Redeveloping an introductory course in microcontrollers through the lens of educational theory

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SESSION C1: Integration of theory and practice in the learning and teaching process

CONTEXT

This paper reports on the redevelopment of a poorly performing introductory theory course on microcontrollers through the application of educational theory. The course begins with seven weeks on digital electronics then four weeks on microcontrollers. For a number of years the microcontroller section of the course has had low achievement and negative feedback from students as well as from staff in subsequent project-based design courses.

PURPOSE

The aims for the redevelopment were to 1) improve student understanding of microcontroller based systems and 2) improve the student learning experience - a key faculty goal.

APPROACH

A period of discovery was undertaken in 2015 by observing both this theory course and the subsequent project-based design course by attending lectures and laboratories, reviewing course materials and results, and taking part in discussions with students, staff and teaching assistants. This revealed low level and poorly linked understandings. A full redevelopment of this part of the course was undertaken with reference to educational theory and best practices in teaching. The redevelopment brings together two knowledge realms; the first is the engineering knowledge of embedded systems and the second is pedagogy. The synergy of the two into one rich knowledge base is Pedagogical Content Knowledge (PCK), a requisite for making subject matter "comprehensible to others" (Shulman, 1986, p. 9).

RESULTS

Course evaluations show a marked increase in student satisfaction ratings with the course overall rising from unsatisfactory to above average in university wide rankings. Student behaviour and results in the examination reveal positive change and feedback from students in the subsequent design course reveal increased engagement and understanding.

CONCLUSIONS

Bringing together engineering knowledge with theory and best practices of education allowed the diverse requirements of student understanding, engineering theory and department goals to efficiently converge toward a best fit for a course. The results also indicate the benefits of grounding trials of new teaching and learning strategies (e.g. a new software tool) in theory and practice so as to make a fairer assessment of their potential in benefitting students.

KEYWORDS

Microcontrollers, learning outcomes, Pedagogical Content Knowledge, epistemic ascent, Technological Pedagogical Content Knowledge

Introduction

Fundamentals of Computer Engineering is a first semester, second year theory course for all Electrical and Electronic, Computer Systems, and Software Engineering students at the University of Auckland. The course begins with seven weeks on digital electronics and Field Programmable Gate Arrays (FPGAs) followed by four weeks on microcontrollers.

The microcontroller section has four weeks of lectures, four voluntary tutorials, an assignment and a single two-hour laboratory. In the final exam students are required to answer five of six questions; four relate to the digital/FPGA content and two relate to microcontrollers. In 2016 86% of the students chose the four digital questions before choosing one of the microcontroller questions to answer. The average grades for students were 82% for the digital questions and 59% for the microcontroller questions. As well as the low achievement by students in the exam the microcontroller section of the course has received very low evaluations in course surveys and negative comments about students' abilities and understandings by teaching staff in subsequent project-based design courses.

Learning issues identified during observations of students and discussions with them in this and other courses revealed a reliance on procedural knowledge or 'know-how' with inadequate conceptual understanding or 'know-that'(Winch, 2014), this led to students inability to apply their knowledge in new situations. Students also showed preference for just-in-time studying for assignments and tests, and avoidance of non-assessed learning tasks. Examining the course structure revealed a series of isolated topics, with little progression from underpinning concepts, and only one laboratory session for working with hardware; hands on experience is recognised as the only way learners can fully appreciate the nuances of embedded systems (Koopman et al., 2005).

The first author who redeveloped the course is undertaking PhD research in student understandings within the department. He is an engineer with 40 years' experience in various electronics industries, secondary school teaching and teacher education.

Pedagogy

In this section pedagogy underpinning the redevelopment is discussed, in the subsequent section there is an explanation of how pedagogy was applied within the course.

While there is much quality literature for tertiary educators e.g. Ambrose et al. (2010), Biggs and Tang (2011), there is a significant body of educational literature in school education that tertiary educators may be less familiar with which can also enrich their practice. This literature includes one well researched analysis of pedagogy by Professor John Hattie whose research team synthesized understandings from over 900 meta analyses (representing over 50,000 research studies) to identify what works best for student achievement (Hattie, 2012, 2014). They concluded the most powerful impacts on learning were from educators who are proficient in their subject knowledge and passionately engaged with teaching and learning. Passionately engaged means: being aware of students' pre-existing understandings, establishing learning outcomes and specific criteria against which both educators and students use to monitor performance, providing formative feedback, structuring learning sequences that bring together single ideas into complex constructs, creating opportunities for learners to actively construct understanding and providing safe places for risk taking and learning from failure (Hattie, 2014). Over and above best practices their research identified characteristics of expert educators. Expert educators are vigilant about evaluating their impact on student learning. From careful evaluation of student results experts develop the ability to adapt to what has the most impact on student understanding, this gives the expert the ability to more accurately anticipate learning issues.

Three questions that underpin student success

Student success begins with making the learning process visible to students and not something that only the educator knows about (Hattie, 2014). This visibility comes about when students are taught to ask and reflect on three questions about their learning: “Where am I going? How am I going? Where to next?” (Hattie & Timperley, 2007, p. 86).

The first question includes the overarching goal and the outcomes for their learning. In education the overarching goal is ‘literacy’, e.g. scientific literacy or mathematical literacy (numeracy). A common complaint in engineering is that student’s ‘math is not good enough’, even though they can carry out complex mathematical procedures. Numeracy however “involves students recognising and understanding the role of mathematics in the world and having the dispositions and capacities to use mathematical knowledge and skills purposefully” (ACARA, 2017). Writing a literacy focussed goal for a subject and keeping it in front of students helps them to know the answer to ‘where am I going?’

To become literate the ‘I know where I am going’ learner needs learning outcomes that give structure to their learning path. Bloom’s Taxonomy (Krathwohl, 2002) provides six levels of cognitive skill for student tasks: remembering (lowest), understanding, applying, analysing, synthesizing and evaluating (highest), which are useful starters for learning outcomes. Educators often express learning outcomes in concrete terms i.e. as skills or abilities. This reflects the common practice of educational writers which is to discourage the direct use of cognitive skill levels such as ‘understand’ when writing learning outcomes, instead recommending the use of action verbs (Ambrose et al., 2010; Biggs & Tang, 2011). Using action verbs however leads educators to directly include content and context in learning outcomes such as those given as examples by Ambrose and Biggs and Tang. This overt focus on content has led to tertiary education being accused of “content tyranny” (Prince, 2004, p. 229). The outcomes of academic learning however are not content, they are generalisations or abstract understanding - “a description of the world that does not consist in doing the activity alone” (Laurillard, 2002, p. 19). Learning outcomes then would be best to state the abstract concepts that we want a student to understand at course completion. This is reflected within school education, where the movement has been away from writing content and context in learning outcomes (Clarke, 2005, 2008; Hattie, 2012).

The second question students need to learn to ask is ‘how am I going?’ To directly help students with this question, learning outcomes are unpacked into specific skill or knowledge statements called ‘success criteria’ which both educators and students can measure progress against (Clarke, 2005, 2008; Hattie, 2012). Success criteria make use of action verbs, so they appear in a form which many educators would describe as the same as their current learning outcomes. Using this fuller three-step process of literacy goal to learning outcomes to success criteria however encourages educators to bring deep abstract understandings to the fore of learning rather than content related actions which focus students on an appearance of understanding, something we should never do (Winch, 2013). We do this however with content focussed learning in physics and engineering where complex tasks are regularly streamlined into algorithmic procedures (Case & Gunstone, 2002) in order for students to undertake drill and practice with them. While practice is critical for competence, without relating it back to a deep understanding goal, it has long been recognised as “an inadequate basis for later learning” (Brownell, 1935, p. 6). In this way a student’s response to the question about how well they are going can be framed in terms of understanding rather any ability to use a formula.

The third question learners need to ask is ‘where to next?’ This relates not to the next step in the learning sequence but to metacognition - which means the student is able to recognise deficiencies in their understanding and choose paths about how to solve them. Ownership of learning is something that we desire of students in their project work; however it is also something we can encourage in all courses. To do this we need to regularly reinforce goals, learning outcomes and success criteria with students (Clarke, 2005, 2008; Hattie, 2012), in this way students become purposefully engaged with the real goal of their education, the development of academic or abstract understanding.

With dependent learners there needs to be an explicit training and a gradual handing over of responsibility for learning. To achieve this educators can rephrase the three questions for these learners as: Which learning outcome does this task relate to? How do you relate what you are doing to the learning outcome? What questions do you still have about your own understanding and how will you resolve them?

Formative feedback

Feedback directly relates to the second question and it is through feedback on tasks that student learning occurs (Hattie, 2014). Feedback comes in many forms, from ineffectual praise to in/correct results to more powerful formative forms. While at times helpful the confirmation of in/correctness does not always make visible what is required for a student to develop. Formative feedback involves giving directions for students to pursue or making strategies explicit or more powerfully from comparative effects to other students or the provision of less explicit cues. Feedback needs to be explicitly linked to learning outcomes so that students begin to monitor and self-regulate their own learning. Feedback must also be critically timed in relation to student effort; this for instance can make computer-assisted feedback powerful (Hattie & Timperley, 2007). A highly useful tool for deciding what level of feedback to give students is the SOLO (Structure of the Observed Learning Outcome) Taxonomy (Biggs & Collis, 1982). SOLO helps educators recognise at which of five conceptual levels a student is working. Pre-structural means a student has no knowledge of the content; uni-structural, they have a single fragment; multi-structural, they have unconnected fragments of knowledge; relational means linked (conceptual) understandings - they can express the interactions between various parts; and extended-abstract, a student is able to abstract understandings into new contexts. Feedback is best focussed on the level the student is operating in relation to where they need to be.

Subject hierarchy / epistemic ascent

Another key aspect of the second question is the awareness that both educators and students need of a subject, that the knowledge within it has epistemic ascent – it is tiered and exists in a hierarchy (Winch, 2013). This requires that a learner builds successive understandings or fits new knowledge correctly into the existing hierarchy. This is an important recognition of and requirement for an educators own deep understandings of their subject, as without this proficiency any hierarchy becomes elusive making it impossible to adequately identify success criteria.

It is crucial to recognise that higher up the epistemic hierarchy terms become more semantically dense or terse as they encapsulate more and more meaning. ‘Timer’ and ‘ADC’ are examples of semantically dense terms. Often educators’ understandings are highly tacit and what we once had to learn to understand a term has long been condensed into it. Pedagogy involves fleshing out a subject’s hierarchy and density and then building a hierarchy for learner progress. One aspect of formal teacher education involves this unpacking of knowledge; however this is not an aspect of most tertiary lecturers’ backgrounds. Where one aspect of understanding condenses another, we need to be aware that not making the linked hierarchy visible can lead students to build isolated clusters of knowledge which compromise their conceptual development (Winch, 2013). This was noted in a digital electronics module of a course when a student remarked “it’s like you had to be a hobbyist already to understand it”.

Scaffolding

This is the term we use to plan the conceptual chunks (not procedural steps) in the epistemic hierarchy; Vygotsky developed the theory of the zone of proximal development (ZPD) which has been used to inform pedagogy around scaffolding (Chaiklin, 2003). When scaffolding learning there are concepts that students can learn with no external support, there are those which students need external support to learn and there are concepts they are not ready for. In the latter case further work is needed in unpacking the hierarchy and the development of more intermediate conceptual chunks. The work in threshold concepts (Meyer & Land, 2003) particularly in our domain of electronics (Scott & Harlow, 2012) highlights the significance of concepts which students are not ready for. An educators practice involves planning a manageable hierarchy of conceptual chunks and then evaluating the effectiveness of our efforts in terms of students' subsequent understanding.

Direct instruction

A constraint in tertiary education is the large cohort. Lecturing to large classes often attracts criticism as being transmission of information to a passive audience. Direct instruction is the method that incorporates lecturing, but it does not assume that learners are passive. Direct instruction is most powerful when centred on learning outcomes, has a 'hook' for student's attention, when concepts are fully explained, practice is guided, and there is a way to check understanding through independent practice in a new context (Hattie, 2012, 2014). In response to the negativity around lecturing student-directed models of learning (inquiry, social-constructivist, problem-based) are increasing in popularity. These however rely on the student discovering the knowledge needed to solve a problem, which will only work when learners already have satisfactory prior knowledge and understanding (Kirschner, Sweller, & Clark, 2006).

Student dispositions toward learning

One of the most significant and negative impacts on question three for students (where to next) is the role that summative assessment plays in credentialing students, lecturers and institutions alike. Students driven by heavy workloads and constant time pressure (Case & Gunstone, 2002) recognise the value of understanding in their learning but shortcut it, and educators focussed on manageable assessments develop isolated tasks that encourage shallow and fragmented learning. Our prior research focussed on developing conceptual tutorials (Collis, Rowe, & Donald, 2016) about which one student remarked *"I could have answered the test questions without having known this, but knowing it is just better"*. We need to change student perception about deep learning from being 'better' to that of being 'essential' so that they change their disposition toward learning and then their agency - their conscious choices around learning behaviours. One effective method is to be insistent about learning, to move beyond "this would make a good exam question" to focussing students' on learning outcomes and graduate attributes in spite of any looming test or exam. This is one aspect that Hattie (2014) says differentiates the expert educator.

Educational technology

Leveraging off modern technology can increase the power of teaching around question two, how am I going? Benefits however are only realised when the technology is integrated using sound pedagogy (Laurillard, 2002). The expertise and capacity to teach in a particular subject area using learning technologies has been called Technological Pedagogical Content Knowledge (TPCK). This entails an extension to educators pedagogy as it "requires an understanding of the representation of concepts using technologies" (Mishra & Koehler, 2006, p. 1029). One such application of educational technology is creating and using visualisations that can make, for example, the forces, state changes and trends of otherwise invisible phenomena visible (Gibbons, 2008), something so often lacking in students' awareness of electronic circuits.

Developing an understanding of pedagogy (both educational theory and practice) is critical for educators, just as critical as foundations of sound theory and practice are for engineers. Pedagogy gives us the power to critically evaluate student's understandings and our own teaching practice. We can then design ways in which our students can best gain deep understanding.

From theory to practice

Replanning the section on microcontrollers involved application of the theory discussed above: the three questions for students, formative feedback, epistemic ascent, scaffolding, direct instruction, student dispositions and educational technology. The educational technology used is an online assignment tool (Figure 1) employing visualisation of circuits and microcontrollers developed by the first author as part of his PhD research[1].

Qu 1: Where am I going? Development of a literacy goal

The previous course aim ('using commercially available hardware and developing a solution using a high level programming language') was replaced by a literacy goal. This goal was based on research from teaching and learning computer programming and relates to the student developing a mental model for a 'notional machine' (Sorva, 2013). The literacy goal became 'develop a viable mental model (useful abstraction) of a microcontroller based embedded system".

Qu 1: Where am I going? Development of abstract learning outcomes

Learning outcomes previously written for this course directly related to content such as GCC memory allocation and the AVR stack frame. These outcomes do not focus students on the goal of tertiary education which is 'academic' learning – the ability to work in the abstract. New abstract learning outcomes were written after reviewing academic literature in embedded systems relating to the understandings that new learners need to develop (Koopman et al., 2005; Winzker & Schwandt, 2011). Some of these are:
LO1: understand the interrelatedness of hardware and software in Embedded Systems (ES)
LO2: understand the ES as an automaton
LO3: understand the ES as reactive and responsive to its environment

Programming syntax and semantics for microcontroller programs is complex and students had previously completed the course with highly fragmented understandings (no epistemic ascent) of what a program for embedded systems was, as they had only ever had one laboratory experience. Their understandings were evident in their haphazard approach to software in the subsequent design course. Outcomes written for developing student software were:
LO4: understand the importance of transparent software practices for ES's
LO5: understand the benefits of using a state machine model for programming ES's

Qu 2: How am I going? Development of concrete success criteria

Understanding as an abstract learning outcome was unpacked into concrete success criteria; e.g. understand the ES as reactive and responsive to its environment was unpacked into:

- explain polling in relation to making an ES responsive
- explain contact bounce issues with physical switches and software de-bounce code
- describe how microcontroller timers are used to make an ES responsive
- explain how microcontroller external interrupts are used to make an ES reactive
- setup a microcontroller timer to make a microcontroller responsive to its environment

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[1] (The course resources and online assignment are available at www.XplainItToMe.com. A simple online registration process with the University of Auckland is required to gain a logon ID).

- describe the significant characteristics and features of an internal ADC
- discuss issues of an ES's responsiveness with regard to polling, blocking and interrupts.

Success criteria begin with action verbs, this follows one practice surrounding success criteria which relates to student metacognition and owning their learning, where a student puts the words "I can" in front of each statement. Some of the success criteria are extended with the learning outcome, to purposefully direct students back toward the required abstract understanding, e.g. 'explain polling in relation to making an ES responsive'.

Direct instruction and epistemic ascent

Lectures followed a process which began by focussing students on abstract learning outcomes and not the content to be covered. Demonstrations (conceptual models) used in lectures were not just 'hooks' to engage students but presented as rich contexts to describe the abstract principles in action. For example a quiz game controller was built and used to explain the previously introduced concept of the reactive nature of embedded systems and how polling made the ES reactive. It was also used in an assignment question to engage students with visualisation of polling as a software process (Figure 1). Lecture notes and the assignment were planned to build the hierarchy or epistemic ascent required for conceptually linked rather than isolated understanding. To learn about how an embedded system is made to be responsive to the environment involved building up a sequence of understandings. In the assignment a sequence of eight questions for hardware timers (Figure 2 and 4 are the first and last circuit exercises) and nine questions on ADC circuits, each designed as a sequence of proximal conceptual chunks which became increasingly more dense and abstract.

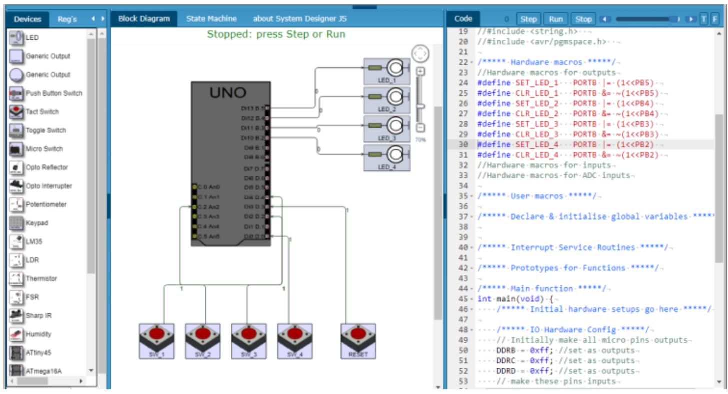

Figure 1: Quiz game - polling visualisation

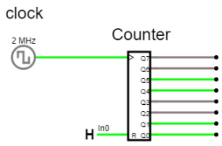

Figure 2: Simple counter circuit exercise

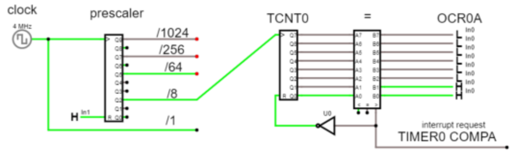

Figure 3: Full AVR timer circuit exercise

Scaffolding using educational technology

Novice students' learning to program in a proficient and transparent (easily readable and maintainable) manner is a crucial practice in embedded systems work. While commercial tools exist to help developers they require initial proficiencies that novices do not have. The assignment tool includes a microcontroller simulator (Figure 1) with a drag and drop interface for a variety of sensors that automatically creates well-structured program code allowing students to quickly grasp good practice. Once students are familiar with syntax and fundamental programming statements they often transition to completing given programs or predefined tasks, however they then struggle to transition to the next stage of designing programs. This course leads into a project-based design course where student's struggles with software were profoundly evident. This led to software design being introduced in the microcontroller theory course using the simulator's integrated state machine editor. State machines are devoid of syntax so are intuitive ways for students to begin software design. To scaffold students from the lower cognitive activities at the bottom of the Bloom's Taxonomy into the higher creative layers, where they can design their own software, the state drawing tool automatically creates program code as states and transitions are drawn.

This visible design process was used in the assignment to support students in identifying design issues relating to non-deterministic behaviour in state models.

Qu 2: How am I going? - Formative feedback using educational technology

The assignment tool provides immediate and specific feedback to students in the form of written comments and control of simulations. When an answer is correct feed forward comments become visible to reinforce abstract understandings along with next steps for learning. Some assignment questions were summative with marks only becoming visible after the assignment closed. To increase their learning power, feedback on these was provided after the assignment closed in order to give them a formative purpose as well.

One question that relied on providing a cue as feedback related to correct use of variable types in C, a crucial understanding for embedded systems engineers. Types were introduced in a lecture and case studies were presented where type errors had caused loss of life or major cost. Type usage was then practiced in the assignment via questions on type choice, overflow and underflow. The assignment question developed to investigate students' genuine understanding of type usage involved displaying numbers and had no reference to being about data types. Students were required to change the simulation from displaying numbers in the range 0 to 999 to 0 to 99999. The cue (subtle hint) was that the provided program could actually only display numbers in the range from 0 to 255 (not 999). An aware student would realise that the provided program would not work and then extrapolate as to what data type would be correct for their final program. In this question the simulator provided a safe environment for failure (as a well-planned laboratory experience could); following the adage that "good decisions come from experience and experience comes from bad decisions".

Qu 3: Where to next? – Student metacognition and learning dispositions

A number of strategies were employed to encourage students to develop positive dispositions towards their learning: overt use of learning outcomes in the lecture notes and assignment questions, the simulation based assignment with immediate feedback centred on learning outcomes, regularly encouraging students to begin the assignment and analytics integrated into the assignment front page showing students their own progress in comparison to that of the whole course.

Methodology and Results

A mixed methods approach was developed to collect and analyse data from the theory course and subsequent project-based design course in both 2015 and 2017. Prolonged engagement with staff and students in lectures, tutorials and laboratories allowed rich qualitative data to be collected from observations and discussions. Student voice was collected as much as possible as it is a recognised tool for assessing teaching practice (Cook-Sather, 2006) and follows the course goal of improving the student learning experience. Qualitative data from all courses were analysed thematically to identify both semantic and latent levels (Braun & Clarke, 2006). Quantitative data collected included test, assignment and examination results. Collecting data from several sources allowed a triangulation process to establish trustworthiness of the full dataset (Case & Light, 2011).

Examination results.

There was a marked change in student exam behaviour and grades from previous years. In 2016 86% of students had answered all four questions about the digital section of the course before choosing one of the two microcontroller questions; in 2017 student behaviour reversed with 86% choosing to answer both microcontroller questions and three of the digital questions. Scores also changed with averages for the two microcontroller questions moving from 59% in 2016 to 69% in 2017. Not all students succeeded in the course, 24 students did not do the assignment (their average exam grade was 51%) and several students began the assignment late and did not finish it.

Student voice.

199 of the 221 students attended the theory course laboratory in 2017; each student was canvased for their opinions about the course material. 174 students rated the material as understandable (25 added it was ‘fun’ or ‘loving it’), 25 students rated it as difficult. Most students made comments indicating they developed good understanding and had a positive learning experience. Comments covered all aspects of the course: learning outcomes*, “it’s not like other courses you know what is expected of you”;* epistemic ascent, “*completely new, kind of easy to understand”, “being taught C coding for micro-controllers without just making the assumption we know how to do this”*; visualisation, “*I can see C in action”*; the new assignment tool: “*yeah, I can do assignment questions on the bus”, “simulations make it well worth doing the questions online”, “I definitely think it was one of the best learning tools of any course”*; motivation, *“easier to do work when I am interested in it”*, course notes: “notes *make lectures interesting keeps me awake”;* semantic density, *“it let us practically understand the things we were learning which I think was very important because the content is something that I personally found difficult to get my head around due to all the technical terms”*; direct instruction, “*Being shown the thought process our lecturers use when they solve problems*”; demonstrations, “*gadgets and devices were super helpful to see what was actually going on at the physical level*”; experience of learning, “*rather than theory which we are used to it’s interesting”;* formative feedback, *“feedback in questions is excellent”;* metacognition*, “assignment was actually pretty good at helping me evaluate my learning”;* link to rich context, *“real world examples which seemed kind of silly but ended up being really useful’*; student agency*, “I wouldn’t have thought about it while playing a Gameboy but I got an insight and now can see the opportunities”.* Some negative feedback about the course related to laboratories,” *I would be keen to do some of the tasks with a real microcontroller instead of simulation*”. Students also made negative comments which indicated their summative assessment driven approach to learning, e.g. “*there should be a fully completed version of the write-on course notes for exam preparation”* and *“it’s difficult to tell how this will relate to questions in the exam”*. Some students also struggled with C and their feedback related to needing more fundamental programming skill development.

Course evaluations.

There was a marked increase in student satisfaction ratings with the course rising from a previously very unsatisfactorily ranking to above the university average.

Discussion

The course goals were to help students build a viable mental model (conceptual understanding) of an embedded system and improve their experience of learning; these were met for a clear majority of students. The results cannot be attributed to a single aspect of the change as there were significant changes to the course materials and staff. Many of the comments students left about the course however made direct or indirect reference to making learning visible and epistemic ascent. The visible learning process was centred on clearly articulating abstract principles in learning outcomes and regularly focussing the takeaway learning from concrete activities and success criteria back onto those abstract principles. The epistemic ascent was focussed around richly contextualised examples each developed through systematically linking epistemic (hierarchical) and manageable learning chunks suitable for novice learners and not treating content as isolated fragments.

A number of other comments made by students pointed toward other aspects of the course that also had powerful effects. These revolved around the clarity of the course materials and the clarity of presentation in lectures. These are already well-known indicators of student satisfaction in the department. The course also relied heavily on the use of a new online assignment tool to guide conceptual understanding via visualisations and promote student engagement through automated formative feedback. While visualisation is not a replacement for ‘real’ work with microcontrollers, several students directly commented on how it significantly enhanced their understandings of the dynamic processes involved.

The results overall indicate the benefit of a systematic coupling between educational theory and pedagogical practices when setting out to investigate and enhance student understanding. Future work in the course will involve a focus on metacognition; one of these aspects will be to structure the assignment grading in such a way as to reinforce regular activity rather than the common just-in-time approach currently used by many students.

Terminology

- Academic /Abstract knowledge – descriptions of descriptions of the world
- Agency – students conscious choices concerning their learning behaviours
- Assessment – gaining a valid realisation of student understandings
- Bloom’s Taxonomy – six level cognitive hierarchy for planning learning outcomes
- Conceptual understanding – links between aspects of knowledge
- Epistemic ascent – the development of a linked learning hierarchy
- Expert educator – constantly refines practice through critique of their impact on learning
- Feedback – helping students identify where they have not understood
- Learning outcome – what we want students to focus their learning towards
- Literacy – being able to use knowledge in the real world
- Metacognition – self-awareness and control over ones thought and learning processes
- PCK –pedagogy and subject knowledge brought together to build student comprehension
- Pedagogy – discipline relating to teaching practice underpinned by educational theory
- Scaffolding – sequencing learning chunks that stretch but do not exceed student understanding
- Success criteria – concrete or contextualised activities that backup learning outcomes
- SOLO taxonomy, five level tool for recognizing students relational conceptual capabilities
- TPCK – representation of concepts using educational technology

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