Embedding Technical, Personal and Professional Competencies in Computing Degree Programme

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ABSTRACT

Many factors influence computing graduate employment prospects, including human capital, social capital, individual attributes, individual career-building behaviours, perceived employability, and labour market factors. Whilst most computing graduates go on to be beneficially employed, a small minority remain either underemployed or unemployed. Computing curricular recommendations increasingly advocate a competency-based approach to bolster graduates' perceived employability. Hence, the discipline is evolving to incorporate competency-based approaches. However, "competency-based" can mean any of three different "kinds" of Competency: technical, personal and professional. "Technical Competency" is the ability to apply acquired content knowledge and skills to develop solutions to unseen problems. "Personal Competency" is the personal behaviours and interpersonal skills required for success in the modern workplace. "Professional Competency" is Technical and Personal Competency combined and applied in a real-world context.

This position paper provides illustrative examples of how to embed all three kinds of Competency. Based on examples from the undergraduate computing programmes at UK universities, it provides examples of embedding each kind of Competency: Technical Competency (teaching programming through craft computing and approaches for developing cybersecurity Competency), Personal Competency (teaching teamwork through project-based learning and creativity via problem-based learning), and Professional Competency (developing work-ready Competency using industrial placements, and co-delivery within industry via Degree Apprenticeships), providing a valuable foundation and framing for portability and extension in other institutions and jurisdictions. Furthermore, these distinctive types of Competency form a helpful taxonomy when considering how to embed Competency in computing courses and are candidates for inclusion within future computing curricula guidelines.

CCS CONCEPTS

• **Social and professional topics → Computing education**;

KEYWORDS

Computing competencies, Personal competencies, Professional competencies, Curriculum design

ITiCSE 2024, July 8–10, 2024, Milan, Italy

ACM ISBN 978-1-4503-XXXX-X/18/06
https://doi.org/XXXXXXX.XXXXXXX

ACM Reference Format:
Anonymous Author(s). 2024. Embedding Technical, Personal and Professional Competencies in Computing Degree Programme. In *Proceedings of the 2024 Conference on Innovation and Technology in Computer Science Education V. 1 (ITiCSE 2024), July 8–110, 2024, Milan, Italy.* ACM, New York, NY, USA, 7 pages. https://doi.org/XXXXXXX.XXXXXXX

1 INTRODUCTION

1.1 Stimuli for this work. Multiple factors promote computing graduate employment prospects. The professional skills graduates can demonstrate are important [12, 23, 67]. Recent studies have emphasized that the employability of graduates is influenced by a combination of factors such as human capital, which includes skills, professional skills, and work experience; social capital, which comprises networks, social class, and university ranking; individual attributes and behaviors, such as career self-management and career-building skills; perceived employability; and labor market factors [12]. All these factors play a crucial role in shaping the employability of graduates. [12]. Regarding human capital, there is a reported skills-gap between employer expectations and that presented by graduates [1, 7, 19, 27, 32, 52]. Further challenges exist in the human skills (also known as soft skills) subset of human capital, with students commonly not seeing value in such skills and over-rating their abilities [58]. The importance professional competencies play in obtaining beneficial employment has also been discussed [14, 15, 19, 47, 48, 59]. Indeed, adopting a competency-based approach has become a recommendation in many curricula guidelines in the UK and various other jurisdictions [11, 13, 46] and an approach to help address the reported skills-gap. Moving from a knowledge-focused approach requires an urgent re-think of many educational practices.

The rise of generative AI has promoted further adjustment and disruption to computing education [24, 44]. Competency-based approaches provide one mechanism to help adopt AI, as the focus can be on addressing authentic and real-world challenges with the support of various approaches, tools and technologies, including AI.

Studies [5, 36, 50] suggest the two key motivations to study computing are either its intrinsic value (i.e. a love of the discipline) or its utility value (a link to rewarding careers related to Tech). Developing work-ready competencies is critical for those students whose primary motivation is utility.

1.2. Background. A competency-based approach where "A competency specification enumerates knowledge, skills, and dispositions that are observable in the accomplishment of a task, a task that prescribes purpose within a context" [11, p. 47] is advocated by the CC2020 guidelines. Knowledge is seen as "know-what", skills are seen as "know-how", and dispositions are individual behaviour patterns ("human-skills"). Knowledge, skills and dispositions are expected to be successfully applied at least only *once* in *live or simulated real-world* computing tasks. Alternatively, in the Skills for the Information Age (SFIA) [65] model, Competency combines professional skills and generic attributes (i.e. autonomy, influence, complexity, business skills and knowledge). In the SFIA model, competence is evidenced by *repeatedly* applying professional skill and attributes in a *real-world context*. The CC2020 definition arguably represents capability (i.e. has been achieved once), and the SFIA definition represents Competency (i.e. has been achieved repeatedly in a real context) [47]. Growing workplace capabilities or competencies would benefit both graduates and their employers. In many other professions (e.g. law, medicine, nursing, and teaching), some form of supervised practice is anticipated before full professional independence is achieved so that the CC2020 capacity-oriented definition may be sufficient [47]. However, this may be only part of the story as there continues to be a reported skills gap [7] and the career benefits [56] for completing an industry placement (a mechanism for evidencing competence by the SFIA definition) may make a case for the adoption of the SFIA definition. However, it is notable that in many professions, regulating bodies are responsible for registers of practice rather than education providers; e.g., the General Medical Council maintains the list of medical professionals licensed to practice in the UK.

"Competency" is somewhat overloaded in educational and real-world contexts. It is helpful to distinguish between three common kinds of Competency. *Technical Competency* - which probably corresponds most closely to the common meaning of "Competency" in everyday language - is the ability to apply acquired content knowledge and skills to develop solutions to unseen problems. Such abilities are typically developed by established approaches such as active learning [6]. More recently, there has been a considerable focus in education on "21st Century Skills" [68], seeking to capture the personal behaviours and interpersonal skills, or *Personal Competencies*, needed for success in the modern world. However, [33] defines *(Professional) Pompetency* as the combination of these two: *"Competence involves the ability to apply knowledge and skills [...] to achieve a successful result on an ongoing basis [...] apply[ing] sound judgement, mak[ing] correct decisions, apply[ing] the appropriate skills and knowledge and mak[ing] use of relevant professional attributes."* Not only does this definition require both *Technical Competence* and *Personal Competencies*, but it also requires that both are demonstrated *on an ongoing basis*. Professional Competency corresponds more to the SFIA concept of Competency than that advocated in CC2020.

2 MOTIVATION

An ongoing challenge to adopting a competency-based approach is how to systematise the inclusion of Competency across the curricula. Several alternative approaches have been advocated to achieve this. One option is to begin with the knowledge models that are embedded in ACM/IEEE Curriculum guidance(CC2020) (e.g. [11]) and then identify the competencies that are related to the knowledge area [35]. An alternative approach is to start with the competencies desired by the industry as encoded in a skills framework such as Skills for the Information Age (SFIA) [65] and then explore approaches to embedding such competencies [7]. Thirdly, the computing industry has many preexisting badges and micro-credentials related to the successful completion of specific learning, and one approach is to embed such informal qualifications [69, 70]. The strength of the first approach is that it builds upon existing curriculum recommendations. The strength of the second approach is that it focuses tightly on employer needs. The strength of the third approach is to help bridge the gap between formal and less formal learning and hence may help promote the lifelong learning required by careers within the tech industry [73]. In all cases, familiarity with the related models of competency is required, be that with the ACM/IEEEE model [11], or with SFIA [65] or other internationally recognised competency framework or with the details of the related micro-credentials or badges (for example Microsoft Credentials [53] or CISCO Credentials [18]). This paper argues that those less familiar could benefit from further scaffolding. The taxonomy of Technical Competency, Personal Competency and Professional Competency are a candidate for part of this scaffolding. This paper provides illustrative examples of how each kind of Competency can be embedded.

3 RATIONALE FOR THE SELECTED EXAMPLES

Proven educational approaches were selected to illustrate the development of Technical, Personal and Professional Competency. The examples were selected from other potential candidates based on students and their employers attesting to the usefulness of the adopted approaches for developing graduate competencies. Graduates have also volunteered the utility of the experiences described in this paper in terms of refining their career aspirations and supporting them to achieve beneficial employment. The graduate outcomes of all the represented degree programmes related to the paper are above the national average. Given that graduate employment is multifaceted [12], and many facets of a degree programme help a graduate achieve employment, it is not appropriate to attribute successful employment outcomes to one intervention. However, the student and employment feedback provides reassurance that the approaches discussed contributed to successful employment outcomes.

4 THE EXAMPLES

This paper considers embedding Competency in undergraduate computing degrees at four UK universities. The examples selected were mature and have been provided for several years, illustrating the sustainability of the approaches used. The demographics of the students studying the programmes are typical for the sector [31]. None of the involved universities are small or specialist, suggesting adoption in various university types across the UK and in other jurisdictions would be possible. The citations supporting each section illustrate similar practices to those observed in the universities involved in the study rather than necessarily at the universities involved in the study.

4.1 Technical Competency

4.1.1.Technical Competency- use of craft computing to teach programming. CC2020 [11][p. 64] recommends including software development within all the identified families of computing education. The content of the software development curricula for differing families will vary, however, *programming fundamentals* is a recommended curricula element across the families. The Gamma draft of Computer Science Curricula 2023 [62][p. 180], provides curricula recommendations for the knowledge content for *Fundamental Programming Concepts and Practices.* The SFIA Framework defines the skill *programming/software development (PROG)* [64]. The expectations from SFIA for PROG at an introductory (level 2) are "Designs, codes, verifies, tests, documents, amends and refactors simple programs/scripts. Applies agreed standards and tools to achieve a well-engineered result. Reviews own work." [64]. This broadly speaking includes the CC2023 expectations for *Fundamental Programming Concepts and Practices* alongside *Software Development Practices* [62][p. 181]. Whether by accident or design, many fundamental programming courses in the UK tend to follow broadly follows the SFIA content.

Programming competencies may represent a threshold concept [20, 51], without which accessing other areas of the curricula may be problematic. Programming effectively is not a knowledge-based activity. It requires the demonstration of a variety of competencies, including code literacy, when to take a break, problem analysis and solving, computational thinking, when to ask for help, when to offer help to peers, testing, IDE usage, increasingly the usage of generative (and other forms) of AI [44], debugging, and classical coding. This requires experiential learning [6, 22].

Programming competencies have been argued to be programming craft having more in common with craft skills (such as carpentry) than traditional academic study [20]. Learning a craft requires repeated practical application. Crafts have been taught for centuries via an apprenticeship model. In this case, a Master Craftsperson (commonly a senior professor) leads the delivery of classes run in large (100-plus seat) laboratories. Several Journeypeople support the Master Craftsperson. Journeypeople are typically PhD students (as opposed to academic faculty) and are occasionally senior students. The students themselves follow the role of apprentices. The Master Craftsperson provides one traditional one-hour lecture. This is supplemented by one problem-solving class and one large programming class. The Master Craftsperson delivers these, supported by one Journeyperson per 15 students. A Journeyperson looks after the same students weekly to help develop a relationship and promote the establishment of a learning community. The assessment is a traditional combination of 50% examination and 50% coursework. Attendance is further incentivised by the use of *tickables.* Tickables are checklists the Journeypeople can use to document the completion of the problem-solving and workshop tasks. Students have to complete 80% of the tickables, or their grade is reduced pro-rata. The focus throughout is on developing practical and usable software artefacts. The approach thereby promotes the development of the components of programming competency discussed above.

The COVID-19 pandemic promoted considerable experimentation in computing education [54, 55]. One common enhancement to programming course has been the adoption of Jupyter Notebooks[74]. Juypter Notebooks were employed by a minority of computing departments before the pandemic, During the pandemic, Jupyter Notebooks support for the blended study increased their adoption, and they continued to be used post-pandemic. The emergence of generative AI is promoting further consideration of how programming is taught since Generative AI tools can generate code of similar quality to high-performing introductory programming students [44]. Exploring prompt engineering may become part of how programming fundamentals are taught [21, 44]. However, the emerging curricula recommendation is that this shouldn't be at the expense of code comprehension [62].

4.1.2. Technical Competency - approaches to developing cybersecurity competency. CC2020 [11][p. 64] recommends including *Security Technologies and implementation* within all the identified families of computing education. The content of the cybersecurity curricula for differing computing subject disciplines will vary. SFIA covers cybersecurity by Information Security and Information Assurance skills [66] and other more specialist skills, including Digital Forensics, IT Infrastructure, Penetration Testing, Threat Intelligence and Vulnerability Assessment. Cybersecurity is the crucial aspect of computing that aims to mitigate cyber-attack risks. There has been increased digitisation of activities in recent years, and growth in cyber attacks has paralleled this increase in digitisation [25]. Cybersecurity education has become an essential component of all computing degree programs [14, 15, 45]. There is a growing agreement among the professional, regulatory, and statutory bodies (PSRBs) recommending the inclusion of cybersecurity as core curricula within computing degree programmes [2, 11, 13, 38, 46].

Cybersecurity is generally considered a technical subject, and indeed, some parts of cybersecurity are very technical, such as reverse-engineering a zero-day. Indeed, technical aspects predominate in many of the proposed competency models, such as CyBOK [49]. A recommended curriculum[14, 15] for a general computing undergraduate degree was established as part of the collaborative project between The BCS, The Chartered Institute for IT, The Council of Professors and Heads of Computing and (ISC)2: Information and risk; Threats and attacks; Cybersecurity architecture and operations; Secure systems and products; and Cybersecurity management.

It has been noted that the lack of focus on social, personal, and methodological competencies in these models is a significant oversight [4]. Since cybersecurity is a meta-discipline [43], the breadth of the competencies developed may well be quite wide. Indeed a survey [29] of the most significant non-technical skills required by Cybersecurity professions indicated curiosity and creativity, inclusivity and teamworking, Communication, and life-long learning. Elsewhere an analysis of security-related job adverts [57] highlighted the criticality of communication skill, project management skills and analytical skills. It has been argued [14] cybersecurity required coverage of knowledge and skills to address technical, managerial and psychological issues, and requires a variety of dispositions including problem-solving, communication, analytical thinking, collaboration, team working and attention to detail.

There is a very wide range of careers under the broad label of "Cybersecurity", most of these is the requirement to "think like a hacker", or "look at it from the opponents' point of view". A good example is that the defender sees "Single Sign-On, Two-factor Authentication, Web Application Firewall" whereas the attacker sees "Facebook, LinkedIn, SQL Injection". In practice, mindsets are much harder to teach than facts or tools: a mixture of case studies and practical exercises seems to be the common route. It has long been recognised that students and IT professionals must be able to switch from traditional conditioning to the attacker's way of thinking to thwart an attack [8]. It has been argued [40] that real-world attacks can be quite chaotic due to the adversarial mindset a hacker might adopt, and as such, narrowly focused coursework/examinations will leave potential future cybersecurity professionals poorly prepared. One helpful analogy is that Karate martial art has been criticised for its choreographed movements and katas, leading to a closed mind that poorly prepares for mixed-martial-arts fights [40]. The competencies required suggest a broader and more challenging to implement curricula.

There are benefits from teaching cybersecurity in a practical manner, and the traditional lecture, workshop, or examination manner can result in sub-optimal results [71]. The use of the hacker curriculum also has its proponents [9] and as discussed earlier there is growing acceptance of the need to develop an adversarial mindset [40] again highlighting that complex, open-ended, real-world case studies and practical work has some primacy. In terms of how to achieve this, it has been recommended [45] to embed a specialist cybersecurity course within the general computing programme and additionally revisit relevant cybersecurity concepts within other courses, for example, teach SQL injection within Databases course [60].

4.2 Personal Competency

4.2.1. Personal Competency: teaching teamworking competency using capstone and group projects. As discussed in section 1, the dispositional/human skill dimension of the curricula is critical. One of the dispositions recommended by CC2020 is collaborative dispositions that include “team player / willing to work with others” [11][p. 51]. In SFIA the behavioural factor *collaboration* is represented across the generic attribute of influence [63][p. 4]. Teaching these collaborative dispositions/behaviour factors requires experiential learning [6, 22]. This experimental learning in the form of project and project-based learning has been significant within computing degree programmes for many years [26]. Much practical computing work is completed via projects, and teams complete much professional computing work; as such, project-based learning continues to be a core curriculum component of many computing degrees. Project-based learning can be seen as a teaching approach that “engages students in sustained, collaborative focus on a specific project, often organized around a ”driving question” chosen by students themselves or provided by an outside organization or company” [26]. Indeed, it has been suggested that “sustained team interactions on scalable complex problems that require constant synthesis and the application of core computing concepts throughout the curriculum place students on a trajectory toward becoming professional software engineers” [28] To realised this curricula recommendation, Computing degrees commonly employ team development projects where students apply the knowledge, skills, and dispositions they have learned in their studies or broader professional/life experiences.

How such projects are embedded in the curricula varies. In the UK, where students commonly have the opportunity to complete a paid industrial placement between their second and final year, significant team projects are often in the second year to develop collaborative competencies partly to ensure placement year students are appropriately equipped for their placements. Some universities employ projects in the first and/or second and/or final years to provide rigorous development of collaborative competencies, each year addressing projects of increased complexity and challenge. Team projects completed in the final year are termed capstone projects [34], and such projects integrate the knowledge, skills and dispositions from the student’s degree as a whole and require students to apply them to a project. The focus of team projects may originate be the technical aspects or the open-ended nature of requirements. For example, a group project in the second year may focus on developing competencies around sandbox projects, whereas a capstone project may focus on real-world projects. Real-world projects can take various forms, some addressing the needs of external or industrial collaborators, others addressing open-source software, and others harnessing student entrepreneurship. It is common practice for teams of students to develop software projects from initial need through to minimal viable prototypes and often beyond. Student teams are commonly primarily self-managed with the support of an academic facilitator (usually on a weekly or fortnightly basis). Peer assessment [16] is frequently used to help promote fair outcomes for contributions made, and several commercial tools are available to support this (e.g. [10]). Indeed, employing an appropriate peer assessment scheme may provide a mechanism for exploring the disposition dimension of Competency in collaborative working [17]. These team projects/ capstones are a time-served method for developing personal competencies (i.e. collaborative competencies).

4.2.2. Personal Competency: Teaching creativity and teamwork via Problem-based Learning. Considering again, one of the dispositions recommended by CC2020, namely *Inventive* includes “: Exploratory. Look beyond simple solutions” [11][p. 51]. In SFIA the behavioural factor *creativity* is represented across the generic attributes of complexity and business skills [63][p. 6]. Teaching the creative/inventive dispositions requires experiential learning [6, 22]. Whilst much practical computing work is completed in projects that generate software/computing artefacts of some sort or focus on a driving question, other aspects of the computing discipline relate to generating the solution to open-ended problems. Such problems require the application of the *Inventive* disposition. The development of the related competencies here can be promoted by problem-based learning. Problem-based learning is the teaching approach where students work in groups to solve open-ended problems [39]. Hence, problem-based learning differs from project-based learning, which focuses on a ’driving question’. Problem-based learning, hence, will, in addition to developing students’ collaborative competencies, also promotes the development of their creative competencies. One example of a curricula area which commonly employs problem-based learning is exploiting the hacker curriculum to promote the development of cybersecurity competencies [9]. A second example is Game development, in which teams of students define the game they create [37]. Indeed, use of playful learning [72] is one education approach that can be used within problem-based learning to promote creativity. In playfully learning, participants enter the *magic circle of play* [72], encouraging them to safely imagine ideas outside the real world, promoting new ideas and innovative solutions. Such playfulness is a key promoter of creative competencies.

4.3 Professional Competency

As discussed in section1, the current CC2020 [11] definition of Competency requires Competency to be evidenced within a *context*, with the SFIA [65] definition of competency additionally requiring Competency to be evidenced *repeatedly* within a *real-world context*. Work experience is highlighted in the wider research as a factor promoting employment [12], the extension of which has been a recommendation [11, 52]. Such work experience facilitates developing the SFIA definition of Competency.

4.3.1. Professional Competency: use of industrial placements. "Sandwich" degree programmes, where students work full-time for an employer between their second and final year (bachelor) or between their 4th and final year (integrated master), have existed for many years and are a common feature of many computing programmes in the UK. The uptake of such schemes varies from being an exception to it being the norm, with, for example, about 80% of students opting to undertake a placement at one of the universities related to this paper. Maintaining high placement uptake requires significant institutional and departmental support [30]. The existence of placements presents more novelty in an international context. Sandwich placements enable the development of professional competencies, and when students return for their final year, they have gained real-world experience to contextualise their studies. Placements have positively impacted graduate employment [56]. One challenge is promoting and documenting the professional competencies as the placement develops. RITTech (Registered Information Technology Technician) [3] is a professional qualification that demonstrates and validates competencies, and was launched by BCS, The Chartered Institute for IT in 2015. RITTech provides a mechanism to demonstrate competence in several industry-wide recognised skills to employers. It is possible to seek accreditation for placement years to RITTech, and one of the universities related to this paper has successfully achieved this by adhering to the following process. Before undertaking their placement, students are supported in identifying and expressing the goals, outcomes and skills they hope to gain from their placement year. Throughout the placement year, the employer and the placement team monitor progress to achieve these goals. This progress is documented in a portfolio. Students are visited by an academic faculty member whilst on placement to help promote the best possible experience. At the end of the placement year, students are invited to reflect upon their experience and skills acquired through a written report, a poster presentation and their portfolio. The portfolio is designed around the RITTech criteria, so a student who successfully passes their placement year is also eligible for RITTech registration. This provides certification of the professional competencies they accumulated whilst on placement.

CC2020 [11] does encourage Work-study and Cooperative Programs section in 7.2.2. However, CC2020 does not directly consider the impact of such initiatives on students' competencies, which, as discussed above, is not insignificant. The section 7.2.2. of CC2020 is 176 words in length, which arguably does not fully address the opportunities presented by such initiatives. Extension in this area is a candidate enhancement for future versions of curricula guidelines.

4.3.2. Professional Competency: co-delivery with industry via degree apprenticeships. Across the four nations of the UK, one approach to integrating academic and work-based learning is the completion of a higher/degree-level(graduate) apprenticeship [61]. These higher or degree (graduate) apprenticeships enable the integration of studying for an undergraduate or masters-level qualification whilst employed full-time. Higher degree apprenticeships enable the attainment of a para-professional qualification such as a Higher National Diploma or Foundation Degree. The term degree is used in England, and the term graduate in Scotland. Apprentices typically spend 80% of their time at work and 20% of their time in formal study. Apprenticeships typically take slightly longer to complete than a standard degree; for example, in England, an undergraduate degree (without a placement year) would take three years, whereas a degree apprenticeship would typically take 5 or 6 years. Normally, apprentices have the opportunity to continue to be employed at the end of their apprenticeship. However, in the rare occasions, they are not, they would complete their apprenticeship in receipt of a formal education qualification and work experience that makes them attractive to other employers. Degree (graduate) apprenticeships are designed in collaboration with employers. The expectation is work-based learning will take place alongside the formal 20% of learning that an apprenticeship will be expected to attend. This provides a significant opportunity for experiential learning [6, 22]. There is synergy between formal learning and work-based learning, which particularly suits the learning preferences of students whose motivation to study computing is for its utility [5, 36, 50]. As with placement years, it is also possible to seek accreditation for the competencies gained in the work place by RITTech Accreditation.

CC2020 [11] does encourage Work-study and Cooperative Programs section in 7.2.2. However, CC2020 coverage of intensively co-delivered courses such as degree apprenticeships is limited, which can be argued to be an opportunity lost. The extension of coverage in this area is a candidate enhancement for future versions of curricula guidelines.

5 CONCLUSION AND FUTURE WORK

There are subtle but significant differences in terms of CC2020 and SFIA-defined competency, as discussed in 1 and 4.3. This creates tensions regarding how it is realised in computing degree provision. The CC2020 definition provides a well-grounded mechanism for promoting the Technical and Personal Competencies discussed in this paper. However, it provides less signage for the Professional Competencies gained from more extended work-based learning. Given their role in establishing graduate competencies, further consideration of Work-Study and Cooperative Programs, particularly intensively co-delivered ones like degree apprenticeships, could be made. Given the continued reported skill gaps, there is a benefit to be realised from further exploitation of work-based learning. Hence, this paper recommends exploring Technical, Personal, and Professional competency within curriculum guidelines.

The examples provided illustrate progress in terms of realising the curricula recommendations related to competency [11, 65]. However, there is still further work to do. Rashik Parmar, CEO of BCS, Chartered Institute for IT, indicated at the 2023 International Cyber Expo [42], "You won't lose your job to AI: you'll lose your job to someone who can use AI better than you!", articulating the need for the computing discipline to adapt to the opportunities offered by AI and to explore the competencies required for effective AI usage. Building on the progress in embedding cybersecurity and adopting recommended curricula [14, 15], a related competency model for security embedding social, personal, and methodological competencies is in urgent demand [4]. The ethical dimension of computing remains critical [11, 13, 46] and exploring the related Competency expectations is an urgent task. Whilst there is some exciting emerging work related to fostering cultural competencies [41], fully addressing equality, diversity and inclusion within computing curricula [2, 11, 13, 62] is a priority for the discipline.

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