Transitioning from Teaching Canonical Engineering to Sustainable Development

Key words: Cognitive apprenticeship, Team teaching, Software engineering

Abstract

Purpose: Taking on the task of teaching sustainable development can be a daunting challenge for any engineering teacher. Not only does it require new knowledge in terms of sustainable development terminology and concepts, you also need to get involved with the question of what sustainable development actually means within your engineering community.
Approach: This paper describes a personal reflection on the transition from teaching a canonical engineering subject to involving the students in projects for sustainable development. This meant overcoming both the challenge of insufficient training as teacher and how sustainability has been interpreted within the software engineering community. The strategy follows the principles of cognitive apprenticeship where the teacher makes up for the lack of a dedicated master by involving a diverse set of external experts to facilitate the transition.
Findings: The transition thus starts with observing how others interpret and manage the challenge within a software engineering course, moving through taking responsibility for the project part of a course on sustainability and giving guest lectures to finally having sustainability as topic in a project course.
Practical implications: The contribution is a guideline which details both how to scale ambitions over time and seek collaborations for gaining access to the skills, knowledge and resources needed for carrying out the transition.
Research implications: To what extent the guidelines work outside of the author's context is an open question. Can similar collaborative environments be found elsewhere? And are they transferable to other engineering disciplines?
Value: If sustainable development is to gain traction within engineering education there is a need for contributions describing how the current educators can be part of such a development. This is an attempt in sharing experiences to lower the threshold for others to take their own first steps.

1. Introduction

Sustainable development is recognised as a challenge to teach within the software engineering curriculum (Penzenstadler, 2013; Klimova et al., 2016). The challenge has been described as a confusion around how software engineering and sustainable development in general interact (Penzenstadler, 2013; Venters et al., 2014) but also as overloading educators as sustainable development requires subject knowledge beyond both canonical engineering courses in general (Azapagic et al., 2005) and software engineering courses in particular (Penzenstadler and Fleischmann, 2011). This is not exclusive for engineering education, e.g. Jones et al. (2008) report that the enhanced set of necessary knowledge and skills for including sustainability was a barrier for university teachers across a variety of university disciplines, the teachers simply felt overloaded by the task.

At the same time, "education is critical for promoting sustainable development" (United Nations, 1992). In 2012, the United Nations again felt it necessary to emphasize the importance of SDE and declared an ambition "to promote education for sustainable development and to integrate sustainable development more actively into education" (United Nations, 2012). Yielding to the obstacles is clearly not an option, but it is still not obvious how teachers are to face the challenge. The aim of this contribution is subsequently to address *how a teacher can transition from teaching a canonical engineering subject into an educator in sustainable development without becoming overloaded by the task*?

The theoretical framing of the contribution is presented in section two, Learning Together. Section three, Mastering Sustainable Development, describes the details of the transition from teaching canonical engineering to sustainable development while section four continues by discussing the main contributions. The conclusions and openings for future research are finally presented in section five.

2. Learning Together

The term cognitive apprenticeship derives from Brown, Collins and Duguid (1989), who use the metaphor of the novice and the master to describe the different strategies one can apply to master a new discipline. However, while the masters of the past taught a practical craft where the skills could be visualised through the work of the hands, academics of today are often involved in cognitive trades and the challenge is therefor to visualise the workings of the brain so that the cognitive process can be transferred from the master to the novice. To his or her aid, cognitive apprenticeship formulates six different strategies:

Modeling – the master demonstrated the own reasoning behind a given situation, including deviations and dead ends so the novice can see the decisions and their effect and thus form his or her own cognitive model. *Coaching* – the master observes and provides feedback while the novice takes on a cognitive task. *Scaffolding* – the novice takes on a task where the master has excluded or restricted certain aspects so the task is less demanding or emphasises specific elements. *Articulation* – the novice verbalises the own thoughts and reasoning or thinks aloud in order to put words on the cognitive process and make the silent knowledge explicit. *Reflection* – the novice reflects on the own ability and skills in order to see what works and when, alternative paths or formulate new objectives. *Exploration* – the novice takes on a task in order to try the new skills and abilities without the guidance of the master.

The authors stress that there is no given progression between the strategies, nor are they necessarily orthogonal. Instead, they are to be combined as appropriate for the specific context of each apprenticeship.

Applied to an educational context, cognitive apprenticeship resonates with the ideas behind team teaching. Team teaching can be managed in many ways, where examples from literature include organizing cross-disciplinary courses where different teachers are responsible for the course content of their respective disciplines (Plank, 2012; Buckley, 1999); letting a team of faculty members be in charge of a set of courses to increase the alignment between course objectives

(Garmston 1987); or by having two teachers co-lecture a single course (e.g. Burden, Heldal, and Adawi 2012).

For instance, Henderson, Beach and Famiano (2009) describe a team teaching setup where one teacher is the master and the other is the novice. In their case the master prepares the novice for lecturing by modeling his own understanding of teaching while the novice explores through giving lectures and then articulates and reflects with support from the master. In this way the teacher training takes the form of a cognitive apprenticeship where the novice is gradually introduced into teaching before becoming course responsible, i.e. the teaching activities are used for "training-on-the-job" (Buckley, 1999; Liebl, Burden and Heldal, 2017).

3. Mastering Sustainable Development

This section describes a sequence of events in order to show how the transition from teaching canonical engineering to sustainable development can be achieved. In the case of the author, the overall transition has followed a progression from observing masters and reflecting on their actions and analysis, over trying out scoped and limited activities within the own teaching to finally arrive at a point of exploring the possibilities of running a course both on and for sustainable development.

3.1. Educational Context

The answer is derived from the experiences of giving a project course on Software Engineering since the autumn of 2014. The course is given twice a year and is mandatory for students taking one of the four bachelor programs in Computer Engineering, Software Engineering, Business Management with an IT specialization and the Science Engineering Program (Burden, Steghöfer and Hagvall Svensson, 2019). In broad terms the course aims to facilitate the learning of how to run a software project, managing resources and time constraints while ensuring that the developed product delivers value to a stakeholder outside of the development team. The endeavor is supported by two introductory weeks where the basics of software engineering are introduced through lectures, agile project methodologies are tried through exercises and the scope of the project is given. Then follow six weeks where the students apply their knowledge and skills in a project supported by weekly supervision. The course is then concluded with a final presentation after which the students write a report reflecting on their application of agile methodologies, how the product delivers value for different stakeholders and their development choices in terms of used resources and technologies.

In the context of the course, the definition of reflection follows Smith as "assessment of what is in relation to what might or should be and includes feedback designed to reduce the gap" (Smith, 2001). The definition facilitates a structure for the students when they reflect as it makes the otherwise vague concept of reflection more operational – describe the current situation, describe where you want to be, describe what to change to get there.

3.2. Baseline

The journey begins in the spring of 2015. This was the first time the course was given by the author as course responsible, having successfully defended a PhD thesis the previous autumn and

therefor qualified to take full responsibility. The PhD studies contained an obligatory two-week course on sustainable development, which is the only formal training the author has on the subject. The assignment as course responsible was complemented by a position at a research institute.

During this course instance the students could choose their own project scope and the focus during supervision was tool and technology related. There was no mentioning of sustainability nor partners with a stake in the project outcome.

3.3. Modelling and Reflecting

Through colleagues at the research institute involved in public transport there was an opportunity to involve the students taking the course during the autumn of 2015 in an open innovation contest promoting services to improve the public perception of public transport (Smith et al., 2016). Thus began the first shift in engaging the students in sustainable development as the students developed applications promoting low-carbon modes of transportation, raising public awareness through gamification, facilitating more effective or enjoyable bus trips as well as digital services enabling more customer segments to choose public transportation.

A key contribution was that it was the colleagues and the external stakeholders (representing the public transport authority, the operator, the bus manufacturer, the software and component suppliers, the local and regional government) that defined what sustainability meant for public transportation, how that translates into stakeholder value and subsequently evaluated the student contributions towards that end. The course assessment and learning objectives remained the same as previous years and the role as course responsible only changed as to merge the various activities of the contest with the standard course activities. E.g. three of the weekly supervisions were held at one of the stakeholders instead of a lecture room and the project scope was introduced at the launch of the contest instead of through a lecture. The student grades were not based on the externals stakeholders' assessment of the delivered value but on the reflection report in which the students articulated their decisions and actions towards creating value in terms of promoting sustainable public transportation.

The inclusion of external stakeholders as providers of course content was smooth, perhaps due to previous experiences of team teaching where the roles and responsibilities between the teachers are based on mutual trust and collaboration (Burden, Heldal and Adawi, 2012; Liebl, Burden and Heldal, 2017). Since the stakeholders motivated their decisions and reasoning through the different phases and activities of the collaboration, they enacted the modeling strategy and contributed novel insights possible to reflect on for defining what could be possible to do in terms of combining canonical software engineering and sustainable development in the future.

3.4. Articulating, Coaching and Scaffolding

The experience from 2015 was promising but it would take time before next opportunity emerged. A few opportunities arrived but either the ambitions of the external stakeholders did not fit the context of the course or the suggested topic was unsuitable for the students to work with based on their pre-knowledge.

So, it was not until two years later that plans were formulated to replicate the course organization, this time in another course. Through mutual contacts, a teacher responsible for a course on sustainable development and ethics for the bachelor program in Computer Engineering got to know about the setup in 2015. The course responsible articulated her intentions and approach to teaching sustainable development and the challenges she faced in making the topic relevant for the students. A plan was formulated over a couple of informal meetings which led to a formal request to the program manager for resources to change the course curriculum from a lecture-based course to a project-based course for the course instance to be held November 2018 to January 2019.

Here the experiences from 2015 came to use for organizing the project activities in the new course setup and involving a subset of the stakeholders from 2015 to define a suitable project scope. Again, the responsibilities were split so that the course responsible was in charge for the overall course organisation and lecture content regarding sustainability while the author took charge of the project organisation and scope.

Due to the division of roles and responsibilities it was possible to be involved in supervising students during their project work and supply feedback on how their applications related to the sustainability goals in a general sense but also in relation to the specific aims of the external stakeholders. Here the task was to support the students in relating what they were currently doing to what the stakeholders had expressed during the project introduction in terms of ambitions and needs relating to sustainable development. In terms of cognitive apprenticeship it gave plenty of opportunities to articulate the own take on the intersection of computer engineering and sustainable development, in a scaffolded educational context enabling focus on a restricted set of the course activities as well as being coached on how the project activities were progressing from both the course responsible and the external stakeholders.

3.5. Exploring

With the experiences from the participation in the sustainability course it was time to take the last step and explore the possibilities to include sustainability in the software engineering course without external help. The course instance was given for the Software Engineering and Business Management students, where the latter had taken a course on sustainable development and ethics before taking the project course. This meant that they were familiar with the Sustainable Development Goals (United Nations, 2015) and their rationale. The decision was further boosted by being asked to give a guest lecture based on the experiences from collaborating with the computer engineering students the previous term. The guest lecture was given to students from the bachelor program on Science Engineering and the invitation came from a colleague of the course responsible from the course on sustainable development and ethics.

The software engineering project course was subsequently conducted with sustainable mobility as the overarching theme. It was the same theme as during the autumn of 2018 but this time there were no external stakeholders acting as masters. Instead, the author relied on the knowledge gained by interacting with the masters from previous collaborations.

In terms of outcome the integration of sustainable development affected the assessment and the activities of the course organization while the learning objectives remained the same. That meant that there were no explicit learning objectives towards sustainable development but that the students had to relate how their value proposition and its implementation contributed towards a more sustainable mode of transportation. The teams were organized so that each team had at least two members from Business Management and therefore had a general understanding of sustainable development. To complement their knowledge a lecture was given on sustainable mobility, introducing concepts such as last-mile, cannibalism and mobility-as-a-service and relating the specifics of mobility to the general sustainability goals. During the supervision the teams reflected on their contribution towards sustainability in terms of value for whom and in relation to which context. The role as teacher was then to coach them to articulate their own reasoning in a scaffolded educational setting while modeling the own reasoning and motivation for the valuation of the team reflection.

4. Discussion

From analyzing the own progression from teaching an engineering subject to sustainable development, two main lessons can be learned – scale the complexity iteratively and incrementally while embracing the help of others to carry out the transition.

4.1. Scaling complexity

The first recommendation is to increase the personal commitment over time, to take new responsibilities and roles as the personal confidence and skills develop through experience. This resonates with Kolb's experiential learning cycle (Kolb, 1984). By reflecting on the own experience it is possible to identify the next opportunity and subsequently new ways to move forward. This requires considering the possibilities and mapping these to your ambitions and goals as well as restrictions in order to determine if the prospect is strong enough to make the effort. Sometimes it is better to wait than trying to take on too much at the same time. After all, there is a reason why literature (e.g. Azapagic et al., 2005 and Jones et al., 2008) mentions overloading in terms of taking on sustainable development education.

From a personal perspective it was instrumental that the first collaboration had digital services as a main component in what the students were asked to work with, had the scope targeted chemical compounds for new battery solutions or architectural solutions for bus stops, the task of integrating the collaboration with the own teaching had been overwhelming.

On the other hand, a course on software engineering should not become a course on sustainable development, but could be a course where students learn software engineering by applying their skills and knowledge for sustainable development. Such a transition does not require a change of learning objectives but instead a reorientation on what kind of software the students are to produce and subsequently, which stakeholders they are to interact with.

4.2. Strength in Numbers

The second recommendation is to partner with people and organisations that can share the responsibilities and provide the skills and knowledge you do not have yet as well as provide resources that you need for the transition. Then the partnerships can evolve over time as new needs and opportunities arise, or you team up with new actors if that resonates better with your own progression.

Teaming up with your peers follows Boyer's idea on integrating education with applied and fundamental research (Boyer, 1997) so that different actors can enrich and learn from each other. In 2015, the consortium representatives also gave access to a network of other professionals which the students could tap in to and benefit from in their own professional development. The setup also enabled professional development for the involved teacher, in terms of knowledge in sustainable development as well as getting to know new peers for future collaborations. Collaborating with external stakeholders also saved time since some course activities were now planned and carried out by others than the course responsible. And the students got to act for sustainable development and had the opportunity to reflect on their coming profession as engineers while reporting that they enjoyed being taken seriously by their future peers.

Collaborations pose new challenges for both teachers and students in how to reach out and get involved with external stakeholders but that is also an important task to acknowledge if universities are to train engineers capable of managing the challenges of the future. And by trying it yourself you will be better prepared to coach the students and model your own reasoning. The importance of collaboration with non-academic partners is also high-lighted by Agenda 21 in relation to promoting ``teaching approaches on sustainable development" (United Nations, 1992). There are several publications on how engineering education and outreach with non-academical partners can be combined for teaching professional skills, see for instance Coyle et al. (2005), Klimova et al (2016) or Steghöfer et al. (2018). And since outreach is a core assignment for academia there is often a central university body that can help in setting up partnerships as well.

Remember, you are not alone. Someone else is struggling with the same challenges, or they want to get in touch with future employees who can contribute to their products and services, or they are teaching a course on sustainable development and want your help in finding concrete and relevant tasks. Either way, together you can complement each other in terms of knowledge and resources in teaching sustainable development. And being more than one makes reflecting on the outcome and defning the next step more enjoyable and productive.

4.3. Limitations

Guba lists four criteria for assessing the trustworthiness of qualitative research (1981):

1. Credibility - How well do the results mirror reality?
2. Dependability - To which extent are the results dependent on the analytic process?
3. Transferability - To which extent can the results be applied to a wider population?
4. Confirmability - To which extent are the results dependent on the attitudes of the researchers?

Credibility was addressed by assessing the implementation and outcome of each iteration together with the involved stakeholders. In this way the analysis was not the result of the sole

author although framing them in terms of team teaching and cognitive apprenticeship is. This leads us to the question of dependability which was met by detailing the context of each cycle and the implemented changes so that the reader can assess the logic of the reasoning and judge to what extent the results are transferable to the own context. The contribution resonates with Denscombe (2000), who argues that iterative research should both consist of a sequence of changes to improve a given situation as well as generating guidelines for best practices. Finally, the theoretical framing was not chosen before the transition began. It has slowly grown and taken shape during the last iteration. Another theoretical framing would most probably lead to another analysis and another formulation of the guidelines. Still, the recommendations to scale over time and involve others in the transition are general and mirrors modern software development (see e.g. Schwaber, 1997). To what extent the guidelines can be applied by educators in other engineering fields or in a context less open for collaborations is still an open question.

5. Conclusion

Combining canonical engineering disciplines with education on and for sustainable development is a challenge as it requires new skills and knowledge as well as courage to act without being overloaded. But the challenge can be addressed by giving yourself plenty of opportunities for reflection on your own action and team up with those who have the resources you lack. By working iteratively and incrementally you get more opportunities for reflecting on what works and not for you. Add complexity and take on new challenges when you master those at hand and seek new collaborations with people and organisations that can take an active part in your teaching and that complement your own skills and knowledge.

To what extent these guidelines work in another context is an open question. The described transition would not have been possible without numerous collaborations with competent people, both within and outside of academia. Finding such collaborations is not always straightforward and a topic for future work.

Can you ever master sustainable development? Perhaps not. But there are ways to master how to integrate sustainable development within your own engineering discipline.

Acknowledgements

The transition, and subsequent personal development, had not been possible without the help of the many colleagues and collaborators involved over the years. In some cases their commitments have been funded by public agencies. The support of program managers and study administrators should also be highlighted as a necessity for the transition. The feedback from the involved students has helped in evaluating the progression towards integrating sustainability with a canonical engineering discipline and form the next steps. Thank you.

References

Azapagic, A., Perdan, S. and Shallcross, D. (2005), “How much do engineering students know about sustainable development? The findings of an international survey and possible

implications for the engineering curriculum", *European Journal of Engineering Education*, 30, (1), pp. 1-19.

Boyer, E.L. (1997), *Scholarship reconsidered: priorities of the professoriate,* Special report, Carnegie Foundation for the Advancement of Teaching.

Brown, J. S., Collins, A., & Duguid, P. (1989), "Situated cognition and the culture of learning", *Educational Researcher*, 18, pp. 32-42.

Buckley, F J. (1999), *Team teaching: what, why, and how?* Thousand Oaks, CA, Sage Publications.

Burden, H., Heldal, R. and Adawi, T. (2012), "Pair lecturing to model modelling and encourage active learning", in *Proceedings of ALE2012 11th Active Learning in Engineering Workshop,* Copenhagen, Denmark.

Burden, H., Steghöfer, J-P. and Hagvall Svensson, O. (2019), "Facilitating Entrepreneurial Experiences through a Software Engineering Project Course", in *Proceedings of ICSE 2019 Software Engineering Education and Training*, Montreal, Quebec.

Coyle, E. J., Jamieson, L. H. and Oakes, W. C. (2005), "EPICS: Engineering projects in community service", *International Journal of Engineering Education*, 21, (1), pp. 139-150.

Denscombe, M. (2000), *The Good Research Guide for Small Scale Social Research Projects*, Taylor & Francis.

Garmston, R. (1987), "How administrators support peer coaching", *Educational Leadership*, 5, 44, pp. 18-26.

Guba, E. G. (1981), "Criteria for assessing the trustworthiness of naturalistic inquiries", *Educational Technology Research and Development*, 29, (2), pp. 75–91.

Henderson, C., Beach, A. and Famiano, M. (2009), "Promoting instructional change via co-teaching", *American Journal of Physics*, 77, (3), pp. 274-283.

Jones, P., Trier, C. J. and Richards, J. P. (2008), "Embedding education for sustainable development in higher education: A case study examining common challenges and opportunities for undergraduate programmes", *International Journal of Educational Research*, 47, (6), pp. 341-350.

Klimova, A., Rondeau, E. Andersson, K. Porras, J., Rybin, A. and Zaslavsky, A. (2016), "An international Master's program in green ICT as a contribution to sustainable development", *Journal of Cleaner Production*, 135, pp. 223-239.

Kolb, D. A., (1984), *Experiential Learning: experience as the source of learning and development,* Englewood Cliffs, Prentice Hall.

Liebl, G., Burden, H. and Heldal, R. (2017), "For Free: Continuity and Change by Team Teaching", *Teaching in Higher Education*, 22, 1, pp. 62–77.

Penzenstadler, B. (2013), "Towards a Definition of Sustainability in and for Software Engineering", in *Proceedings of the 28th Annual ACM Symposium on Applied Computing*, Coimbra, Portugal, pp. 1183–1185.

Penzenstadler, B. and Fleischmann, A. (2011), "Teach sustainability in software engineering?", in *Proceedings of 24th IEEE Conference on Software Engineering Education and Training (CSEE&T)*, Waikiki, Honolulu, pp. 454-458.

Plank, K. M. (2001), *Team Teaching: Across the Disciplines, Across the Academy.* Sterling, VA, Stylus Publishing.

Schwaber, K. (1997), "Scrum development process", *Business Object Design and Implementation*, Springer, pp. 117–134.

Smith, G., Burden, H. and Hjalmarsson, A. (2016), "Catalyzing Knowledge Transfer in Innovation Ecosystems through Contests", in *Proceedings of 22nd Americas Conference on Information Systems, AMCIS 2016*, San Diego, CA, August 11-14.

Smith, R. (2001), "Formative Evaluation and the Scholarship of Teaching and Learning", *New Directions for Teaching and Learning*, 88, pp. 51-62.

Steghöfer, J-P., Burden, H., Hebig, R., Calikli, G., Feldt, R., H.ammouda, I., Horkoff, J., Knauss, E. and Liebel, G. (2018), "Involving External Stakeholders in Project Courses", *ACM Transactions on Computing Education*, 18, (2), pp. 8:1-8:32.

United Nations. (1992), *Agenda 21 – United Nations Conference on Environment and Development*, Rio de Janeiro, Brazil, available from https://sustainabledevelopment.un.org/content/documents/Agenda21.pdf.

United Nations. (2012), *The Future We Want – Outcome Document of the United Nations Conference on Sustainable Development*, Rio de Janeiro, Brazil, available from: https://sustainabledevelopment.un.org/futurewewant.html.

United Nations. (2015), *General Assembly Resolution A/RES/70/1. Transforming Our World, the 2030 Agenda for Sustainable Development,* available from: http://www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1&Lang=E.

Venters, C. C., Jay, C., Lau, L., Griffiths, M. K., Holmes, V., Ward, R. R., Austin, J., Dibsdale, C. and Xu, J. (2014), "Software Sustainability: The Modern Tower of Babel", in *Proceedings of the Third International Workshop on Requirements Engineering for Sustainable Systems, RE4SuSy 2014*, Karlskrona, Sweden, August 26, 1216, pp. 7-12.