Conclusion

The research aim outlined at the beginning of the thesis was to answer: *How*, *where* and *why* can EM benefit learning and education? The broad scope of these three questions has been answered in three sections. In Chapter 1 I have shown 'why' there is a need for educational technology that is better aligned to learning, and in Chapter 2 I have offered EM principles and tools as a suitable approach and technology. Chapter 3 has explained 'why' EM offers a better solution over conventional software development and use. In Chapter 4 I have shown 'where' EM can be of benefit in computer science education. Chapter 5 has highlighted the potential 'where' EM can be of benefit in other subjects, in teaching, in lifelong learning and in collaborative learning. Finally, I have shown 'how' EM can be of benefit in Chapter 6 by examining evidence from projects and coursework undertaken by students in computer science at Warwick.

In Chapter 7 I have brought together the motivations (the 'why'), the principles and tools (the 'where') and the practical evidence (the 'how') in acknowledging the qualities of EM as an approach to constructivism. This leads to a vision for EM as computing that is constructivist in spirit, drawing on all aspects of EM activity, as depicted in Figure 0 on page 3. The contribution of the thesis is the complete approach to learning and education that is offered by EM. The significance of the contribution is that this complete approach overcomes the paradigmatic conflict between formalised educational technology and everyday sense-making and between the rich potential for enhanced learning afforded by new technology and the constraints of old-style educational practice, as discussed in Chapter 1.

To evaluate the contribution of the thesis, it is helpful to take a step back from the points raised in relation to EM and consider a broader agenda. There has been much discussion of different approaches to technology enhanced learning from a technology perspective. However, any technology enhanced learning is going to be heavily affected by the education system, whether it be schools, universities, or adult education. It seems to have been a common problem for technologists that they can get too excited about the innovation in technology and forgetful of the goal of innovation in learning.

In concluding the thesis I want to think about the situation 'on the ground' (e.g. in classrooms in schools) and consider the contribution that work such as this can potentially make. The average school teacher would no doubt regard the content of this thesis as concerned with problems largely disjoint from those experienced in a classroom. In the UK, the Teaching and Learning Research Programme (TLRP) is attempting to highlight the problems in our classrooms by putting practitioners and researchers together, in a hope that improvements can be made to teaching and learning practice. In September 2007 the TLRP sent out to all UK schools a guide to teachers entitled 'Principles into practice' highlighting ten principles for effective teaching and learning [TLRP07]. In an article about the ten principles, Andrew Pollard, director of the TLRP, proposes that schools forget targets and imagine aims that are 'much broader, more interesting and more intellectually challenging' [TLRP07]. The ten principles are introduced as a guide to effective teaching and learning that are not target-oriented, but are evidence-informed based on the collaboration of practitioners and researchers around the country [TLRP07]. The ten principles say teaching and learning should:

> "(1) equip learners for life, in its broadest sense; (2) engage with valued forms of knowledge; (3) recognise the importance of prior experience and learning; (4) require the teacher to 'scaffold' learning (support pupils as they move forwards); (5) make assessment congruent with learning; (6) promote the active engagement of the learner; (7) foster both individual and social processes and outcomes; (8) recognise the significance of informal learning; (9) depend on teacher learning; and (10) demand consistent policy frameworks, with support for teaching and learning as their main focus." [TLRP07]

There are some connections between the above ten principles and the eight characteristics of learning through EM. Both are suggesting a more *experimental*, *flexible* and *meaningful* approach to learning. There are also some indications to suggest that learning supported by model-building with EM may go some way to satisfying the ten principles of effective teaching and learning as set out by the TLRP.

The principles are much concerned with making teaching and learning more *meaningful* by *engaging with valued forms of knowledge* (2), *recognising the importance of prior experience and learning* (3) and *recognising the significance of informal learning* (8). Model-building supported by EM has been shown to be useful for exploring artefacts that are related to well-known topics and prior experience outside of school. Model-building is a personal experience and takes account of personal experience in the way that the ten principles encourage learning that takes account of personal and cultural experiences of different individuals and groups. The activities in the sudoku (§7.3), planimeter (§6.2.1) and Thai language (§5.1.2) models demonstrates that, as Pollard suggests [TLRP07], informal learning, such as learning out of school, is at least as significant as formal learning, and could be used within formal education. There is scope for using EM to support learning in an open-ended manner that could not be expected of conventional educational technology that is designed for a specific purpose. The value of EM is its openness to incorporate a wide variety of sources in any learning activity, whether they are traditional classroom sources such as books or more informal sources such as a student's experience from an activity outside the classroom. EM can support the TLRP call for more practical meaningful experiences in classrooms in ways that much traditional educational software cannot.

A requirement for teaching and learning to be *flexible* is expressed within Pollard's ten principles [TLRP07]. The first principle is concerned with *equipping learners for life in its broadest sense* (1) meaning that a broad view be taken of learning outcomes because learning is about developing people's intellectual, personal and social skills to equip them for their lives. To consider the curriculum as the most relevant subject-matter is a narrow view of teaching and learning. Educational technology that is closely based on aspects of the curriculum (e.g. a microworld for teaching Newton's laws of motion) engages with outcomes that are typically prescribed when building the software. EM is not constrained by a particular topic or outcome, as can be seen from the history of the 3D room model, which started life as simple DoNaLD example and later became a specialised component for teaching and learning about 3D to 2D transformations in computer graphics (see Figure 4.10 on page 103). A further aspect of flexibility relates to another of the ten principles which states the importance of *fostering both individual and social processes and outcomes* (7). The case studies in databases and computer graphics indicate the potential for EM to support both individual and teacher-student model-building, and the section on 'collaborative learning' (§5.4) has introduced the possibility of model-building in a classroom-like social environment. A topic to which this has given little consideration is assessment. One of the ten principles is that learning and teaching *needs assessment to be congruent with learning* (5) and an important point here is that assessment should help to advance learning. Assessment in model-building rests on Jonassen's maxim that if you can build a model of something then that is a good indication that you understand it [Jon06]. EM is well-aligned to this idea, as assessment could also rely on the history of interactions with a model, as well as the model itself. In this way, assessment using EM offers much more flexibility over conventional educational technology whose methods of assessment are constrained by a pre-specified functionality.

The third focus of the thesis on learning's *experimental* characteristics is also conveyed in Pollard's ten principles for effective teaching and learning [TLRP07]. According to the TLRP, a chief goal of teaching is to *promote the active engagement of the learner* (6) especially in terms of encouraging independent and autonomous learners. EM supports active engagement on the part of the learner by making model-building a personal activity that encourages model-builders to think about their own experience. The TLRP also acknowledge the essential part a teacher can play in experimentation by stating that effective teaching and learning *requires the teacher to scaffold learning* (4). EM offers a mode of interaction where the roles of student, teacher and developed are integrated. The section on presentations and lectures (§5.2) highlights the potential to support the teacher and at the same time provide scaffolding for the learner. Moreover, collaborative learning with EM offers another environment where the integration of student and teacher roles might help scaffold learning. The TLRP have another principle stating that effective teaching also *depends on teacher learning* (9), meaning that teachers should be actively engaging in developing their knowledge and experimenting with their skills, in order to benefit the learner. Beynon's experimentation with the 3D room model (§4.2) shows how EM can be equally beneficial to teachers and students.

The final principle to be covered says that effective teaching and learning *demands consistent policy frameworks with support for teaching and learning as their primary focus* (10). This principle is aimed at policy-makers in government, local education authorities and schools, asking for policies "to be designed to make sure everyone has access to learning environments in which they can thrive" [TLRP07]. Although technology might develop and styles of learning might change, it suggests that a main focus should be placed on maintaining consistent learning environments. As evident from the wide variety of models in this thesis, there is potential for EM to adapt to different technologies and styles of learning, whilst offering a consistent environment focussed primarily on learning.

The future of the work in this thesis depends on bringing the principles and tools closer to practitioners in education by taking it to teachers and schools, lecturers and universities, and more generally to lifelong learners. The successful application of EM as a support for learning requires more resources and better support from educational institutions and organisations such as the TLRP. In order to achieve such targets, there is potentially beneficial development of the tools to be considered. Some of the features I envisage for a state-of-the-art EM tool are: a web-based application for global access; a graphical interface for building models to bring the benefits of spreadsheet-style model-building; interface variations suitable for school children, university students, and teachers; built-in version control (for model-builders and researchers); a more accessible repository for sharing models amongst learners; collaborative capabilities for discussing, sharing and building models.

The benefits of these additional features in an EM tool would not only attract students and teachers but would also help researchers conducting empirical studies. Given the resources and interaction with students and teachers, the potential for EM to support learning and education as expounded in these pages might then be realised.