Chapter 2
Teaching and Researching Visual Representations: Shared Vision or Divided Worlds?

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Abstract The relationship between research and practice is highly controversial and many reports describe a gap between the priorities of educational research and those of teachers. Our research explored the extent of this gap in the specific area of visual representation in science education. To identify research priorities, we searched educational databases in the years 2010–2012 and identified 401 journal papers that addressed visual representation in science education. These were coded in terms of their research questions, representations, research methods and disciplinary domains. In addition, six teachers were interviewed about their use of visual representations in the classroom, their priorities and whether and how they engaged with research. Findings revealed that both researchers and teachers considered visual representation to be extremely important across many aspects of science education. They also discovered many points of overlap in terms of shared interests and questions, in some of the representations mostly frequently referenced, the issue of multiple representations and in some of methodologies used to answer research questions. However, it also showed teachers to have different rationales for using representations, to utilize some representations far more frequently than they were present in research base and to treat as default that teachers mediated representations for students whereas research rarely addressed this issue. One of the solutions frequently proposed when considering the research and practice divide is to encourage and value two-way dialogue between the communities. We hope that in identifying where they converge and diverge, we can help make such conversations more fruitful.

Keywords Research • Practice • Teachers • Multi-representational practices • Scientists • Domains • Research-practice gap • SREM • Visual representations • Effectiveness • Learning outcomes • Multimedia • Design • Student learning

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2.1 Introduction

The research reported in this chapter set out explores what researchers and teachers understand about visual representations in science education. It seems evident that both communities place a great deal of importance on such representations. Walk into a typical science classroom and the walls will be covered with pictures, diagrams, maps and graphs; an animation may be projected onto a whiteboard; 3d models will be on desks; textbooks are full of photographs, drawings, charts; and students will be filling their notebooks with a range of multimodal constructions. Similarly, even a quick scan of research literature reveals hundreds of publications every year reporting a variety of studies and theories concerning teaching and learning with pictures, animations, diagrams, multimedia, augmented reality, simulations etc. Such an interest is not unsurprising given the well documented multi-representational practices of professional science and scientists (e.g. Gooding 2004; Kozma et al. 2000; Latour 1999; Lemke 2004) where it is shown that scientists rely on a variety of visual forms to generate new insights and discoveries, explain findings to colleagues and students, and increasingly to excite public interest. If we want students to learn to think like scientists, then it is clear that science education with, about and through visual representations will be crucial.

What is less immediately clear though, is whether the priorities and concerns ("What matters" in Yates's (2004) terms) in teaching and research communities about visual representations are shared equally or whether the different communities have distinctively different issues. We suggest that this question is important, however first we want to argue against a simplistic 'client and customer' interpretation of our question. We are not proposing that researchers should only be permitted (or funded) to research questions of immediate use to classroom teachers. Nor do we propose that teachers should be viewed as passive consumers of research created in Universities. Indeed, the apparently clear differential between teacher and researchers is, of course, questioned daily by the action research practices of teacher-researchers (Cochran-Smith and Lytle 1999; Goswami and Stillman 1987). For example researchers studying for PhDs are often recent or practicing classroom teachers, and teachers are involved in research in a variety of ways as readers, as participants in the studies of others and well as experimenters in their own classrooms (Bates 2002). However, even though the teaching and research communities may have shared membership, it remains the case that "what matters" may differ.

This issue of the relationship between research and practice is clearly fraught and often highly politicised. Consequently, some have attempted to stipulate what makes 'good' educational questions (Hargreaves 1996), others to explore what are appropriate methodologies to answer educational research questions e.g. (Oancea and Furlong 2007; Slavin 2002; Torgerson and Torgerson 2001) and others to identify how best to engage in strengthening the connections between research and practice (e.g. Levin 2013). The goal of this chapter is more humble. We agree with others who suggest that dialogue between members of the communities is a necessary (although far from sufficient) condition for closing a research-practice gap

(Bates 2002; McIntyre 2005). Consequently, we argue that it may be helpful to know what each community talks about. What questions and issues concern researchers? What questions and issues concern teachers? To what extent are these shared issues and to what extent are these distinct concerns of a particular community. In this chapter therefore we attempt to explore "what matters" to whom by exploring the focus within publications in peer-reviewed journals as an indication of research priorities and by interviewing science teachers about their practice with visual representations as well as their views of important research questions and any existing use of research literatures.

2.2 Method

2.2.1 Identifying and Coding the Publications

The research literature was interrogated to answer the question "What are the major foci of published research in the area of teaching and learning with visualisations?" rather than a specific question such as "Do animations help people learn?" or "Do visualization skills predict learning from graphs?" As a result, our search strategy was broad in that we were not aiming to identify relatively few papers to provide direct comparable answer to a specific question as in a systematic review or meta-analysis. It was also broad in that we did not wish limit ourselves to few types of visual representations or particular age range of students. However, it was narrow in that to answer the question of publication and research focus we deliberately chose only journal publication rather seeking grey literatures, conference publication or blogs, etc. We also chose only to look at the last 3 years (2010–2012) as we were interested in the current state of the field and not in how it may have changed over time.

Accordingly the titles of publication in both Educational Resources Information (ERIC) and Web of Science (WoS) were searched with the following word stems: visualisation, visualization, picture, map, diagram, drawing, representation, graph, chart, icon, multimedia. These search terms had been refined through expert consultation. Papers were excluded automatically if they did not refer to peer reviewed published journal papers or were not concerned with educational research. This resulted in an initial set of 898 abstracts. Further exclusions were applied through hand searching these abstracts to exclude papers that were not concerned with primary research (e.g., book reviews, editorials), which used the terms metaphorically (e.g. drawing together, seeing the big picture), where the primary focus was using representations for non-educational purposes (such as knowledge representation in artificial intelligence or pictures in speech therapy) and where representation did not refer to a type of external representation but instead referred solely to mental, political or social representation (such as the under-representation of women in science). Finally, papers were excluded if the domain of study was not Science, Technology, Engineering or Maths (STEM). However, papers that referred to issues that were applicable to STEM domains (such as those described as understanding complex concepts) were included. This initial stage of data reduction resulted in 401 abstracts that were subsequently coded.

We chose to code four aspects of these abstracts – namely the research question or questions under investigation; the representations that were scrutinized in the study; the methods that were employed in the research and disciplinary domain. Appendix summarizes these codes and provides definitions and examples.

The most important code to answer our question concerning the priorities or "what matters" to researchers was to identify the types of research question that the paper was addressing. Consequently, we coded whether the focus on this research was teachers, students, materials or theory and whether the study investigated issues such as learning outcomes, engagement practices, assessment etc. For some issues we have both teacher and student parallels (e.g. student and teacher practices with representations) whereas for others there are only student codes (e.g. representations influence on student learning outcomes or engagement). As many studies explore multiple issues, multiple codes are frequently applied; for example, a study that explored whether students who learned collaboratively rather than individually reported greater motivation and learnt more from an animation than a static picture would be coded as effectiveness, engagement and student practices.

Secondly, we coded the representations that were discussed in the paper. The taxonomy we applied was based upon published taxonomies of representations (Bertin 1983; Lohse et al. 1994) and adapted to include more recently developed representations (e.g. 3d visualizations). We chose to code in relatively broad categories (e.g. graph) rather than more specifically (e.g. line graph, pie chart, box plot). We only coded representations not typically considered as visual (e.g. text, equations but see (Landy and Goldstone 2007)) when they were studied with more traditionally visual forms. One possibly contentious decision has been our choice to distinguish, for some forms of representation, the distinction between construction of the form and interpretation of the form (i.e. drawing/picture; writing/text; talk/narration). These were distinguished because there were sufficient numbers of distinct examples of both uses in the dataset and because research questions were often very different when the study concerned construction rather than interpretation. For example, studies looking at narration were almost invariably concerned with design and effectiveness whereas those that focus on talk normally concerned teacher or student practices. In contrast, other representations such as graph often involved both interpretation and construction in the same study and others still in this dataset were solely used in one way (e.g. interpreting multimedia rather than constructing it). A further concern that should be raised about representation coding is that we typically used the term that the authors used themselves – so it is more than possible that some researchers might have used the term picture where others used diagram to refer to the same representation. Alternatively, people may use the same terms but refer to different representation (for example, it is clear that for some researchers animations mean dynamic depictive representation and count narration as a separate representation whereas other use animation for both). As with research question coding, many studies received multiple instances of this code (e.g. a study could be about diagrams, equations and text).

The third code applied described the research method employed. These were based upon standard categories of methods described in research textbooks (e.g. Cohen et al. 2011; Robson 2011). In general we chose the most specific term appropriate to the study, for example a field experiment that also reported a correlation between a process and an outcome variables as a small aspect of the study would be coded as field experiment whereas the code correlational would applied when the purpose of running the study was to relate two or more variables without an experimental intervention. It was rare for papers to combine multiple studies with distinct research methods (such as a field and a laboratory experiment or an interview followed by correlational study). Nevertheless, such papers were given two codes when they did so. However, in accordance with the definition of case study, which is normally seem as inherently multi-method (Yin 2008), this term was applied if a single study which explored the use of representations in a context was addressed through multiple methods (e.g. survey, interviews, and observations).

The fourth code describes the domains of the study. Standard disciplinary terms were applied (e.g. physics, chemistry, history) rather than specialized areas within these disciplines (e.g. mechanics, optics, thermodynamics). If in the abstract and keywords the domain was only described in general terms as science, engineering, technology then we used these terms. If it was not possible to identify the domain at all we used the term comprehension. Most papers were coded with a single domain but multiple domains would be coded if the research reflected this.

In all these cases, we must acknowledge the limitation of identifying papers from titles and coding them from abstracts and keywords. Papers that referred to visual representations but did not reflect this in the title would not have been selected. Thus, our sample will be an underrepresentation of the number of published papers. Secondly, it must be acknowledged that coding from abstracts and keywords required a degree of inference in multiple cases. Given the large number of papers analyzed in this exercise, it was only practical to code information that was typically available in abstracts. For example, it would have been interesting to code for the age of study participants but as such a large number of papers do not state this in abstract it was not possible to include such a code. Furthermore, abstracts clearly differed in how explicit they were about the details of their study. For example, it may be that many of the papers coded as comprehension were in a specific discipline also coded in our data set but this was not made explicit in the abstract. In summary, given our intent in coding these papers was to identify the focus of research concerned with visual representation and the abstract reveals the authors' view of the most important aspects of their work to highlight, we suggest that these compromises are acceptable. Working within these constraints has allowed us to look much more broadly than would otherwise have been possible. Finally, we do note that as part of our routine professional practice we had in fact read many of the papers that are in the dataset and this clearly would have influenced our interpretation of these abstracts. Thus, it is possible that others would not form the same interpretation from the abstracts as we did.

2.2.2 Interview

Six (2 male and 4 female) science teachers currently working in local (UK) secondary schools were interviewed for this study. They had been teaching for an average of 6.5 years (minimum 2 years and maximum 12 years) and included specific biology, chemistry and physics teachers as well as teachers who taught across the whole science curriculum in their school. One taught only 16–18 year olds whereas the rest taught students from 11 to 18 years.

The semi-structured interviews took around 45 min and consisted of six questions. The structure and content of the interview was inspired by that of Ratcliffe et al. (2004) who focused on teachers' view of research in science education in general but here we modified and adapted to focus specifically on visual representation in science education. Consequently, we asked teachers about how they currently used visual representations; what difficulties students faced in using them; what they would like to know to improve their practice with visual representations and whether they have previously consulted researched to help them; what contributions they thought research with visual representations could make across; and how research could be made more useful for teachers. A card sort presented them with 8 example studies extracted from the dataset above, each presented in a structured template of around 100 words that made clear the research questions, main findings, representations used, topic, methodology employed and context for the study. We chose the cases to ensure a distribution of research questions (as the main priority) but also tried to make sure that topics, research methods and visual representations were also drawn widely. Needless to say, with only eight cases it was not possible to fully counterbalance our selection. Teachers were asked to rank these cases in terms of how useful they or their colleagues would find it and to provide a justification for this ranking. By using a mix of questions that included asking them to recount of their daily practice, questions concerning their view about ideal research and actual examples of research for them to consider, we hoped to gain better insight than if we had simply questioned the teachers about their understanding of the research literature. Following the interviews, each was transcribed and then subjected to thematic analysis by both the authors of this chapter.

2.3 Findings

In this section, we organize the results of these analyses by considering six key findings that emerged from this processes. In each case, we base our discussion on the coded research literature and then consider the issue from the perspectives of the teachers interviewed using illustrative quotes where appropriate.

2.3.1 Visual Representations Are Important in Teaching and Learning Science

In the introduction, we suggested that both researchers in education and science teachers consider visual representations to be an important aspect of science education. This speculation was confirmed by our research. One of the most striking findings to emerge from this exercise is how actively the topic of visual representations in STEM education is researched. We identified 401 journal papers published over 3 years (2010–2012) that had a clear focus on visual representations in STEM education. Moreover, this number is clearly an underestimate of the research activity in this area, as it does not include publications in conferences, books, book chapters or other forms of report. In addition, our selection processes would have excluded papers that did not make a 'representation' in some form or another explicit in their titles. Clearly therefore many researchers consider this to be one of the paramount issues to understand in STEM education. Moreover, the teachers in our study shared this view. All six teachers when asked to recount example of the use of visual representations in their classroom were immediately able to list many examples in their day-to-day practice. Visual representations were commonplace in their classes (e.g. *"almost everything we do involves some form of visual representation"* or *"so many and varied"*). Consequently, it seems that for interviewed teachers that although being asked to explicitly reflect upon the visual representations was an unusual experience, teaching with visual representations was not.

2.3.2 A Diverse Range of Visual Representations Are Important Within STEM Education

The diversity of the research field is reflected in the broad range of visual representations that are studied. We coded 15 different types of visual representations in the research studies and finer grained taxonomy would have identified more than this. For example, we coded diagram rather than its many subtypes (e.g. Venn diagram, circuit diagram, vector diagram, etc.) and graph rather than specific types of graph (e.g. pie chart, histogram, line graph, etc.). All these types of representation may well have distinct benefits for science education as well as potentially facing teachers and learners with distinct problems. Clearly, at whatever level of granularity one chooses to define visual representation (and there is no agreed taxonomy to draw upon) the diversity of representations studied is manifest. Moreover, across the six teachers we interviewed when asked to describe "a few examples from their classroom" 13 of these 15 were mentioned (the exceptions being map and geometry software and it should be noted we did not speak to geography or maths teachers). Note, we did not ask the teachers to list all the representations they used or to recount their teaching practice over extended periods of time, yet no one mentioned fewer than seven distinct types of representation.

2.3.3 *Much Learning with Visual Representations Involves Multiple Representations*

Altogether 679 representations were identified in the 401 papers. We also coded 50 papers with the code "multimedia" and so by definition those papers also involve multiple representations. Again given the coding decisions described above this will be an underestimation of the frequency of multiple representations. Clearly, therefore a single type of visual representation is rarely used in isolation. However, only 42 papers explicitly referred to "multiple representations" or "multimodal" representations in their title or abstract suggesting that this is more implicit than explicit in many cases.

Teachers also referred to multiple representations either implicitly or explicitly. When describing how they teach a topic, teachers often referenced multiple representations. They talked about using alternative representations at different stages (for example by describing how they would ask students to draw something prior to make a model of it); for different purposes (e.g. "*in a table they cannot pick any patterns but they can from a graph*") or to accommodate different students' preferences ("*some will want to draw things out in pictures or mind, whereas others will choose not to; they prefer to see it written*"). Finally, they also mentioned the intrinsic value of multiple representations for students "*its trying to look at it from different points of view and different perspectives*" whilst being alert to the difficulties that this could bring for students (such as students failing to appreciate that a ball and spring, and a space filling representations were showing the same molecule). All of these issues are key area of concerns within the research literature.

2.3.4 *Some Visual Representations Are Seen as More Central in STEM Education Than Others*

As can be seen in Fig. 2.1, some representations receive more attention than others. The most frequently coded visual representations in the data set were graph (22 % of papers referred to this form of representation), diagram (also 22 %) and animation (17 %) with text also explicitly mentioned frequently (19 %). This distribution had some parallels with those of the interviewed teachers. The visual representations most frequently referenced by the teachers were diagrams and animations as all six mentioned these forms when asked to list visual representations they used. Five of the teachers also referenced pictures. However, only three teachers mentioned graphs suggesting that either teachers focus less on graphs in the classrooms that the research literature or that teachers do not immediately think of graphs when asked to reflect on visual representations.

However, the teachers (4 from 6) made much more reference to photos and videos than the coded research literature as only 2 % of papers were coded as referring to photographs and 3 % to video. Four teachers also mentioned modeling (4 %)

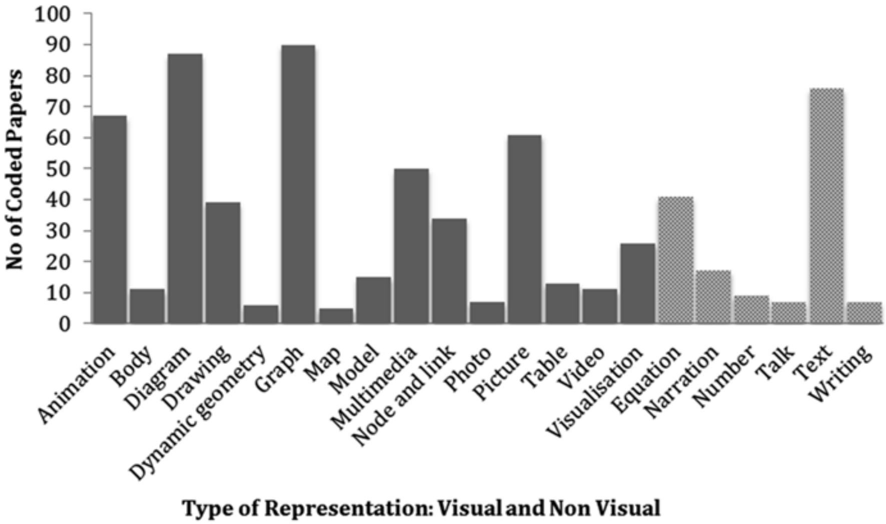

Fig. 2.1 Types of representations coded in the data set

and drawing (10 %) which relatively speaking seems to suggest that these representations loom larger in teachers' minds that in the research literature.

2.3.5 There Are a Range of Important Questions to Be Answered Concerned with Teaching and Learning with Representations

The research papers in this dataset addressed a diverse range of issues as can be seen in Fig. 2.2 However, it is clear that the issue of effectiveness (is representation X more effective than representation Y for improving student learning outcomes) predominate as 31 % of papers were primarily concerned with this issue. These papers are similar in style and focus to papers coded as design that concern whether representations should be designed in particular ways (e.g. segmentation of animations or learner control of video) to enhance their effectiveness (13 %). Evidently, the majority of research is concerned with how the design and choice of representations influences students' learning outcomes. However, relatively few papers addressed the teacher's role when considering visual representations in STEM education (8 %) suggesting the majority of papers did not see a role for the teachers in mediating the ways that representations influence student learning. Other questions which had little presence in the coded dataset were papers which addressed on how representation are used for assessment (5 %) and those which focussed specifically on theory building (2 %) (proposing new theoretical approaches or specifically setting out to test predictions of a theory rather than applying a theory to understand results).

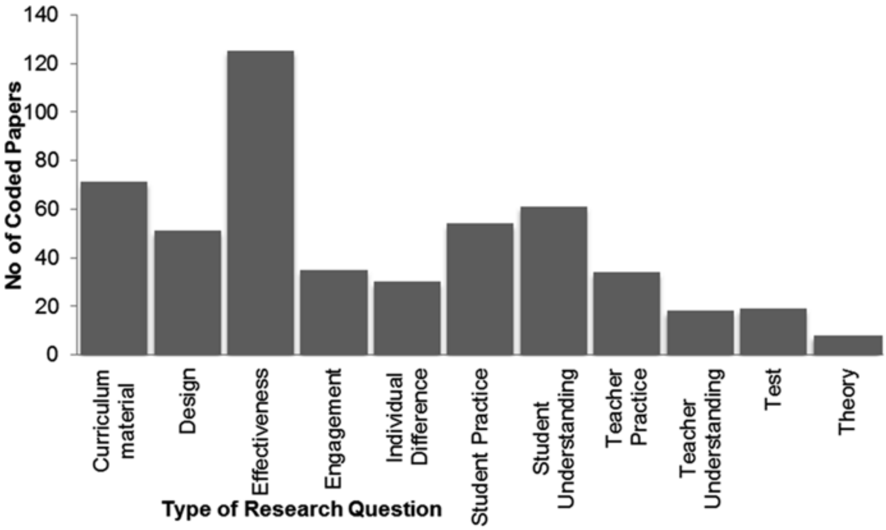

Fig. 2.2 Frequency of research questions coded in the dataset

In terms of what teachers saw as important questions to be concerned with – 'what matters' in Yates' (2006) terms, four of the interviewed teachers' priorities when directly questioned were also concerned with effectiveness of different forms of representations (e.g. *"whether using a certain types of visual representation would improve their (student) learning"*) or how representations should be designed to most enhance student learning (e.g. when talking about the complexity of information shown in a representation *"whether it would better to go more simply or more complex and dial it down a little bit"*). In the research literature (e.g. Vanderlinde and van Braak 2009), one often cited reason for the gap between educational research and practice is the view that teachers are focused on finding out "what works" and educational research is therefore of too little practical relevance. Bates (2002) has argued that teachers tend to want solutions to problems whereas the researcher seeks new knowledge. In this specific research area, however there seems to be general alignment between the new knowledge sought by researchers and the questions that the interviewed teachers consider important.

However, this does not mean that all teachers felt that the research literature would be the obvious place to turn for answers to these questions. Two interviewees questioned whether studies would be necessary to tell them this suggesting "*But that then is where your professional judgment as a teacher comes in, to figure out what is appropriate for the student sitting in front of you*" arguing that their experience as classroom teachers has provided them with many opportunities to assess when a representation was effective for their students. In addition, some raised doubts as to whether the sorts of answers found in the literature would be helpful for them. One questioned whether research concerning students from outside the UK would be helpful *"there is a cultural way that students are going to approach their* *learning and also differences how they might be examined as well"* and another raised the issue of generalization overall *"Because it will always be different for different students"*.

The other teacher who saw an immediate and strong rationale for research focused particularly on misconceptions and wanted to know more about the difficulties that representations can bring in addition to their benefits. In the dataset 15 % of the papers described student understanding or more commonly misunderstandings of a type of representation (e.g. the difficulties students experienced in understanding graphs of motion). Consequently, it also seems for this teacher that the research base can provide an answer to questions that interest her, but as we argue below this conclusions needs to be considered in reference to the type of representations as well as the research questions.

As part of the interview, we had provided teachers with the eight examples from the dataset to be ranked in terms of what they thought were would be useful. This task also revealed their interest in the design and effectiveness of representations. The paper ranked as most useful overall concerned the effectiveness of different forms of representation for teaching chemistry. All teachers ranked this in the top half of the cases, often making reference to it usefulness and relevance to their practice as well as their view it had a strong research design (see below). The (joint) second highest-ranking paper concerned design of multimedia and pace of instruction. Teachers typically also considered this a strong study with one considering it a model of what he wanted the research literature to look like. However, some teachers questioned its value for them as teachers arguing it was more suitable for animation developers and another that it did not have a specific lesson objective. Interestingly, the teachers who did rank it highly considered how they could adapt and apply its findings to situations over which they did have control (such as how they could talk or not over an animation in a PowerPoint presentation).

In terms of what the six teachers considered less useful, a paper describing textbook design and how it has changed over time was almost universally judged as uninteresting. Rationales for placing this as least useful were that it did not address whether some designs were more effective than others, did not tell them anything surprising ("*its just common sense*") but also for two teachers they no longer (or rarely) used commercially published textbooks preferring to develop their own materials. Two further papers ranked almost equally low but for very different reasons. The first focused on whether teachers understood a topic and could draw it; and here the rationale for ranking low concerned how this paper would directly help them teach their students as well as sympathy for the tested teachers. The second was an extended case study of a single student learning physics in a representationally rich sequence of lessons. The rationale provided for ranking this paper lower often rested on the interviewed teachers concerns about the methodology of the research (see below). This case was also most representative of the type of study we coded as curriculum material (17 %) in the dataset. These studies typically describe a proposed novel representation or lesson plan involving a representation without providing much in the way of evidence of their use in classrooms either in terms of student practices or outcomes. These sorts of studies are particularly frequent in disciplinary journals often aimed at teaching professionals as much as researchers. Our teachers' responses suggest they would place only limited value on such accounts.

Two of the cases to be ranked addressed how teachers' practices can support student learning; one a more focused case study based on interview and lesson observation of a small number of teachers and the second a large survey of 100s of students and their teachers. These papers were almost identically ranked at the centre of distribution. However, these studies provoked with widest variation in teachers' responses. Some argued they were beneficial as they revealed the roles that teachers could play, but others felt that they added nothing new to their knowledge as practioner as they already supported student learning in the ways that the paper describe.

There were two significant issues for teachers, mentioned by all six interviewees, which do have relatively low coverage in the research literature: (a) the ways that representations can shape engagement and motivation and (b) individual differences in student learning with representations.

All six teachers were clear about how important it was that representations interested students and for many, it was the most important reason for them to select a representation. Their understanding of student interest was nuanced – they spoke about the importance of not over using forms of representation which might seem superficially likely to engage (such as video) or simply entertain without strong educational purpose. In contrast, engagement is raised in the research literature, but it does not receive strong attention as it was addressed by only 9 % of the coded research paper.

The other factor that was common to all the interviewed teachers was their interest in individual differences and whether learners with different epistemological beliefs, with different prior knowledge or different abilities would respond to representations differently or require differentiated teaching. This was not a strong focus of research with only 6 % of papers coded examining how individual differences between students influenced their learning.

Finally, teachers also raised a host of other issues in their general discussion and which show in many instances strong overlap between the concerns of the two communities. For example, teachers discussed their worries about how pictures were often simply used to decorate textbooks rather being functional – linking with the research communities interest in the functional roles of pictures (Levin et al. 1987) and whether this leads to seductive details effects (Harp and Mayer 1998). They wondered when more realistic images were more helpful than abstract ones (e.g. Scheiter et al. 2009). They also mentioned the value in knowing how to help students become independent learners able to regulate their own learning with representations (e.g. Azevedo and Cromley 2004). They spoke about visual representations being useful when they made visible for students things that would otherwise be impossible to show in the school classroom because they are invisible without specialized equipment or at timescales not possible to experience, (e.g. Olympiou et al. 2012). Finally, they often spoke of issues only just becoming topical in the research literature such as the value for students in drawing their own understanding (Ainsworth et al. Tytler 2011), the value of a representationally rich curriculum (Hubber et al. 2010) embodiment (Hostetter and Alibali 2008) or in how to "flip" their classroom (Goodwin and Miller 2013) by using social media to present students with animations or videos to be discussed in class later.

2.3.6 Certain Research Questions Are More Often Associated with Particular Forms of Representations

It is clear from the coding that certain research questions were differentially associated with different forms of representation. For example, effectiveness and design questions were coded in 43 % of the papers making the issue by far the most frequently researched. These issues were frequently associated with animation (81 % of paper coded with animation addressed these questions) and multimedia (74 %) but much less, for example, with graphs (15 %). However, graphs were the most frequently studied representation when addressing student understanding (25 %) whereas animations (4 %) and multimedia (3 %) barely featured. It is not clear why there should be such disparity between representations. One possibility is that as research with a representation matures the field moves from what Goldman (2003) calls first generation research (typically "is this representation effective?") to second-generation questions, which address issues such as who benefits from learning with (specific forms of) representation? How do they learn and how does this change over time and how does the wider context influence learning with representations (Ainsworth 2008). As representations such as animation, 3d visualizations and multimedia have only recently become technically possible, research may be more likely to be first generation in style whilst representations such as graphs (which in many forms have been available for centuries) could be expected to be associated with a wider range of issues. One lesson that could be learnt if this is the correct explanation is that research that has looked for simple "first generation" answers to effectiveness questions has not typically found them to apply. Consequently, it may be more appropriate to raise a wider range of issues earlier in researching new forms of representation.

We did not ask teachers specifically about whether there were some issues that were more important for them with particular representations. However we did note that in common with the research literature they also focused on the difficulties students have with graphs. Other issues raised by the teachers that have also be discussed in the research literature include the difficulties of relating 2d and 3d (Huk et al. 2010) representations, representing invisible objects (Wu et al. 2001), students be able to distinguish conventional aspects of the representation from those which have more intended meaning (Hubber et al. 2010) and the problems of helping children understand representations which do not accord to their own mental representations of the phenomena.

We now turn briefly to the final codes we applied to the dataset, methodology and topic (Fig. 2.3).

The three most common methods in the dataset were case study (23 % of the papers used this method), field experiment (19 %) and lab experiment (16 %). As would be expected, certain research questions were differentially associated with these methods: 75 % of design and effectiveness questions were answered using experimental methods whereas 55 % of studies concerning teacher or students practices used case study methods. Perhaps the only surprise is the infrequency of papers in the coded dataset that included multiple methodologies. Although case studies

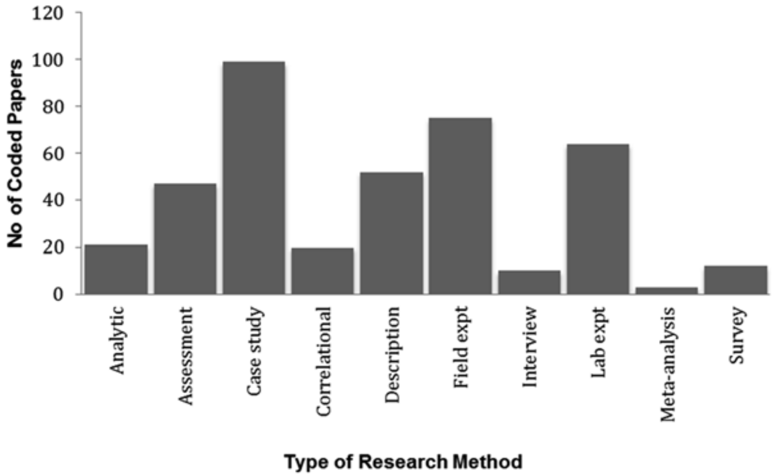

Fig. 2.3 Frequency of research methods coded in the data set

were frequent (which could include multiple methods of data collection with a single study), only two papers were coded as using multiple methods, which meant they included at least two separate studies that used different methods for different studies (e.g. a lab experiment followed by a field experiment or an interview with teachers followed by case study of classroom practice). This is perhaps a concern given the increasing recognition that multiple methods can offer distinct benefits for addressing educational questions (Johnson and Onwuegbuzie 2004).

In terms of teachers' views of methods, others have noted (Ratcliffe et al. 2004) that science teachers have a preference for experimental methods in judging research quality. We did not specifically focus on this issue in the interviews. However, three of teachers did explicitly mention methodological criteria when justifying their ranking of the presented and tended to see experimental methods (whether laboratory or field) with larger number of participants as preferable to smaller more detailed case studies. They were all clear that they wanted evidence and so the method we coded as description, which was typically associated with the development of curriculum materials and reported an innovation without evidence concerning its effectiveness, engagement or impact on student practices or understanding, was not considered of particular value (Fig. 2.4).

Finally, we report the domains that we identified in the dataset. It is clear that the issue of visual representation is of interest widely across the STEM disciplines. However, there are predictable domain specific differences in the types of representations associated with each domain. For example, physics and chemistry were both coded 42 times in the dataset. Graphs were more frequently studied in physics (40 % of paper coded in physics concerned graphs) than chemistry (10 %) and animations (23 %) more frequently in chemistry than physics (10 %) whereas both domains discuss diagrams and equations with roughly equal frequency.

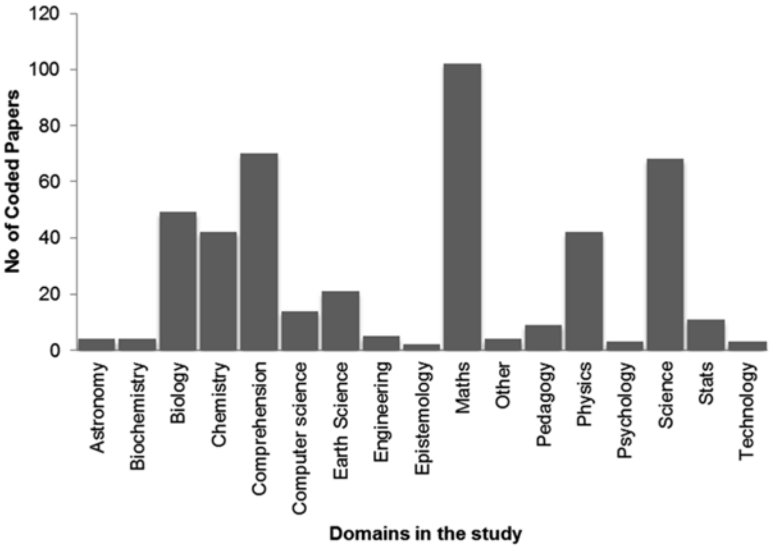

Fig. 2.4 Frequency of domains coded in the data set

We had deliberately sought teachers across the range of science disciplines to interview (although we must note the lack of maths teachers) in order to limit sampling bias. However, as with the research literature there was equal interest in visual representation from the teachers of all topics, with again predictable domain specific interest (for example, a biology teacher was concerned with fidelity of representation whereas the a chemistry teacher was concerned with how students related 2d pictures in textbooks to 3d models in their hands). In terms of what teachers felt was most interesting or useful for the research, we observed no strong disciplinary differences with our interviewed teachers able to put themselves into their colleagues shoes when necessary (for example, physics teachers as well as chemistry teachers ranked the paper on 3d stereochemistry representations as most useful). Nonetheless, our teachers commonly taught across a range of science topics as well as their own specialty so it may be the case that teachers of single subjects would have made different decisions.

2.4 Discussion

The relationship between research and practice has been highly controversial for many years and remains so. Many see a huge gap between research and practice (Hargreaves 1996) although others point out that research influences practice in a variety of ways which can be indirect and subtle (Bates 2002; Yates 2004). One reason that if often cited for this gap is a difference between the priorities of researchers and research, and the priorities of teaching and teachers. Consequently, we set out to explore in the very specific domain of visual representation in science education the extent of the differences and overlap between the two communities views of “what matters”. We did this by coding a significant proportion of the research literature and interviewing a sample of practicing science teachers.

Our research suggests that a general level there is strong alignment between these two communities. Both communities consider visual representation to be fundamentally intertwined with science education. In terms of the strong presence in the research literature and frequency of use in the science classroom, it is clear there is a strong basis for conversation. Visual representations were researched across a wide range of STEM disciplines and the teachers in our study came from biology, chemistry and physics backgrounds. More specifically, researchers in this area share with teachers a strong interest in the effectiveness of a particular design of visual representation for teaching a particular topic. To some extent this is surprising, as much has been written about the gap between teachers who wish to find out “what works” and researchers who do not attempt to address this question (e.g. Vanderlinde and van Braak 2009). In this area at least the priorities of the two communities align, although we personally share the belief of others (e.g. Goldman 2003) that in fact the answers to this question are more complex than either community may desire. Further commonalties can be seen in the emphasis on multiple representations, and the tendency of researchers in this area to use experimental methods. Finally, some of the most frequently studied representations (animations, diagrams) also seem to be the ones that the teachers most frequently used.

There were however some differences in the two communities’ priorities. Teachers in our study frequently talked about using representations that have received relatively little attention in the research literature – at least between 2010 and 2012– most notably photographs and video but also the use of models and student drawing. They also were concerned with issues that did not receive much attention such as individual differences and engagement. Another key difference between the communities is in the role of teachers in supporting student learning from representations. Only 8 % of the papers addressed these issues but for the teachers we spoke to, it was clear that their professional practice involved constant mediation between the students and the visual representations with which the students were working.

The major question that arises from having identified the gaps between research and practice, what if anything, should be done to fill them? One frequent suggestion is that researchers should pay more attention to the issues that face teachers and turn their attention more often to issues such as engagement or teacher mediation or representations such as photographs. Although, we would not want to argue that all research should be led by classroom teachers’ preferences, many researchers may welcome the opportunity to explore issues of more immediate practical benefit. Moreover, the value for research of seeking to formalize and theorize practice and craft knowledge, and in the consequence, the two-way nature of the dialogue between classroom and university is now recognized in general (McIntyre 2005). However, it is not clear how much this has influenced research with visual representations.

Another solution is that teachers should be made more aware of the research findings and adapt their practice accordingly. The problems with this solution are well documented (e.g. Williams and Coles 2007; Levin 2013; Ratcliffe et al. 2004). For example, teachers face a multitude issues in their day-to-day practice, clearly they cannot consult the literature about everything; even if that literature was relevant, easy to find, free to use and written accessibly (and clearly in many cases none of this will be true). Consequently, the teachers in our study (and those of others, Ratcliffe et al. 2004) valued dissemination through membership of professional associations, from peers and senior leaders in their schools, professional development, indirectly through resource provision ("good biology diagrams are so hard to find") and increasingly through social media such as Twitter (e.g. Donmez et al. 2012).

Moreover, as many of our teachers articulated, the importance of personal and professional judgment acquired through experience will often remain more important than researchers' findings when it comes to changing and adapting their practice. Their views of themselves as teacher-researchers accords here with many others (e.g. Goswami and Stillman 1987). Published research filters into these activities more tacitly and through changing conceptual structures rather than in specific findings. However, not all the teachers valued this approach and would not consider that their own actions to improve their teaching as research. Consequently, a diversity of approaches to filling the gap remains appropriate (McIntyre 2005).

In conclusion, we must mention the limitations of the research and how we intend to take it forward. Clearly the main limitation of the study is that only six teachers were interviewed and many of them were alumni of the University of Nottingham where teacher education explicitly addresses the value of practioner inquiry. Consequently, we need to expand our sample of teachers to include those from a more diverse background and with differing experiences of research. As we include papers in the area of mathematics within our coded data set, then seeking the views of mathematics teachers would be opportune. It would also be desirable to code a portion of the dataset from full papers to identify how much our decision to code from abstract and keywords has influenced our conclusions about their content as well as seek inter-rater reliability checks with those who have not read the papers. Furthermore, there were many issues in the dataset and interviews that we had not covered in this initial report of our research. Finally, by undertaking this exercise we have reawakened our desire to participate in the dialogues whose value we have articulated and to continue to contribute to the development of a shared vision for research and teaching with visual representations in science education.

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Appendix: Coding Rubric

Code	Definition
	Research question
Curriculum material	Discusses a lesson plan, an innovative piece of software, analysis of a textbook etc. Does not report student or teachers use of it, responses to it, etc
Design	Examines a design choice within a representational format; for example segmentation of an animation or sequenced or simultaneous text or pictures
Effectiveness	Is a representation effective at teaching something; e.g. do animations help student understand the cardio-vascular system
Engagement	Is a representation engaging? What are learners affective responses to the representations?
Individual difference	Individual differences (gender, expertise, spatial ability etc) in students learning with representations or with teachers teaching with representations
Student practices	This codes refers to what do students do with a representation and also if students have been directed to perform a particular practice; for example, how students coordinate representations or asking learners to self explain a picture.
Student understanding	Explores what students understand or misunderstand about a topic or representation
Teacher practices	What do teachers do with a representation?
Teacher understanding	Explores what teachers understand or misunderstand about a topic or representation
Test	Explores the way that a representation can be used as an assessment; for example; how useful are concepts maps for assessing student understanding of a topic
Theory	Research which specially tests, refines or develops a theory of learning or teaching with representations but not one which simply uses a theory to help explain other research.
	Representation
Animation	A dynamic representation which is pictorial
Body	Gesture or whole body enactment and haptic representations
Diagram	A 2d graphical representation which relies on some abstraction
Drawing	Self generated graphical representations
Dynamic geometry	Specific geometry software
Equation	Any kind of symbolic formula include maths and chemistry
Graph	Any type of graph, line graph, bar chart, pie chart etc
Map	Geographical map
Model	Physical 3d model not digital also using for manipulative
Multimedia	This term is used when the system is described as multimedia without further specification such as animation + narration.
Node and link	Any type of node and link representation (e.g. argumentation map, mind map, concept map)
Number	Numbers in digit form
Photo	Photorealistic picture
Picture	Depictive graphical representation (not self generated)
Narration	Spoken text provided by software not spoken by learners
Table	All tabular representation

(continued)

Code	Definition
Talk	Talk by learners
Text	Written text presented to students
Video	Dynamic visualisation that is photorealistic
Visualisation software	Digital visualisation not of the specific types already coded
Write	Written text constructed by student
	Method
Analytic	Expert analysis of an representational practice using a specified approach (e.g. semiotic analysis)
Assessment	A method based primarily of getting people to answer questions, perform a task (and can include interviewing people as they perform the task)
Case study	Explores activity in a context and can include a range of methods
Correlational	Relates two or more variables collected by survey; experiments which reports correlation between process and outcome variables are not coded as correlational
Description	A description of representation or pedagogy which is likely to be intuitive
Field expt.	Experiment in a field context and could include quasi-experiments
Interview	A method based primarily of getting verbal responses to questions without specific emphasis on performing tasks
Lab expt.	Experiment an artificial context but could include a school setting if it used a lab approach (e.g. not a normal class, students random assignment, learning something not in their course)
Meta-analysis	Statistical process to combine findings from different studies
Survey	Surveys students or teachers, not case study as no real description of context; not correlational as not related to other measures
	Domain
Astronomy	Study of celestial objects
Biochemistry	Chemical processes in biological organisms
Biology	Study of life and living organisms
Chemistry	Study of the composition, properties and behavior of matter
Comprehension	When domain is not specified (e.g. reading a complex text)
Computer science	Approaches to computation includes programming
Earth science	A broad category for understanding the earth
Engineering	A broad category for all topics related to understanding machines and structures when no specific information is provided
Epistemology	Refers to teachers or students beliefs about knowledge
Maths	A board term for all mathematical topics including algebra, geometry, calculus etc
Other	Topics such as history, English etc when included in a paper which was also about STEM disciplines
Pedagogy	When the topic represented was pedagogy rather than the focus of research question
Physics	Understanding such concepts as matter, force, space and time
Psychology	Refers to human mental function and behaviour
Science	When the domain is just described as science
Stats	Study of the organization, analysis, interpretation, and presentation of data
Technology	Used when the topic is technology without specific information

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