kate. All teachers were quite experienced, Suzie and Jaz had taught at Salsa College for several years, Alice was in her first year at Salsa College and Kate was in her first Term. The topic of astronomy dealt with explanations associated

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[1] Pseudonyms have been used for the school as well as the teachers mentioned in this paper.

with such phenomena as day/night cycle, phases of the moon, seasons, gravity and eclipses. The intention was to address the new Australian Curriculum: Science (ACARA 2010) and so the content of this topic addressed this curriculum.

The external domain consisted of curriculum resources and professional development (PD) delivered to the teachers in various forms by the CRISP research team. Each of the teachers was given curriculum resources developed by the RiLS project. This resource consisted of pre- and post-tests (with previous performance data), written descriptions and teacher reflections of various activities that illustrated the representational approach, examples of students work from the RiLS project, and digital resources in the form of PowerPoint presentations with embedded interactive simulations and video.

In addition to these resources Alice had prior knowledge of the representational construction approach through participation in a 3-day Switched on Secondary Science Professional Learning (SOSSPL) program the previous year whilst teaching in a Victorian Government school. The SOSSPL program, a Victorian Department of Education initiative, was developed and delivered by RiLS/CRISP research staff and informed by the representation construction pedagogy. Suzie and Jaz had undertaken a 2-hour after-school workshop delivered by the CRISP researchers to the science staff at Salsa College. In the workshop importance was placed in modelling the representation construction approach by the CRISP researchers.

The support given to the teachers also consisted of weekly meetings during the teaching sequence where the CRISP researchers and teachers had reflective discussions as to the previous week's teaching in addition to planning the future week's teaching. A few months following the teaching sequence the CRISP researchers and teachers had a whole day workshop review of discussions and presentations. The presentations involved examining students' artefacts that included their responses to a variety of representational challenges and reflecting on segments of the teaching sequence shown in the classroom video that was taken of one lesson taught by each of Jaz, Alice and Kate. The workshop review also included discussions about the teachers' perceptions of the representation construction pedagogy in relation to their practice.

3. – Methods

As mentioned in the background there were four Year-8 teachers who taught a four week teaching sequence in astronomy to 5 classes of boys (class size 28–30 students). In determining the issues that faced the four Year-8 teachers in implementing the representation construction approach the following data collection instruments were used:

- pre- and post-tests;

- classroom video of one lesson of three of the teachers—the lesson was chosen by the teacher;

- recorded, and transcribed, teacher and selected student interviews following the teaching sequence;

- student artefacts, in particular, their project books which contained a record of their responses to many of the representational challenges as part of the representation construction approach;

- recorded, and transcribed, conversations among the CRISP researchers and teachers every week of the teaching sequence; and

- whole day review with CRISP researchers and teachers which involved discussions of the student work and selected videos of the teachers' practice — the review was recorded and transcribed.

4. – Findings

Whilst the teachers were given curriculum and pedagogical advice by the CRISP researchers they had final say as to what resources they would use and the manner in which they were to interpret and implement the representation construction approach. It was found that the teachers enacted many of elements of the CRISP external domain in their teaching sequence. It was also found that the teachers modified some of the resource material in addition to introducing others as they trialled and reflected on the application of the representation construction approach in their teaching. The main findings are outlined in the following themes:

- Student learning.

- Pre-testing and alternative conceptions.

- Student record keeping.

- Summative assessment.

- Teaching for meta-representational competence.

- Teacher collaboration.

- Representation construction approach as inquiry.

4˙1. *Student Learning*. – The teachers perceived the students' learning gains as measured by their performance in multiple choice questions on the pre/post-tests as a significant salient outcome as the gains were higher than those obtained by a study undertaken by Kalkan and Kiroglu (2007). This study involved 100 pre-service primary and secondary education teachers who participated in a semester length course in astronomy. A measure of comparison of pre- and post-test results is the normalized gain index, $\langle g \rangle$, the ratio of the actual average student gain to the maximum possible average gain: $\langle g \rangle = (\text{post}\% - \text{pre}\%)/(100 - \text{pre}\%)$, reported by Zeilik, Schau and Mattern (1999). Gain index values can range from 0 (no gain achieved) to 1 (all possible gain achieved). The mean gain reported by Kalkan and Kiroglu (2007, p. 17) was described as a "respectable 0.3". In contrast the mean gain for this study was significantly higher at 0.52.

4˙2. *Pre-testing and alternative conceptions*. – The pre-test was developed by the CRISP researchers and whilst the administration of pre-tests was not common practice at Salsa College the teachers agreed to implement it. The teachers initially viewed the pre-test as part of the research rather than integral to the teaching sequence. However, the view by all teachers on the use of a pre-test was positive: *"Yeah, the pre-tests are good, and the way we used them was good too... I think a pre-test is a good idea* (Suzy)". Kate added: *"It just should be teaching practice; it should just be what we do* (Kate)". The prevalence of alternative conceptions was surprising for Jaz who commented: *"I didn't realize. I just thought once kids learn things that they keep a hold of it, but they don't"* so a pre-test that exposes such views was *"really helpful* (Jaz)".

The teachers used the information gained from the pre-tests in their teaching as the illustrated by the following comments:
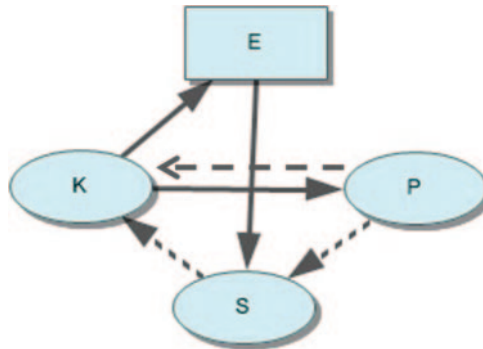
Fig. 2. – Growth network for Jaz.

> *So I would say that, in that question [taken from the pre-test], what did we think and I'd get them to talk about it. And then at the end of the lesson, we'd say okay, so if we saw that question again, how would we be changing our answer to be more representative? [...] we weren't pretending like they had this blank slate and they'd never seen astronomy before. They already had ideas, that we kind of – half the battle was challenging them, more so than teaching them new content* (Alice).

> *I did deal with the topics that they had the most trouble with* (Jaz).

In relation to the theme of pre-testing and misconceptions there of evidence of a growth network for Jaz which is illustrated in the IMTG diagram in fig. 2. In the first instance the pre-test was enacted as part of the research and not, in the minds of the teachers, as part of their professional experimentation. The salient outcome for Jaz was the realisation of the prevalence of misconceptions. She reflected on these and the need to address them in the teaching sequence which she enacted. A further salient outcome of significant learning gains by her students led her to a belief of the need to provide pre-tests as part of her teaching practice and to seek out pre-tests from the external domain. This change was reflected in the following comments made by Jaz 12 months after the teaching of the astronomy topic:

> *[The] pre-test is very powerful. We have a booklet of pre-tests [now available to us]* (Jaz).

> *[...] and the misconceptions; we knew where the majority of the class were thinking so you could direct your teaching to that [...] it highlighted for me the numbers in the class who don't get it, don't get a concept* (Jaz).

4˙3. *Student record keeping*. – The workbooks used by the students were treated more like learning journals. They were project books that were larger that A4 in size and were formatted so that the when opened the left hand page was lined and the right hand page was blank. The use of the project books was new to the students who previously used fully lined A4 sized workbooks.

The project books facilitated the use of drawings in recording what they learned (see fig. 3 for some examples). Drawings were often used in addressing the representational challenges (see fig. 4 for some examples). The blank page encouraged visual forms of
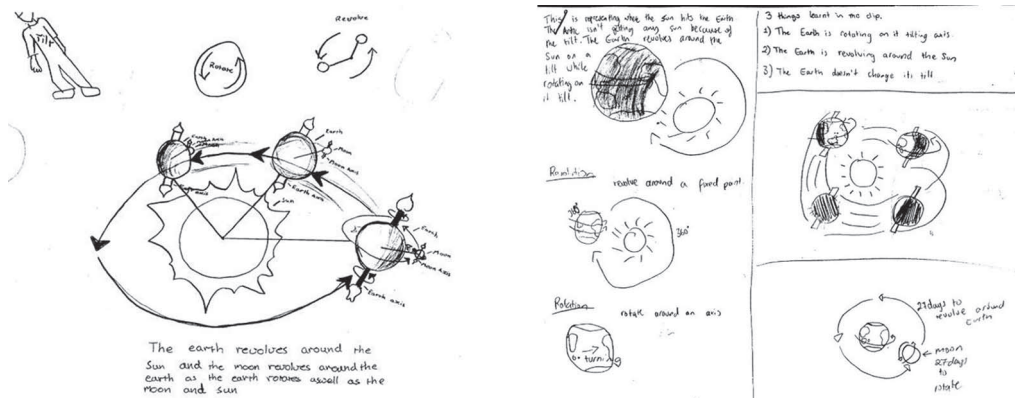
Fig. 3. – Examples of students' entries into their learning journals.

representations. The visual representations provided the teachers with ready insight into students' thinking.

> *Immediately by looking at their representations, I know, okay those boys have got it and those boys are on the right track but those haven't fully kind of understood* (Alice).

> *But the books just having the blank page, I think sometimes, it's just all text that we kind of forget how much the use of those representations and diagrams can really help in science, so it was a good reminder* (Alice).

The students were more willing to use their journals to reflect on their learning

> [. . .] *they seemed more willing to go back over their work and look back at their past stuff as well* [. . .] *And I don't think they do it very well if it's just written stuff and they had a sense of ownership over it which was good* (Kate).

> *They loved their project books. Like ridiculously* [. . .] *it was like this little diary of all the work that they'd done. It was different from what they had been doing* (Alice).

> *What worked well? Perhaps me going back all the time revising and going back to their journal and having them look* [. . .] *They're quite taken with it* (Jaz).

The entries the students' made in their learning journals were seen by the teachers as a vehicle for discussion.

> *And I think* [. . .] *that while they're doing their representations you can have conversations with them and be active with them but it's not such a threat, it's not give me the correct response, it's more about why have you done it that way* (Alice).

> *I found that the discussions were a lot more sophisticated that they were having around the topics than usually with the textbook* (Alice).

In relation to the theme of student record keeping there of evidence of a growth network for Alice which is illustrated in the IMTG diagram in fig. 5.

Representational Challenge: Represent in a drawing the height of the midday Sun in winter from Melbourne
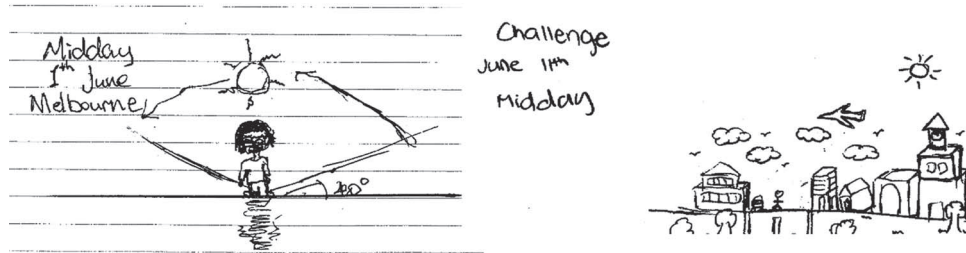
Representational Challenge: Why when we were watching the opening ceremony for the Olympics was it night in London, but morning here in Melbourne?

It is morning in Australia because the Sun is shining on the Earth bit it can't shine all of Earth like a shadow. It is because of the tilt; rotating, revolving around the Sun it rotate
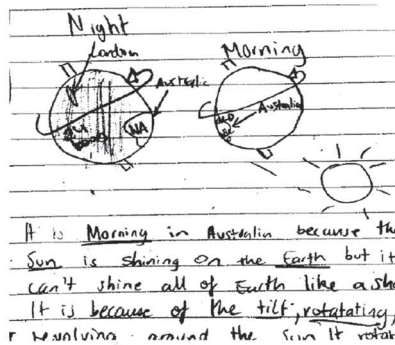
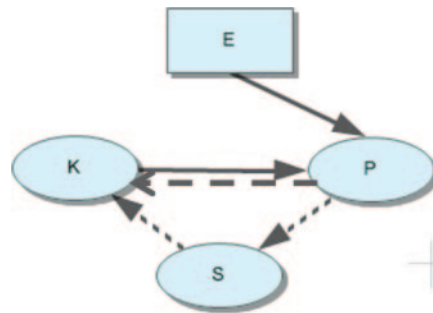Fig. 4. – Examples of students' responses to two representational challenges.

Fig. 5. – Growth network for Alice.

The project books were introduced into the teaching sequence and were reflected on and then used as learning journals. A key salient outcome was that the journals became a formative assessment tool for the teacher and a tool for deeper reflection for the students.

4·4. *Summative assessment.* – The teachers had a long standing policy of administrating pen and paper based tests as a final summative task to the topics that were taught. This practice continued in the Astronomy unit. However, a key salient outcome for the teachers was the multiple modes of representation that the students displayed in their
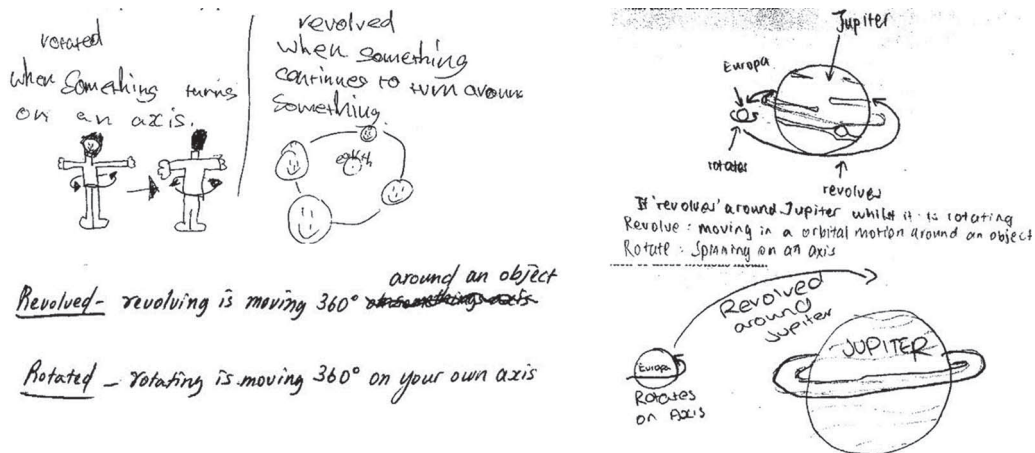
Fig. 6. – Student responses to a test question.

learning journals. This prompted a change to open-ended questions given on the final test challenging students to construct representations and providing a space rather than the traditional lines for students to respond. Figure 6 shows the use of this expanded space for student responses to a test question asking, "An astronomer investigating the motion of *Europa*, which is a moon, or natural satellite, of the planet *Jupiter*, found that it *revolved* as well as *rotated*. Use the space below to clearly explain what each of these motions mean."

In reflection of finding different ways in which the students responded to test questions the teachers commented:

> *In their test answers if we gave them the space they would perhaps do a diagram to help with explanation or we might say use representation, they didn't just stick to the words* (Jaz).

> *And it valued those boys that do like to draw* (Alice).

Following the Astronomy teaching sequence Alice made mention of a continued practice in providing a space for students to respond to test questions.

> *And even with our year 8 exam last semester [outside of the Astronomy topic] like in our extended response more inquiry based we opened it up that they could represent that knowledge in multiple ways (Alice).*

4˙5. *Teacher collaboration*. – The collaboration among the teachers in the past was "*more where are you up to in the text book rather than what the activities are* (Jaz)". The experience in teaching the Astronomy topic was more collaborative and associated with the joint commitment to supporting deeper level student understanding around a conceptual focus. It was more about discussing and sharing representational issues with teaching and learning the concepts.

> *I think we kind of went away from what's in the chapter of the text book that we need a cover into more what key ideas or understanding that we want the boys to take away at the end of the topic* (Alice).

Rather than following the textbook, the introduction of a pedagogy built around a coherent conceptual focus gave the teachers, "*a bit more fluidity as well and flexibility with what we can do as we go* (Alice)." With the collaborative planning of topics from a conceptual focus there is now an emphasis on pre-testing of ideas (mentioned above) and, "being *very conscious of trying to put in representative stuff* (Kate)".

Following the astronomy topic the teachers maintained their diminished focus on the textbook. This finding is reflected in the following comment:

> *I'm not as text book oriented. I found that I don't set questions out of text book or the E book anymore. I just give them a task that suit where they're at and there will be homework tasks that follow on, it's more of a representational deal* (Jaz).

The affordances offered by the representation construction pedagogy for collaboration around student conceptual learning also provided the opportunity for mentoring work amongst the teachers, with those with more experience or productive ideas helping the others, especially new staff as they came on board, with understanding and implementing the approach in novel ways.

4˙6. *Representational construction approach as inquiry.* – The teachers perceived the representation construction approach as one in which the teacher might implement an inquiry approach that supplements textbook teaching. These views are reflected in the following comments:

> *I think it's given us an actual tangible way to do the inquiry base that's an easier way for most staff to sort of like cause when we talk inquiry base they think open ended the kids are going to be all over the shop hey whereas this kind of gives them that ability to have inquiry learning but in a different way* (Kate).

> *Oh it's just reinforced that sometimes text books aren't the answer to all science teaching and if you mix it up I think that's the best approach rather than flogging this textbook idea. I think if you can bring something like this inquiry based learning as a different approach I think that's only going to benefit the kids learning* (Jaz).

The teaching approach is perceived to be effective "*because they're learning by doing it they're not just rote learning or trying to remember facts* (Kate)" and "*having to explain it someone else or to put down what they know* (Jaz)".

5. – Discussion and conclusions

The four teachers demonstrated change in their current practices in implementing the representation construction approach. In relation to the literature on effective professional development (for example, Loucks-Horsley *et al.* 2010) the CRISP project directly aligned with student learning needs; was connected to practice; focused on the teaching and learning of specific academic content, and; provided time and opportunities to collaborate. The Salsa College teachers had ongoing time and opportunity to collaborate and build strong working relationships. In addition, the CRISP intervention was continuously monitored and evaluated by the CRISP researchers and teachers.

The IMPG model proved useful in unpacking the domains of teacher learning and their interconnections for each of the themes discussed, and also the way the external

input operated to support these domains. It enabled us to see the model as consisting of essentially two parts; the enactment of teacher learning consisting of interconnections between the practice, salient outcome and knowledge and belief domains, and the external input which ideally is operationalized to trigger and support these interconnections. The requirement and opportunity for teachers to practice was of critical importance to their learning. For the Salsa teachers classroom enactment provided the basis for collaboratively exploring and honing strategies. The key student outcomes of engagement in classroom activity and discussion, and learning, and realisation of the salient features of teacher practice, were central to learning. Deeper-level student outcomes were realised with more confidence and there was more opportunity to explore the practice-belief-salient outcome cycle through ongoing iterations. Changes in teacher knowledge and beliefs both arose from and fed into their classroom practices and judgments of outcomes, and the Salsa teachers were coherent and confident in their learning. The coherence of the pedagogy and its exemplification in practical classroom activity was important in capturing the commitment of the teachers to their learning cycle.

The external input had core features that were important for teacher learning outcomes. A key feature was the provision of a coherent perspective on learning in science, with illustrative, practical classroom activities flowing from this. The building of collaborative discussion was important and built around planning, implementing and interpreting classroom practices. From the perspective of the IMPG model we found that the domain external to a teacher is highly complex, consisting in our case of university experts, curriculum resources, and also the community of teachers involved. The teachers found that the curriculum resources that included pre-tests with student results from previous research, key ideas and alternative conceptions pertinent to the topic and a variety of activities with a representational focus (with student samples) highly useful in interpreting and adopting elements of the representational construction approach. The teachers also saw benefit in workshop activities where the approach was modeled in addition to discussing and sharing ideas with university staff and other participating teachers. The shaping and coordination of the resources exemplifying the innovation is critical for successful implementation. The importance of peer collaboration is apparent in our data, such that input and feedback from colleagues acts as a critical supplement to the input provided by the researchers.

One can not treat an innovation as a unitary thing but need to think of the Interconnected Model of Professional Growth (IMPG) separately for each aspect of the innovation. In the findings above for the Salsa teachers, change networks were seen with the pre-test and alternative conceptions theme and the student workbook theme. Whilst not shown in this paper change network diagrams may have been constructed for each teacher in the other themes such as collaboration, summative assessment and meta-representational teaching. Whilst the IMPG model needs to be considered separately for each aspect of the innovation connections can be made between change sequences and networks. For example, the change network for Alice in using learning journals reported on the formative assessment opportunities of the student entries in the journal. The journal entries gave insight into the students' thinking including if they have misconceptions. Alice then views the learning journals as supporting the other theme discussed in this paper, which relates to pre-tests and misconceptions. Therefore the two themes are connected to the misconceptions viewed in the learning journals.

Finally, we found variation with the IMPG when thinking about how this model might fit with the implementation of the pre-tests in the Astronomy topic. The model as presented by Clarke and Hollingsworth (2002) (fig. 1) does not allow enactment from

the external domain to the domain of consequence. We found that the teachers initially viewed the pre-test as being associated with research and university researchers. However, the prevalence of misconceptions was considered a salient outcome by the teachers. This supports a link between the external domain and domain of consequence. However, another interpretation is that the administration of the pre-test represents information in the external domain. In this interpretation the teachers reflected on the student results to then change their practice to address the misconceptions elicited.

In terms of implications for scaling up research-developed innovation, the implications of the analysis are not straightforward. Clearly the CRISP project is able to provide more convincing and deeper evidence of teacher learning and of student learning, but this comes at a cost of greater researcher time commitment. It is our hope that at Salsa and other schools we are working at the seeds will be sown for extension of the approach to other teachers and perhaps nearby networks of schools, using the growing experience and confidence of this first generation of teachers.

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