Introduction

Empirical Modelling (EM) is a body of research that has been developed at the University of Warwick by Beynon & Russ [EMW] over the last 20 years. The principles and tools for EM enable model construction and manipulation with a unique emphasis on the role of experience. Model-building is seen as intimately connected with sense-making, and models have a high degree of openness encouraging exploration and embellishment. EM has been used by over 100 students and many researchers for model-building activities, and some of the resulting models are featured in the EM Project Archive, which contains over 160 models at present [EMP]. These models explore a wide variety of topics in computer science, such as concurrent systems, computer graphics and artificial intelligence, and in other subject areas including engineering, business, humanities and education. This work has led to over 100 refereed publications and more than 20 graduate theses on topics relating to computing. The principles, tools, history and philosophy are discussed in depth in the theses of Rungrattanaubol [Run02], Ward [War04], and King [Kin07].

The topic of this thesis is EM as an approach to learning and as a support for education. Given the importance assigned by Beynon & Russ [BR07] to personal sense-making in EM, it is natural to assume that EM is already associated with learning in an informal sense. The thesis develops the idea of *EM as learning* together with the use of *EM for learning* in terms of a methodology for technology enhanced learning. The overall aim of the thesis is to answer the following research question: *How*, *where* and *why* can EM benefit learning? In order to answer the 'why' question, I shall be drawing on external influences that have provided the *motivation* for EM. To answer the 'where' question, I analyse and extend research into EM's *principles and tools* in practical applications. And to answer the 'how', I have gathered *evidence* of student EM activity. These three sections are depicted in Figure 0 and elaborated in this introduction.

The earliest work on the connection between EM and learning is by Beynon [Bey97], who highlights that EM has potential for applications in education because EM's principles

for model-building are bound up with the learning process. According to Beynon's experiential framework for learning[†], to be discussed further in Chapter 2 (see Figure 2.7 on page 51), "cognition and learning are fundamentally concerned with a process of construing phenomena in terms of agency and dependency" [Bey97]. Such a process is empirical, as well as provisional and tentative in that the function of the model is to prompt more precise understanding of the phenomena. Beynon introduces EM as a computer-based approach to constructing models of phenomena in terms of agency and dependency that is concerned with understanding phenomena prior to precise formalisation [Bey97]. This leads Beynon to recognise EM's potential as an approach to generating software for educational use [Bey97]. Beynon demonstrates that EM can offer support for concerns faced by IT managers, teachers and pupils in developing educational software [Bey97]. This work offers some initial clues for answering the 'why' question.

A detailed account of the potential application of Empirical Modelling (EM) to learning is given by Roe in his PhD thesis entitled *Computers for Learning: An Empirical Modelling Perspective* [Roe03]. Roe takes Papert's constructionism [PH91] (introduced in Chapter 2) as his foundation and argues that technology enhanced learning has only realised a fraction of its full potential because traditional programming practice is not well-suited to the needs of domain learning. He suggests that educational technology based on spreadsheet principles (discussed in Chapter 3) offers a more suitable paradigm to support domain learning [Roe03:p.20]. Elaborating on this notion, Roe introduces EM as a powerful tool for constructionist learning offering the characteristics of a spreadsheet environment (i.e. dependency maintenance) with the power of a procedural programming language [Roe03:p.55]. Work by other members of the EM Research Group has improved the general understanding of EM principles and tools. Rungrattanaubol [Run02] has improved the understanding of the principles of EM with her treatise on Modelling with Definitive Scripts (MWDS). Ward has developed and analysed the EM tools over a number of years in response to the needs of students [War04]. King has developed the philosophical basis for EM and prototyped new interfaces for EM [Kin07]. This work provides a basic starting point for answering the 'where' question.

The student-led culture of EM at Warwick has contributed to the application of EM as a support for education. Students have been involved with EM tools through interaction for a module in databases [BBRW03]. Many final year undergraduate projects have

[†]Originally referred to as an empiricist perspective on learning.

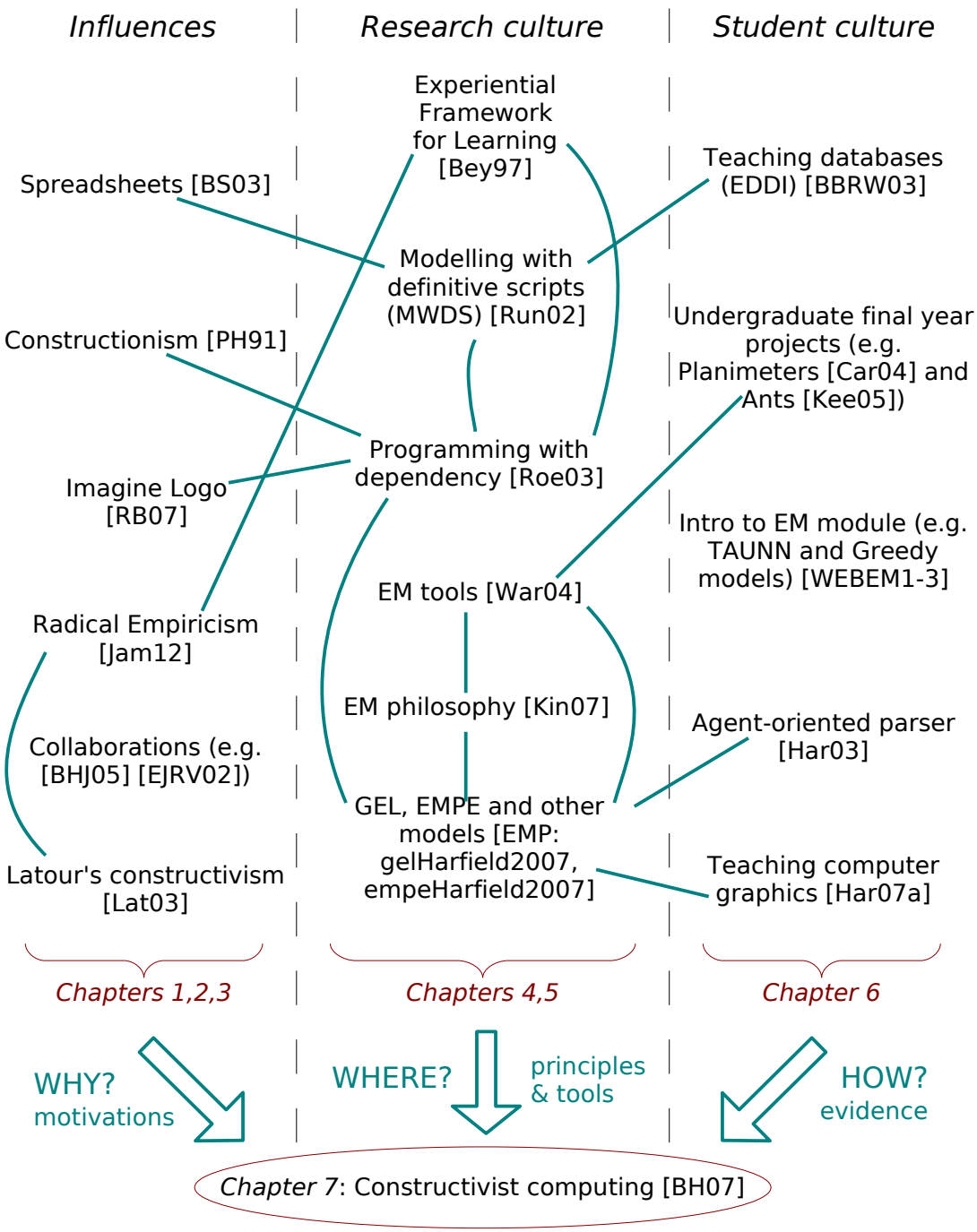

Figure 0: An outline of the thesis drawing together all aspects of EM and learning.

engaged with EM (e.g. the projects on planimeters and ant navigation as discussed in Chapter 6) and also developed new EM tools (e.g. the agent-oriented parser [Har03] as used in Chapter 4). An introductory module to EM, discussed in Chapter 6, has provided students with further model-building opportunities—some models themselves being relevant to education (e.g. the TAUNN and greedy algorithm models from WEB-EM-1 [WEBEM1]). The student culture, as well as collaborations external to Warwick (e.g. joint work with University of Joensuu, Finland [EJRV02] [BHJ05] [BHV07]), has inspired new research directions and provided evidence for the potential of EM in education. This work gives an empirical basis for answering the 'how' question.

In answering the 'how', 'where' and 'why' questions, the thesis brings together evidence from student EM activity, research work into principles and tools, and external influences that have motivated EM. The main contribution of the thesis is to redefine EM as a complete approach to learning and education drawing on all of the previous work as shown in Figure 0. Instead of solely viewing EM *as* learning, as introduced by Beynon, or EM as 'programming with dependency' as developed by Roe, the contribution of the thesis is to acknowledge broader characteristics of EM activity that make it appropriate to consider EM as a new paradigm for technology enhanced learning.

This thesis makes a significant contribution to our understanding of the benefits of EM as an approach to learning and education. Where technology is concerned, there has been much progress in EM's principles and tools, supported by evidence and examples, but the evaluation of the work from an education perspective has been limited by current resources. More support is needed from educationalists and practictioners to do justice to the current work in EM for learning. The aim of the thesis is to develop a broad view of EM in support of learning in order to provide a firm base for future work by educational researchers and practictioners in schools, universities and other organisations.

The thesis can be roughly classified into three sections aimed at providing answers to the three research questions.

Chapters 1, 2 & 3 are concerned with *why* EM might be of benefit to learning and education. In Chapter 1, some issues in educational technology are highlighted that have led to a paradigm conflict between learning using computers and learning in an informal everyday sense, and between the potential for enhanced learning afforded by technology and the constraints of old-style educational practice. An attitude to learning is described, characterised as *experimental*, *flexible* and *meaningful*, to which educational technology

might aspire in order to alleviate issues in the paradigm conflict. Chapter 2 introduces EM as a computer-based approach to model-building well-aligned to supporting learning with experimental, flexible and meaningful characteristics—providing an answer for 'why EM?'. Chapter 3 clearly distinguishes EM from programming, explaining 'why' EM offers a greater potential—over traditional software development and use—for supporting learning as characterised, and compares EM closely to model-building using spreadsheets.

Chapters 4 & 5 are concerned with *where* EM can benefit learning. In Chapter 4, applications of EM to teaching and learning in computer science are explored with specific reference to supporting experimental, flexible and meaningful characteristics of learning in topics from databases, computer graphics and artificial intelligence. Chapter 5 identifies examples of EM support for learning in other subject areas, with a specific example from language learning, for teaching through presentations, for lifelong learning and for collaborative learning. These two chapters contribute to demonstrating 'where' EM might support learning.

Chapter 6 contributes to the 'how' section by providing examples and evidence *how* EM can benefit learning and education. Chapter 6 examines empirical evidence from projects and coursework undertaken by students in computer science at Warwick.

The thesis concludes with Chapter 7 which aims to bring together all three sections—the motivations from Chapters 1, 2 & 3, the principles and tools from Chapters 4 & 5, and the evidence from Chapter 6—as depicted in Figure 0. Chapter 7 considers EM's support for learning from a constructivist viewpoint, resulting in all the elements of EM for learning being brought together in a vision for 'constructivist computing'.