International Journal of Science Education

ISSN: 0950-0693 (Print) 1464-5289 (Online) Journal homepage: http://www.tandfonline.com/loi/tsed20

Reconceptualising inquiry in science education

Stuart Bevins & Gareth Price

To cite this article: Stuart Bevins & Gareth Price (2016): Reconceptualising inquiry in science education, International Journal of Science Education, DOI: 10.1080/09500693.2015.1124300

To link to this article: http://dx.doi.org/10.1080/09500693.2015.1124300

Published online: 24 Jan 2016.

INTERNATIONAL JOURNAL OF SCIENCE EDUCATION, 2016
http://dx.doi.org/10.1080/09500693.2015.1124300

Reconceptualising inquiry in science education

Stuart Bevins and Gareth Price

Centre for Science Education, Sheffield Hallam University, Sheffield, UK

ABSTRACT
Decades of discussion and debate about how science is most effectively taught and learned have resulted in a number of similar but competing inquiry models. These aim to develop students learning of science through approaches which reflect the authenticity of science as practiced by professional scientists while being practical and manageable within the school context. This paper offers a collection of our current reflections and suggestions concerning inquiry and its place in science education. We suggest that many of the current models of inquiry are too limited in their vision concerning themselves, almost exclusively, with producing a scaffold which reduces the complex process of inquiry into an algorithmic approach based around a sequence of relatively simple steps. We argue that this restricts students' experience of authentic inquiry to make classroom management and assessment procedures easier. We then speculate that a more integrated approach is required through an alternative inquiry model that depends on three dimensions (conceptual, procedural and personal) and we propose that it will be more likely to promote effective learning and a willingness to engage in inquiry across all facets of a students' school career and beyond.

ARTICLE HISTORY
Received 17 June 2015
Accepted 21 November 2015

KEYWORDS
Inquiry-based teaching; learning environment; secondary school

Introduction

The effectiveness of inquiry in science teaching and learning has been supported by a wide range of empirical work which reports positive learning outcomes for students in terms of achievement, enthusiasm, ownership and scientific skills development (Minner, Levy, & Century, 2010; Minstrell & van Zee, 2000). This work represents a continuing focus on inquiry teaching in science education and demonstrates its perceived importance by the science education community. However, the majority of existing work tends to report on structures and processes of inquiry in the science classroom and seems to have accepted current models as a *fait accompli*. Furthermore, while much of the extant literature on inquiry-based science education reports on the benefits and effectiveness of using inquiry, it also highlights that teachers can and do face difficulties when attempting to implement inquiry approaches in the science classroom. These difficulties include time constraints caused by content-laden curricula, assessment procedures which may be inappropriate for inquiry approaches, the availability of laboratory resources which can restrict

CONTACT Stuart Bevins s.bevins@shu.ac.uk Centre for Science Education, Sheffield Hallam University, Owen Building, Floor 9, City Campus, Sheffield S1 1WB, UK

the design of an inquiry and the impact of high-stakes assessment outputs (Anderson, 2002; Crawford, 2007). We suggest that these difficulties are exacerbated, in part, by the models themselves and would argue that some existing models reduce inquiry to a sequence of tasks driven by a mechanistic approach which we believe to be unhelpful and ultimately self-defeating in the context of what we believe to be authentic inquiry. We also reject as untenable that the only possible response to these scaffolded models is that inquiry must be entirely student-driven and completely unsupported by the teacher (Kirschner, Sweller, & Clark, 2006). Instead, we suggest a new model of inquiry that identifies three dimensions:

- scientific knowledge—includes facts and theories
- evidence-generating and handling procedures—includes data gathering and analysis
- psychological energy—includes intrinsic and extrinsic motivation

This model recognises the inquirer as an active agent who is required to navigate within, and manage the interactions between, these dimensions to construct a meaningful, productive inquiry that supports the construction of new knowledge, development of evidence handling skills and promotes student autonomy and exploration. We explore the nature of this model later after having considered what is currently understood by inquiry in the science classroom within the existing literature.

The concept of inquiry

The belief, that an over emphasis on subject facts reduces the space for thinking and developing attitudes about science, has been discussed and debated within the science education literature over a number of decades. Over 50 years ago Schwab (1962) argued that school science should more accurately represent science as practiced by professional scientists and this argument continues to influence science curriculum development globally to this day. For example, Minner et al. (2010), conducting a review of 20 years' research into the topic, quotes the following description from the National Research Council (2000) paper as a useful summary of much of the current understanding of inquiry in school science:

(1) Learners are engaged by scientifically oriented questions.
(2) Learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions.
(3) Learners formulate explanations from evidence to address scientifically oriented questions.
(4) Learners evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding.
(5) Learners communicate and justify their proposed explanations.

The updated standards from the U.S.A., the Next Generation Science Standards (2013), extend and develop this description by further emphasising the practice of scientists and engineers rather than the knowledge they have. They also introduce cross-cutting concepts like causality but describe these purely in terms of scientific endeavour rather than a concept which informs a range of other disciplines. They also emphasise the application of knowledge in real world contexts more and explicitly link science to engineering.

The ideology above appears, with minor modifications, in a range of curricula across the world and attempts to define science as 'practised by professional scientists' through a series of procedures which, taken together, are often abbreviated as 'inquiry', the 'nature of science' or 'the scientific method'. In their review Windschitl, Thompson, & Braaten (2008) describe this in the U.S.A. as 'the current paradigm of preference for educators—the scientific method (TSM)—and its role in allowing distorted images of science to be passed down through schooling practices' (p. 942).

Alongside the growth of inquiry has been the development of active teaching and learning approaches, constructivism and the idea that students should have more control over, and take more responsibility for, their own learning. These are often conflated into a single view of science education that could be described as student-centred, progressive or inquiry-led. The term Inquiry-Based Science Education (IBSE) is now used extensively to describe curricula which include at least some inquiry activities designed to reflect this approach. This conflation of a range of ideas into a single identity has created some of the problems we have encountered when thinking about inquiry because many different science education professionals have a highly personal, and distinctive, view of what they mean by inquiry ranging from simple practical work to completely unsupported, student-led learning programmes (Barrow, 2006).

The value of inquiry as a teaching approach

We believe that inquiry is currently the best way for students to leverage their existing knowledge and their investigative skills to find, and internalise, new knowledge and solutions to questions they have formulated. This approach gives students better ownership of their learning and allows them to actively navigate the routes to increased understanding, greater motivation, improved attitudes to scientific endeavour and growth in their self-esteem and their ability to handle new data in an increasingly complex world. However, we feel that many of the existing IBSE approaches fail to leverage the full power of inquiry and that, while they may be the best strategies currently available for learning, we now need to move on to the next, more sophisticated model to reap further benefits.

Despite the confusion around the formal definition of inquiry, the view that helping students to reconstruct their knowledge through interaction with objects in the environment and problem-solving is paramount for the science teacher is supported by a significant amount of evidence concerning teaching and learning science through inquiry (Sadeh & Zion, 2009). Supporters claim that it deepens students' understanding of the Nature of Science (NoS), develops critical and higher-order thinking skills and promotes autonomous learning (Carter, 2008; Kaberman & Dori, 2009). However, other authors have questioned the effectiveness of inquiry claiming that many of the minimally led inquiry learning experiences 'do not work' (Kirschner et al., 2006) or that models of inquiry are too limited, revolve around extensive practical work and omit the wealth, power and complexity of the scientific endeavour. Windschitl et al. (2008) describe the poverty of the 'scientific method' model as practised in many U.S. schools and use this criticism to promote a more sophisticated model-based inquiry which recognises the importance of scientific models as a source of predictions and ideas to test.

Inquiry is not just an algorithmic process

Despite the lack of a definitive statement of what inquiry is in school science few topics have generated as much heat as inquiry over the last few years since it tends to hit at the heart of what many educators regard as 'a good science education'. However, it is likely that teachers do not simply provide either a totally teacher-led, theoretical exposition nor a completely open inquiry diet for their students but instead seek a more practical option taking in to consideration the time demands of inquiry approaches within a heavily content-laden curricula. Even when teachers claim explicitly to be using inquiry as their main teaching strategy there are nuances of meaning based broadly on the level of control the student enjoys. With the lowest level of student control are confirmation or verification activities (these are often not considered inquiry at all) with structured inquiry offering more freedom and guided inquiry even more. Only open inquiry offers students the chance to design and carry out their own investigations into a topic of their own choosing and interpret them with reference to their own scientific knowledge. Detailed descriptions of the different levels of inquiry are given elsewhere (Zion & Mendelovici, 2012); however, Table 1 shows the essential components of the three typical models of inquiry—open, guided and structured.

Table 1, or variations of it, appears in many papers which discuss the nature of inquiry in science education. We argue that, while the models described are valid and helpful, they

Table 1. Models of inquiry and associated skills.

Improved inquiry grid	Inquiry skill areas				
Level	1: Scientifically orientated questions	2: Priority to evidence	3: Explanations from evidence	4: Explanations connected to knowledge	5: Communicate and justify
3: Open inquiry	Learner poses a question	Learner determines what constitutes evidence and collects it	Learner formulates explanations after summarising evidence	Leaner independently examines other resources and forms the links to explanations	Learner forms a reasonable and logical argument to communicate explanations
2: Guided inquiry	Learner selects amongst questions, poses new questions	Learner directed to collect certain data	Learner guided in process of formulating explanations from evidence	Learner directed towards areas and sources of scientific knowledge	Learner coached in development of communication
1: Structured inquiry	Learner sharpens or clarifies question provided by others	Learner given data and asked to analyse	Learner given possible ways to use evidence to formulate explanation	Learner given possible connections to scientific knowledge	Learner provides broad guidelines to use to sharpen communication
0: Confirmation / verification exercises	Learner engages in question provide by others	Learner given data and told how to analyse it	Learner provided with evidence	Learner provided with precise connections	Learner given steps and procedures for communication

constitute only a single component of a more complete description of the nature of inquiry —a component we call 'procedural'.

The procedural dimension depends on a linear Question-Procedure-Result-Interpretation (QPRI) understanding of inquiry. We acknowledge that QPRI is a way *some* scientists conduct *some*, or *much*, of their day-to-day work. The question, often referred to as a 'scientific question' leads to a suitable procedure (fair test, literature search, fieldwork etc.) which generates a result that is interpreted in terms of the original question. This is a clear and convenient statement of the inquiry process and is reflected in many of the rubrics used for assessment of 'inquiry' by awarding bodies in the U.K. (Assessment and Qualifications Alliance, 2013). However, we suggest that this can reduce the students' role in inquiry into a sort of cognitive clockwork toy—just wind it up and watch it go through the pre-recorded sequence of events to produce the answer. This perception is supported by Windschitl et al. (2008) who state that this view works too well for teachers and that:

> The idea of a self-contained procedure, only nominally linked to conceptual content, with orderly, predictable steps and much of the epistemological complexity stripped away, is actually a useful framework. … this highly prescribed protocol may be the only form of investigation seen as manageable in today's overcrowded classrooms. … one can complete the technical aspects of many types of classroom inquiry without knowing the underlying content or being pressed to reason scientifically at all. (p. 947)

The statement above reveals the two major criticisms of inquiry— that it does not link sensibly to any scientific conceptual material and, perhaps more damningly, it does not even require the students to reason scientifically. It can fail to deliver both content and process.

Inquiry as it is, not as we would like it to be

We suggest that Inquiry is more complex than the QPRI model. It does not always start with a clear 'scientific' question that is amenable to simple laboratory experiment. It can begin with an interest, a hunch, a problem defined by another party or even the arrival of a new piece of equipment or development of a new observational technique. If the question is not always present what of the second part—the hypothesis generation, the practical work? These are often labelled as 'the scientific method' (TSM) as if it is the only way scientific evidence is gathered or that it is somehow unique to science.

While there are some procedures that are common to 'science as practised by professional scientists' not all are always clearly defined at the start of the inquiry and much of a research scientists' work is refining and developing their procedures, methods and equipment. Furthermore, results are very often tentative telling us as much about the procedure that produced them as the underlying question we may have wanted to answer or the hypothesis we were testing. Finally, interpretation of these results can be so much more than simply answering the original research question (which could have been lost in the difficulties and refining of the procedures or data collection).

Organising a messy, complex and dynamic process (which has many twists, turns and reversals) into a neat, simple sequence of independent procedures is attractive. These types of scaffolding systems are popular with teachers and can relate to assessment objectives provided by their awarding bodies (Assessment and Qualifications Alliance, 2013) or a conceptual view of TSM like the 5E's or 7E's (Robertson, 2007). Unfortunately, these scaffolds can remove the need for strategic or deep thinking in favour of mechanistic subject content coverage. The arguments against this neatening of inquiry and TSM into a set of manageable events or simple steps designed to deliver inquiry is set out by Windschitl et al. (2008) but fundamentally revolve around the fact that it does not reflect authentic science or generate an assessment of scientific reasoning. The scaffold, in some cases, has replaced the building it was meant to support in that the method becomes more important than the learning or the evidence generated.

Fruit salad science

We propose a model of inquiry that relies on three interrelated dimensions. We believe that this model represents a more complete model of inquiry which resists becoming merely a scaffold and instead promotes students' conceptual and strategic thinking.

- Dimension 1: A body of knowledge: this informs scientists' thinking about phenomena and can generate questions and suggestions for inquiry.
- Dimension 2: Evidence-management procedures: these ensure evidence is generated reliably, interpreted with reference to the underlying ideas and the observed data and communicated appropriately
- Dimension 3: Psychological energy: this provides the energy to create and manage an authentic inquiry.

The three dimensions above have different natures and characteristics and do not link conveniently to each other in a simple sequence. One does not 'lead' to the other nor 'depend' on another in a strict linear sense. All are interrelated but only to the extent that they belong to a system that requires their presence. They are as related to each other as the individual fruits in a fruit salad. They are all essential to make up the salad but apples are not like bananas and pineapples do not lead to oranges or grapes. The system is more than merely the sum of its parts even though the parts might be externally still recognisable.

The body of knowledge described as 'science' is fairly clearly defined and distinct from the body of knowledge familiar to historians or geographers. This includes both the 'great theories' of science (e.g. evolution or atomic theory) to explain phenomena and verifiable facts about a particular situation (e.g. the melting point of sodium). This body of knowledge, both the theories and facts, grows every year and is prone to continuous revisions as new data or ways of interpreting it become available (Figure 1).

Dimension 2 includes a range of mechanical skills that scientists may use in particular circumstances (e.g. using a microscope or heating materials with a Bunsen burner). The catalogue of these skills is extensive with many used in very specific contexts. Other procedures that make up Dimension 2 (e.g. identifying and controlling variables, careful experimentation, hypothesis generation and data analysis) are recognisably scientific when linked to scientific knowledge and are named TSM to distinguish it from other ways of making sense of the world. Dimension 2 also includes a range of other enabling skills that are relevant to inquiry but are not exclusive to science. These include

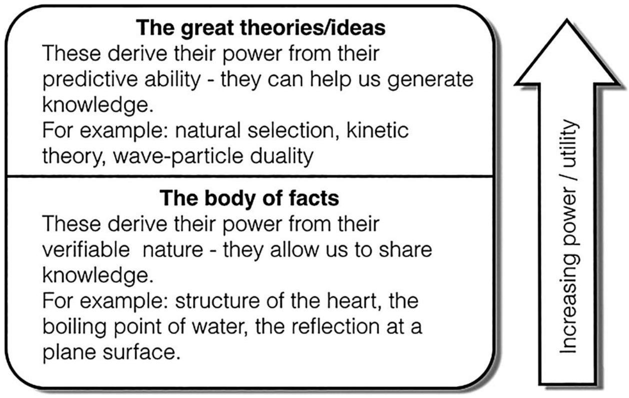

Figure 1. Dimension 1.

communication and teamwork skills, organisational skills and keeping of accurate records (Figure 2).

Dimension 3 attempts to put the 'inquirer' back into the 'inquiry'. This is the dimension that elevates the algorithmic procedures of Dimension 2 into a dynamic, active process that has the potential to generate new knowledge. An inquiry is a temporary, purposeful construction built from relevant Dimension 1 knowledge and useful Dimension 2 procedures driven along by the 'psychological energy' generated by Dimension 3. So, how is this psychological energy, which is the ability to do investigative work, produced in Dimension 3? We suggest that Self-Determination Theory (SDT) (Deci & Ryan, 2008) is a useful way of looking at this.

SDT has been used extensively to explore 'motivation'. In education, motivation is often perceived as a way to encourage students to engage in work that might not otherwise interest them. However, motivation as seen through an SDT lens is better understood as the force that supports and drives any activity and the development of a healthy self

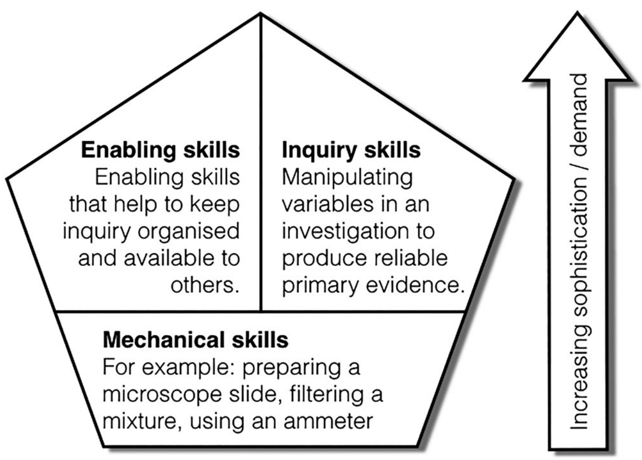

Figure 2. Dimension 2.

(Lavigne, Vallerand, & Miquelon, 2007). Rather than seeing motivation as a single factor that can be measured SDT allows for a number of classes of motivation from intrinsic (the task is perceived as personally worth doing for its own sake) through various types of extrinsic motivation: identified regulation (the task is completed because it fits in with longer term goals, e.g. doing science to make a career as a doctor possible); introjected regulation (the task is completed because it seems to be the 'right thing to do' even if the justification for it has not been entirely accepted, e.g. a student attends a science class because otherwise they will feel guilty, they will be letting someone down) and external regulation where the motivation is contingent on external rewards or avoidance of punishment (e.g. if you do not pass this examination you will not be allowed to graduate). Extensive work on the positive effects of autonomy-supporting motivation (intrinsic motivation and identified regulation) compared with controlling motivation (introjected and controlling regulation) exists reviewing persistence in science courses, (Lavigne et al., 2007), achievement (Ratelle, Guay, Vallerand, Larose, & Senécal, 2007) and a range of other positive behavioural, cognitive and affective outcomes (Guay, Ratelle, & Chanal, 2008). For example, Lavigne et al. (2007) tested a motivational model of persistence in science education. The authors posited that science teachers' support of students' autonomy positively influences students' self-perceptions of autonomy and competence. In turn, these self-perceptions have a positive impact on students' self-determined motivation to participate in science education and their level of achievement. In short, it would appear that the most self-determined kind of motivation is intrinsic motivation (Deci & Ryan, 2000).

In order to generate this intrinsic motivation SDT identifies three basic psychological needs:

- autonomy
- a sense of competence
- relatedness to significant others

Where these three needs are met intrinsic motivation can develop but where they are thwarted to some extent motivation is reduced or converted from the useful intrinsic motivation into the less productive external regulation. A detailed discussion of SDT can be found elsewhere (Deci & Ryan, 2012) but for our purposes we feel that it is the insight into 'motivation' as a driving factor for self-development that fits well with our proposed third dimension. This moves inquiry from a process to be completed to an outpouring of an inquirer's central identity. Therefore, it is the motivation to inquire, to find out and to explore, coupled with a collection of useful procedures and a store of relevant knowledge that allows inquirers to inquire (Figure 3).

Constructing inquiry in three dimensions

Operationalising the third dimension means that the inquirer organises together aspects from all three dimensions to create a temporary, dynamic cognitive object that exists and has meaning as long as the inquiry progresses. Thus, bringing the 3D inquiry into existence requires a student to draw on all of the dimensions purposefully selecting and using knowledge, skills and psychological energy (motivation) to ensure the inquiry

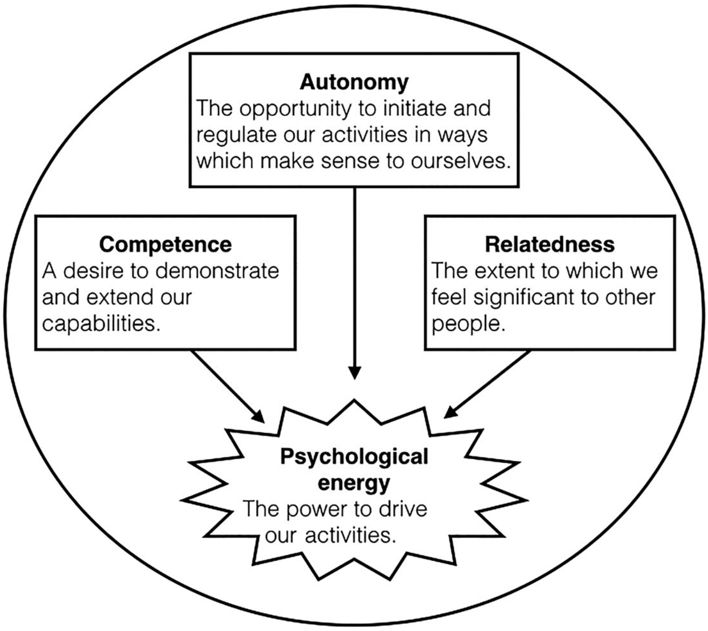

Figure 3. Dimension 3.

remains viable. Just as they select items of knowledge from Dimension 1 so they will select particular procedures from Dimension 2 and develop a dynamic, temporary complex using energy from Dimension 3. Figure 4 shows our proposed model of a 3D inquiry.

The above model recognises and requires active integration of the three dimensions which we feel is more likely to promote reflection on tasks, processes and emergent knowledge than simply following a procedure (even one that has been designed by the student). We believe that it would reduce the chance of students 'drifting' through practical work in a manner identified by Osborne (1998). Of great importance is that the 3D model places the student as an agent within the inquiry process and, therefore, should have greater opportunity for encouraging a more positive attitude to science and personal growth (Guay et al., 2008). Student ownership of their learning is strongly advocated among

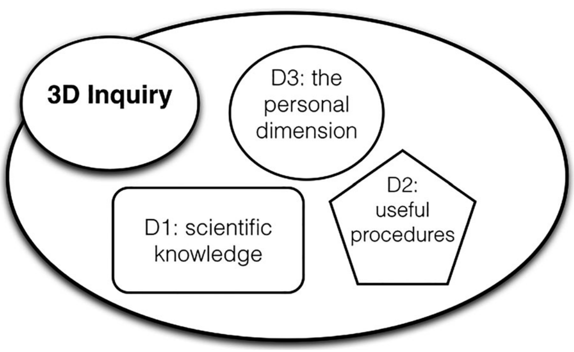

Figure 4. 3D inquiry.

those who favour inquiry approaches to school science and is seen as crucial to developing a sense of value of science and positive dispositions towards scientific study and careers (Carter, 2008; Sadeh & Zion, 2009). In emphasising motivation, contained in dimension three of our model, we would argue that opportunities for encouraging student ownership of their learning are greatly enhanced.

We are mindful that, in arguing for acceptance of the 3D model of inquiry, two key obstacles may prevent its wider dissemination in the U.K.—science education policy and the traditional school science culture. Unfortunately the emphasis on high stakes assessment has twisted many actual classroom inquiries into mechanisms for generating marks in a highly structured assessment model. Students are trained to carry out pre-designed 'investigations' to ensure they fit into the requirements of the mark scheme. For example, in one commonly used qualification in the U.K., students are required to state a clear hypothesis (1 mark), identify variables (1 mark), make a comment about accuracy (1 mark) and, ideally, produce quantitative data that is easy to graph or chart. An investigation that produced complex quantitative data or even qualitative data will often fail to gain these marks even if the quality of the student's work is exemplary. Additionally, traditional student and teacher roles may also be problematic. Nuthall (2005) noted that fixed patterns can arise from 'ritualised routines' within classroom learning and are typically born of the difficulty of managing large cohorts of learners with diverse needs and learning styles. This means that both teachers and students identify parameters within the classroom which become fixed and they are able to, for the most part, comfortably negotiate within these parameters or boundaries. Therefore, we accept that it may be difficult for both teachers and students to move from these more traditional patterns of teaching and learning to a more open inquiry approach.

We are also aware that teachers whom seek to support inquiry work in the science classroom may simply claim they are just practicing 'good teaching' and that the 3D model is merely another description of this. However, while we believe that there is an extensive, and encouraging, catalogue of work looking at SDT and education the full power of this motivational approach has not been used in the context of inquiry. Many of the scaffolding systems and approaches to inquiry work in science education explicitly state that they are designed to increase motivation. But the reduction of inquiry into a series of smaller, simpler steps seems to us to isolate the student and reduce autonomy-support and, in turn, intrinsic motivation. Since autonomy is a central feature of SDT, anything that reduces autonomy, and we would argue that some of the scaffolds do exactly that, will tend to reduce the opportunity for, and performance in, inquiry replacing it instead with the 2D model. In this way, our 3D model shows its utility by allowing us to suggest new ways to support inquiry by supporting the inquirer rather than merely making inquiry more attractive (providing real world contexts) or easier to navigate (scaffolded procedures) or have a more obvious payoff for teachers and students (guided inquiry towards a piece of Dimension 1 knowledge from the curriculum or assessed inquiry towards a mark for public examinations).

This search for new ways to support inquiry without suffocating autonomy, and so motivation, will not be easy. We suggest ways forward below but recognise that potential solutions must centre on the student as an agent who creates and drives inquiries rather than being the operator of a scheme generated, however, carefully and with whatever good ends in sight, externally. This will require us to explore ways to collaborate with students in their learning rather than controlling their curriculum.

Implications and the way forward

We accept that the 3D model does not seek to make the teaching of inquiry easier. Indeed, it arguably makes it more difficult as it identifies yet another area which needs coverage—the personal dimension. We are also aware that to merely claim the existence of a dimension (3D) and not be able to describe in detail its nature, components and ways of operating can be less than helpful. However, we believe that the benefits of pursuing this alternative inquiry model can outweigh its operational difficulties and that we have the beginnings of an understanding of Dimension 3 through SDT. We propose that using the 3D inquiry model is an effective way of avoiding algorithmic and passive learning and is essential for classroom science inquiry as it reflects more closely, than other inquiry models, authentic science. Also it promotes motivation in learners and has the potential for encouraging student autonomy and, therefore, greater potential for developing ownership of, positive attitudes towards and interest in science study and careers.

Our intention is to pursue the development of the model and explore teaching and learning strategies which support Dimension 3 specifically through a pilot study with a number of schools within the U.K. We will use an action research approach to develop the 3D model with classroom teachers and students. We anticipate that working collaboratively with classroom practitioners will identify contexts in which the 3D model of inquiry is most appropriate, enable us to develop strategies to support classroom implementation of it and to find solutions to both the known and, as yet, unknown problems that any new initiative generates.

There is no shortage of inquiry models available in the literature, educational textbooks or Continuing Professional Development courses. Does the world need yet another one? We justify presenting our 3D model as a stimulus to conversation and reflection. We also draw support from Simonton's discussion of the U.S. Patent Office's criteria for deciding if something is worth a patent (Simonton, 2012). These criteria require an invention to be new (N), useful (U) and non-obvious or surprising (S). Creativity (C) is then defined as the product of these three factors where each factor can vary from 0 to 1. $C = N \times U \times S$.

We argue that the 3D model in total is novel even if components are familiar and potentially very useful as it informs development of more engaging and effective curricula leading to more competent and confident citizens. We argue that there is a degree of surprise in that, while so much of the discussion around inquiry concerns detailed definitions of skills, cataloguing of required content, assessment components and scaffolding strategies, the central message of 3D is that it is the inquirer themselves, potentially drowning in the thoughtful advice about the inquiry process, that is central to what we really mean by inquiry.

Acknowledgements

We would like to thank John Leach for his comments and encouragement during early versions of this paper and Murat Gunel for his comments on an early draft. Their contributions are very much appreciated.

Disclosure statement

No potential conflict of interest was reported by the authors.

Notes on contributors

Stuart Bevins is a Senior Research Fellow and leads research in the Centre for Science Education, Sheffield Institute of Education. His research interests are social learning theories and the professional development of science teachers.

Gareth Price is a Senior Lecturer in the Centre for Science Education, Sheffield Institute of Education. His research interests centre around creativity, collaborative work,inquiry and the strategies that support students becoming active constructors of their own knowledge.

ORCID

Stuart Bevins http://orcid.org/0000-0001-7139-1529
Gareth Price http://orcid.org/0000-0003-2728-6769

References

Anderson, R. D. (2002). Reforming science teaching: What research says about inquiry. *Journal of Science Teacher Education*, *13*(1), 1–12. doi:10.1023/A:1015171124982

Assessment and Qualifications Alliance. (2013). *GCSE SCIENCES guidance on controlled assessment.*

Barrow, L. H. (2006). A brief history of inquiry: From Dewey to standards. *Journal of Science Teacher Education*, *17*(3), 265–278. doi:10.1007/s10972-006-9008-5

Carter, L. (2008). Globalisation and science education: The implication of science in the new economy. *Journal of Research in Science Teaching*, *45*(5), 617–633. doi:10.1002/tea.20189

Crawford, B. (2007). Learning to teach science as inquiry in the rough and tumble of practice. *Journal of Science Teacher Education*, *44*(4), 613–642.

Deci, E. L., & Ryan, R. M. (2000). The "what" and "why" of goal pursuits: Human needs and the self-determination of behavior. *Psychological Inquiry*, *11*(4), 227–268.

Deci, E. L., & Ryan, R. M. (2008). Self determination theory: A macrotheory of human motivation, development and health. *Canadian Psychology*, *49*(3), 182–185. doi:10.1037/a0012801

Deci, E. L., & Ryan, R. M. (2012). Motivation, personality, and development within embedded social contexts: An overview of self-determination theory. In R. M. Ryan (Ed.), *The Oxford handbook of human motivation* (pp. 85–107). Oxford: Oxford University Press.

Guay, F., Ratelle, C. F., & Chanal, J. (2008). Optimal learning in optimal contexts: The role of self-determination in education. *Canadian Psychology/Psychologie Canadienne*, *49*(3), 233. doi:10.1037/a0012758

Kaberman, Z., & Dori, Y. J. (2009). Metacognition in chemical education: Question posing in the case-based computerized learning environment. *Instructional Science*, *37*(5), 403–436. doi:10.1007/s11251-008-9054-9

Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational Psychologist*, *41*(2), 75–86.

Lavigne, G. L., Vallerand, R. J., & Miquelon, P. (2007). A motivational model of persistence in science education: A self-determination theory approach. *European Journal of Psychology of Education*, *22*(3), 351–369.

Minner, D. D., Levy, A. J., & Century, J. (2010). Inquiry-based science instruction—What is it and does it matter? Results from a research synthesis years 1984 to 2002. *Journal of Research in Science Teaching*, *47*(4), 474–496. doi:10.1002/tea.20347

Minstrell, J., & van Zee, E. H. (Eds.). (2000). *Inquiry in to inquiry learning and teaching in science*. Washington, DC: American Association for the Advancement of Science.

National Research Council. (2000). *Inquiry and the national science education standards*. Washington, DC: The National Academies Press.

Next Generation Science Standards. (2013). *The next generation science standards*. Retrieved from http://www.nextgenscience.org/next-generation-science-standards

Nuthall, G. (2005). The cultural myths and realities of classroom teaching and learning: A personal journey. *Teachers College Record*, *107*(5), 895–934. doi:10.1111/j.1467-9620.2005.00498.x

Osborne, J. (1998). Science education without a laboratory. In J. Wellington (Ed.), *Practical work in school science: Which way now* (pp. 156–173). London: Routledge.

Ratelle, C. F., Guay, F., Vallerand, R. J., Larose, S., & Senécal, C. (2007). Autonomous, controlled, and amotivated types of academic motivation: A person-oriented analysis. *Journal of Educational Psychology*, *99*(4), 734–746.

Robertson, B. (2007). Getting past 'inquiry versus content'. *Educational Leadership*, *64*(4), 67–70.

Sadeh, I., & Zion, M. (2009). The development of dynamic inquiry performances within an open inquiry setting: A comparison to guided inquiry setting. *Journal of Research in Science Teaching*, *46*(10), 1137–1160.

Schwab, J. J. (1962). The teaching of science as inquiry. In J. J. Schwab & P. F. Brandwein (Eds.), *The teaching of science* (pp. 3–103). Cambridge, MA: Harvard University Press.

Simonton, D. K. (2012). Taking the U.S. patent office criteria seriously: A quantitative three-criterion creativity definition and its implications. *Creativity Research Journal*, *24*(2–3), 97–106.

Windschitl, M., Thompson, J., & Braaten, M. (2008). Beyond the scientific method: Model-based inquiry as a new paradigm of preference for school science investigations. *Science Education*, *92*(5), 941–967. doi:10.1002/sce.20259

Zion, M., & Mendelovici, R. (2012). Moving from structured to open inquiry: Challenges and limits. *Science Education International*, *23*(4), 383–399.