Toward an Integrative Professional and Personal Competency-Based Learning Model for Inclusive Workforce Development

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ABSTRACT [1]

Recent workforce disruptions highlight the need for just-in-time competency acquisition. Developing cyber-human tools that incorporate both human guidance and artificial intelligence may shorten learning and provide better career-upskilling pathways. Deconstructing degree programs to provide adaptive pathways of multi-modal micro-experiences offers greater flexibility. To implement such learning programming, the Calhoun Discovery Program (CDP) at Virginia Tech and its industry and non-profit partners are developing an adaptive education model based on Integrative Professional and Personal Competencies (IPPCs) for Industry 4.0. We argue that implementing whole-person-development-focused curricula that uses heterogeneous analytics and adaptive pathways can increase learners' mobility within current and future economies. With our partners, we have developed real-world applied problem solving experiences to prepare transdisciplinary learners to work collaboratively on Industry 4.0 applications promoting sustainable and equitable development. This paper defines IPPCs and elaborates how they are integrated in the CDP through Problem-based Learning Experiences (PBLE), research and just-in-time modules. We note program outcomes over the first two years or operations and the generalizable takeaways of IPPC-based learning. Next, we describe computer-assisted tools we will develop to help us standardize and scale this learning model and summarize what the learning cycle looks like in our model. We conclude by sketching prospects for scaling this approach to K-12, industry and other settings.

Keywords: Machine Learning, Artificial Intelligence, Prior Learning Assessment, Problem-based Learning

1. INTRODUCTION

There is a well-accepted need to increase and diversify participation in the economy [1, 2]. Jobs of the future will leverage the uniqueness of human-embodied and social intelligence to create complementarity with technology, enhance human skills, and avoid human capital displacement [3]. Diversity of human experience and knowledge will be required to holistically tackle complex 21st century problems. Although future competencies may change, the demand for higher-layer, more transferable human skills (sensorimotor dexterity, cognitive agility, collaboration), will remain constant across competencies and workforce demand shifts [3]. Calls to change professional development and redefine

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competencies are not new [3-5]. Traditional training and development entities are largely unable to offer holistic and flexible methods for skill identification or acquisition or to rapidly scale to address fast-changing, lifelong learning needs in the United States [5]. The majority of outcomes acquired via traditional educational structures and curriculum designs are not aligning with future employers' needs. Such changes require innovation that spans K-12 to adult learning and leverages Quintuple Helix Knowledge ecosystems [6] that foster cross-sector partnerships that span education, industry, government, civil society, and socio-ecological environments. Such ecosystems embody a "culture of participation" in which intelligence is assumed to be distributed, multimodal, developed, practiced, and expressed through "the use of technologically-mediated informational and social networks" (Balsamo, 2010, 424[7]).

To address the challenge of providing complex 21st century learning, we propose developing cross-sector opportunities for delivering content at the learners' point of need. To create such just-in-time, micro-learning experiences [8], an approach is needed that aims to capture the totality of a person's knowledge repertoire in relation to the totality of knowledge needed to accomplish complex tasks and advance knowledge and learners' mobility within the current and future economies [5, 9]. Founded in 2019, the Calhoun Discovery Program at Virginia Tech (CDP) and our industry and non-profit partners are implementing such a learning model based around helping learners to identify and develop what we call Integrative Professional and Personal Competencies (IPPCs), which are defined as holistic competencies comprised of the domain-specific, domain-general, and life skills needed to address complex workforce tasks [10, 11].

Leveraging related prior work [3], CDP approaches integrated professional and personal knowledge as a three-layer hierarchy of skills with life skills and personal fulfillment, domain general, and domain-specific in top to bottom order of complexity [3]. Each higher level can be seen as generalized schemas emerging from individual experiences from lower schemas [12]. Higher-level, generalizable schemas in turn, help transfer of knowledge from previous, specific experiences to new experiences and in the process, influence the forming of lower-level schemas. Some of the hierarchical relations are regular (i.e. domain-general skills that relate directly to domain-specific skills) but some may also be irregular (i.e. domain-general skills in one area may have critical relations to domain-specific skills in others). Future members of the Industry 4.0 workforce will need to be able to combine skills across the three layers to develop custom IPPCs [3].

Our program develops IPPCs through integrated Problem-Based Learning (PBL) and related research on real world problems and accompanying short skills modules. Over the past two years of implementing this model we have discovered that such learning requires a probabilistic rather than deterministic approach to curricula. Therefore, we are planning research and development of computer-assisted tools to facilitate our teaching and learning more easily.

In this paper, we first expand on the background and definition of IPPCs. We then elaborate how they are integrated and put into practice in the Calhoun Discovery Program at Virginia Tech through Problem-Based Learning Experiences (PBLE), research, and just-in-time modules. After that, we note the outcomes we have seen in our program over its first two years and the generalizable takeaways of IPPC-based learning. Next, we describe the computer-assisted tools we will develop to help us standardize and scale this learning model. We then summarize what the full learning cycle looks like in our model and conclude by sketching the prospects for scaling this approach beyond a university setting to K-12, industry and other settings.

2. 21ST CENTURY LEARNING AND INTEGRATED PROFESSIONAL AND PERSONAL COMPETENCIES

Educators can motivate learners and increase the learners' efficacy and efficiency through the identification, analysis, and leveraging of their existing knowledge to structure learning pathways to closely-related competencies required of the current and future economies. Implementing a strategy that focuses on what knowledge, skills, and abilities already exist within learners as opposed to learners' deficiencies may empower individuals who have been left behind or are intimidated by more traditional education or training mediums [13]. An IPPC approach to learning can capture and leverage all types of human skills and thus be more inclusive.

Also layered in our multidisciplinary problem-based learning experiences is the utilization of Autor's [14] approach to task and skills and Dreyfus's approach to developing expertise [9], for a professional assessment of complex outcomes in applied projects as a potential measure of IPPC development. Successfully realizing an outcome requires the full application of integrated skills by the learner and is more observable than the exact makeup of the hierarchical network of skills involved in realizing the outcome. In complex PBLE organized around high –dimensional, real-world problems, like the CDP's, the learner is required to develop and apply IPPCs to understand and solve the problem. Achieving a project outcome, therefore, can be indicative of development of IPPCs even though the specific pathways for developing the IPPC is not fully observable.

3. BUILDING ON THE CALHOUN DISCOVERY PROGRAM

The CDP has partnered with the Boeing Company, General Electric Company, Caterpillar Inc., Capital Youth Empowerment, Achievable Dream Academies, Ithaka S+R, United Way of Southwest Virginia, and the Association for Financial Professionals to develop an educational experience that prepares students to develop 21st century IPPCs with a focus on Industry 4.0 applications that promote sustainable and equitable development. The participating disciplines of the program are: Art, Business, Business Information Technology, Computational Modeling and Data Analytics, Communication Studies, Environmental Policy and Planning, General Engineering, Industrial Design, Industrial and Systems Engineering, Management, Multimedia Journalism, and Smart and Sustainable Cities. The CDP focuses on collaborative socio-technical innovation in Industry 4.0 with emphasis on seven, interrelated application areas: (i) Human-cobot partnership in production; (ii) IoT supported manufacturing; (iii) digital thread and supply chains; (iv) automated inspection of infrastructure; (v) advanced manufacturing; vi) financial analytics and strategy; vii) inclusive human capital development.

Life skills for Industry 4.0 are developed across all components of the CDP experience. Individual domain-specific, domain-general, and life skills are reinforced and integrated into IPPCs through the realization of collaborative Problem-based Learning Experiences (PBLE) that take place in a traditional, face-to-face medium called studio in which cross-sector experts provide real-world PBLEs for the seven Industry 4.0 application areas of the CDP at the novice, capable, and skilled levels.

This CDP PBLE model is an expansion of the IDEO collaborative innovation model [15] and aims to advance collaborative socio-technical innovation that spans four sets of a problem space: desirability, feasibility, viability, and sustainability. From an industry perspective, the four sets represent the following simplified elements of a problem space: (1) desirability aligns with a definable real need from a use case; (2) feasibility aligns with an existing, matured technical approach; (3) viability aligns with the testable, reliable and repeated manufacturing of the technical approach at a cost that is reasonable to the desirability constraint; and (4) sustainability aligns with a solution that embraces societal benefits such as low environmental impact, policy and regulation compliance, life-cycle cost supportable, and inclusive economic prosperity. Elements of the four sets overlap. Systems approaches to sociotechnical innovation must address the interrelations and interdependencies among the elements of the sets through extensive collaboration of people with different but complementary IPPCs.

All Industry 4.0 PBLEs of the CDP cover the four sets of the CPD model enabling the learners to view the problems through the lenses of business, design, technical, and socioeconomic and environmental aspects. Additionally, the learners in the program rank their preferences regarding the pre-set problems and faculty aid in arranging them into heterogeneous teams. The implementation and evaluation of this approach and framework informs current and future iterations with the intended outcomes being increased effectiveness, adaptability, and connectivity among the components. As students do PBLEs and realize what IPPCs they want they are directed to modules that build individual skills of IPPCs. In 2018, a design team and working group developed online, asynchronous microlearning experiences called Skill Modules. These five week, short courses provide learners the opportunity to acquire domain-specific and domain-general individual skills needed for Industry 4.0 at the novice, capable and skilled levels [3]. With the structure and goals of the CDP in mind, we turn to the outcomes and takeaways we have learned over the past two years.

4. CDP OUTCOMES AND GENERALIZABLE IPPC-BASED LEARNING TAKEAWAYS

Since launching the CDP in Fall 2019, we have had two cohorts, each comprised of 40 students representing diverse backgrounds and multiple disciplines, progress through the program. The first cohort that started in Fall 2019 will graduate in Spring 2023. Across the two cohorts, we have retained 78 students. The first cohort has completed one transdisciplinary studio course and is currently enrolled in a second studio course in Spring 2021. The second cohort completed their first studio in Fall 2020. Students completed three rotations in their fall studios, working with a different multi-disciplinary team in each rotation on new, real-world PBLE. Students have also completed subsets of more than 35 different short Skill Modules in addition to coursework within their disciplines.

Over the course of two years of operations, we have collected data in the form of module and studio grades, student feedback, and external assessment that includes interviews and surveys with students, faculty, and partners. Based upon this information, we identified crucial aspects in designing and implementing instruction for developing integrative competencies. First, to implement problem-based, transdisciplinary learning, heterogeneity is critical. Drawing together a community of learners, instructors, and partners who represent different disciplines, have multiple perspectives, and are all committed to building spaces for the exchange of diverse knowledge is a fundamental part of these processes. Developing integrative professional and personal competencies similarly requires heterogeneous skills, knowledge and approaches. Having all participants supporting and participating in this approach is essential to successful implementation. Each of the learners, instructors, and participating partners have joined the program because they have a commitment to this type of education. Participants (students, instructors, and external partners) have articulated that understanding the larger picture of what they are learning could not be done without heterogeneity in approaches, delivery, and material to the broader learning content. Second, incorporating problem-based learning, research, short skills modules, and learners' disciplinary work in an integrative manner is key. Moreover, it is important to create this integrative environment from the beginning of learners' pathways to the end. Across interviews with students, instructors, and partners, we noted that participants are beginning to connect the skills delivered in modules to the IPPCs developed through problems in the studio. They are also beginning to understand how life skills are connecting across each type of learning.

Third, we understand that the IPPCs are not fully observable. They are different for each person as are the combinations of skills, their connectivity, and the strength of connections. The time and order of developing IPPCs also varies greatly. As a result, mentoring and student self-direction and reflection is difficult. This creates a probabilistic education space. We have discovered that even with relatively small cohorts of students, the complexity of learners' existing knowledge, competencies developed and most effective pathways to their individual learning goals is too great to continue to track, analyze, and map by hand. As a result, we need tools to assist all of these processes. A key goal of the CDP and its affiliated research center, the Calhoun Center for Higher Education Innovation is to define a cyber-human methodology and related tools for making these IPPCs observable and for helping learners develop these IPPCs in an adaptive manner that leverages each learner's existing repertoire of these skills.

Therefore, based upon our research and the data gathered from the first two CDP cohorts, specific tools need to be developed to assist in the program's expansion. They include: an interactive IPPC iteration tool, refined and standardized project-based learning, refined and standardized competency-based learning, computational analysis, and an automated recommendation engine (ARE).

5. PLANNED RESEARCH AND TOOL DEVELOPMENT

In view of the above, we propose the following steps and tools that are necessary to refine the model and implement it on a larger scale and with multiple learner populations.

Interactive IPPC Iteration Tools

To update and expand the initial set of problems and IPPCs that our partners have defined, we will develop an interactive tool for Industry 4.0 experts to log into and identify a real-world problem in one of the seven Industry 4.0 application areas of the CDP and then compile one IPPC for each of the four sets (desirability, feasibility, viability, and sustainability) of that application. They will use a drop down menu of 45 Industry 4.0 skills to select up to 8 domain specific, 4 domain general and 3 life skills per IPPC (there will be no minimum limit). They will also identify the level at which each skill is needed (novice, capable, skilled). Experts will also have the option to input a new skill if it does not appear on the list. Finally, they will identify their confidence level in each of their selections. This process will result in 28 IPPC Vectors in all (one IPPC per set (4 sets) x 7 problem areas) with each IPPC being a 45 x 1 vector with four possible values: zero, novice, capable, skilled.

Skill No.*	Skill	SkillType*	IPPC 1
Skill1	0,1,2,3	DomainSpecific	0
Skill2	0,1,2,3	DomainSpecific	2
Skill3	0,1,2,3	DomainSpecific	3
Skill4	0,1,2,3	DomainSpecific	1
Skill5	0,1,2,3	DomainSpecific	1
...	...	...	...
Skill32	0,1,2,3	DomainGeneral	1
Skill33	0,1,2,3	DomainGeneral	0
Skill34	0,1,2,3	DomainGeneral	0
Skill35	0,1,2,3	DomainGeneral	0
...	...	...	...
Skill42	0,1,2,3	LifeSkills	1
Skill43	0,1,2,3	LifeSkills	0
Skill44	0,1,2,3	LifeSkills	2
Skill45	0,1,2,3	LifeSkills	3
*Reference Only			*Example

Figure 1. An example of IPPC Vectors indicating the number, type, and level of skill.

Learner Inventory

Additionally, we will develop a learner inventory. This serves two primary purposes. First, it replaces the negative assumption of a needs assessment by instead acknowledging that all individuals enter training and education experiences with existing knowledge regardless of the mechanism by which they have acquired it (e.g., extra-curricular activities, employment, military) [13]. Doing so may help them connect their prior learning more readily to new content. Secondly, an inventory takes a more holistic view of the competencies by focusing on life, domain-general, in addition to the domain-specific skills category. Learners will enter the IPPC-based learning in a point-of-need manner based on recommendations made by experts using data collected through a Learner Inventory that serves to identify the learners' experiences, preferences, and prior knowledge [16, 17] and is adapted from current practices [18]. This mechanism seeds the data for the AI for the recommendation engine.

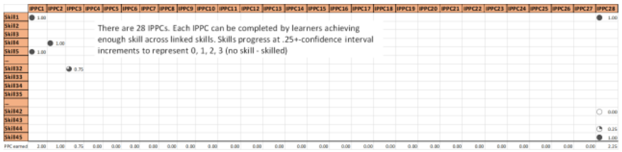

Figure 2: A learner matrix that incorporates the inventory accounting for prior experiences that records 28 IPPCs.

Refined and Standardized Project-Based Instruction

We plan to refine our existing PBLE offerings and expand new ones. Building upon our existing CDP studio-based, teaching activities, we will work to create a framework for developing PBLEs that (a) help students identify and develop the skills that inform their proximal IPPCs and (b) provide standardized data (project outcomes, learning analytics, student reflections) to assist experts in rating standardized Learner Project Outcomes related to IPPCs. Using feedback from our partners (industry and non-profit) coupled with the multiple faculty involved in the course should assist in aligning outcomes to those defined IPPCs. Additionally, this participation example will aid all involved in the instruction to observe the IPPC development via teams' reflections and presentations.

Refined and Standardized Competency-Based Instruction

Working in tandem with the PBLE methods, we propose opening multiple learner pathways towards achieving the desired level of skills that comprise an IPPC. Advising learners on their future module pathways is based on the aforementioned ratings (PBLE) along with the learning management system's data analytics and the Automated Recommendation Engine (ARE). The proximal IPPC recommendations for each learner include both the identified skills of the IPPCs and the level of skill needed for integrated competency. As such, we propose designing individual Skill Modules with partner feedback to follow the theory of how individuals develop professionally [19, 20] through the use of categories called novice, capable, and skilled [9]. By leveraging and monitoring learners' knowledge transfer, we expect learners to show outcomes in achieving observable progress in achieving one or two domain-specific skills and one related, domain-general when engaging with a Skill Module. Additionally, Skill Modules are set up for learner-paced delivery and short endurance. By keeping modules short, models of learner knowledge can be frequently updated resulting in more accurate next-learning-step recommendations. Short modules can also accommodate varying levels of time availability by diverse learners. The module design aims to facilitate active participation by the learner and self-pacing [21, 22].

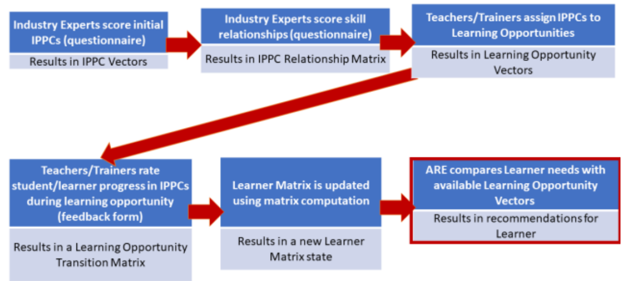

Figure 3: The processes of the Automated Recommendation Engine (ARE).

Computational Analysis and Automated Recommendation Engine

We will develop an Automated Recommendation Engine (ARE) to assist in delivering IPPC-based learning in a point-of-need manner. The ARE is a hybrid tool combining expert knowledge with probabilistic machine learning to (a) trace the proximity of learners' knowledge to IPPC Vectors, and (b) continuously improve our cyber-human loop. It automates the next, best Skill Module and/or PBLE recommendations for a learner and updates the parameters of ARE to close the cyber-human loop.

Before any learners begin the learning cycle (before ARE is used for the first time), the parameters of ARE need to be initialized using expert knowledge. These parameters include IPPC Vectors, relationships between skills, mapping protocol of learning inventory to learner knowledge, PBLE and Skill Module outcomes. Once initialized by experts, these parameters will be updated regularly and reviewed. At any point in time, each learner has a Learner Skill Vector (LSV) and a set of proximal IPPCs to the LSV. As they pass through learning opportunities, learner knowledge moves from one state to another (LSV update) and accordingly the proximal IPPCs are also updated. It is important to highlight that the exact LSVs and IPPC Vectors can never be fully known and therefore they follow a probability distribution. It is possible and highly probable to have multiple pathways from an initial LSV to an IPPC Vector. Assuming a student cannot go back to a previous knowledge state, the network of knowledge states form a directed graphical model [23]. Nodes in this graph are the LSVs and the transition probability from one LSV to another LSV and depends on the aforementioned parameters.

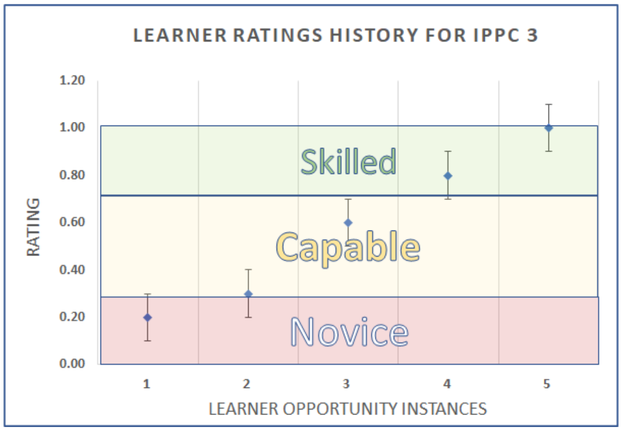

Figure 4: Example of Learner Skill Vectors and the rating of skill level across instances.

Application of similar models of knowledge progress mainly consider Intelligent Tutoring Systems (ITS) whose main goal is to trace a student's current state of knowledge using past responses, a learning model and expert knowledge on correct solution steps to a problem [24]. Early results in this area [22, 25] introduced a Knowledge Component model based on Bayesian Knowledge Tracing (BKT). Two recent surveys argue that linear regression and deep learning methods perform better than BKT [26, 27]. Deep learning offers better estimation performance when large datasets are available but works as a black-box, from input data to decisions with no expert knowledge support or interpretability of the decisions. This project will collect its own data and therefore will have limited data initially. In addition, black-box models will not provide necessary insights to improve our learning model. Our innovation will be using a hybrid model that combines data-driven models with expert knowledge in order to avoid the limitations of both black-box and expert-driven only models. This hybrid model will take advantage of expert knowledge when data is limited and take data into consideration as it becomes available over time. This is critical for continuous improvement of the IPPC development through cyber-human loops that start with expert understanding, go on to develop expert-based algorithms, then to collect data to improve the algorithms, and finally to interpret the algorithms to help improve expert understanding.

6. SUMMARIZING THE LEARNING PROCESS TO DEVELOP IPPCS

Once all tools and processes have been developed, IPPC-based learning will proceed in the following way. Each learner begins by completing a Learner Inventory used to seed an LSV and calculate some proximal IPPCs. The learner is then invited to complete a short PBLE that encapsulates the proximal IPPCs and their related Project Outcomes. We use instructor ratings of the Learner Project Outcomes to reseed the LSV, recalculate the proximal IPPCs and provide a next learning step recommendation in the form of a Skill Module that can move the learner closer to the most proximal IPPC. At the end of the Skill Module, we use the instructors' learner progress ratings to reseed the LSV, recalculate the proximal IPPCs and provide a next learning step recommendation in the form of a Skill Module and/or PBLE. The cycle repeats as needed. We use rich visualization of learner analytics to assist expert rating of student progress. IPPC-based learning leverages expert seeded knowledge components that are gradually improved through computational algorithms, related to the ARE, as more data is collected.

In this way, the system functions as a cyber-human continuous improvement loop taking input from all participants, using computational assisted tools to analyze the inputs and returning updated outputs to all participants. This work is built upon the insight that addressing the future of work in an inclusive and successful manner requires finding and creating a common language to describe and continuously update the totality of competencies and skills that learners have and that employers seek [28]. We recognize the complexity of this task by promoting a probabilistic approach to knowledge definition and instruction for both the human and cyber components of IPPC-based learning. All participants (learners, instructors, professionals) realize that addressing this complex and dynamic space requires a knowledge commons [29] that is fed by the information from partners across all sectors and is in turn available for use by all stakeholders. Designing and sustaining such a commons combining digital and human synergies is most effective when participants build trust, reciprocity and the continual design and/or evolution of appropriate structures [29]. We understand building such a knowledge ecosystem to be a public good [29] with the information and resources developed as widely and openly available and continuously searching for new pathways to discovery.

7. CONCLUSION AND FUTURE ACTIVITIES

Delivering education that incorporates both human-to-human, project-based learning, asynchronous module-based learning and cyber-human tools to provide the learner with a more exact path for career exploration and/or skill competency acquisition can increase/expand access and provide learners with the aligned attributes necessary for greater job mobility and agility. Also, developing a theoretical framework encompassing strategies, interventions, and support regarding holistic competency instruction may motivate the learner, reduce cost to employment in terms of training/education, and better align learners' repertoire of skills to employers' needs.

We hypothesize that deconstructing the current, traditional training and education structures while adapting the sequence, timing, and customization to the learners' needs, preferences, and interests can provide not only a more efficient mechanism for 21st century competency acquisition but also attract, retain, and serve a more diverse population of learners. We believe that the CDP approach to developing IPPCs can be scaled beyond Virginia Tech and the university setting to provide a strong basis for K-12 and workforce training as well.

Additionally, we expect our findings to also start a new path for AI in education research where expert knowledge and interpretability of algorithms is critical. It is possible to apply similar Bayesian Neural Network models to Intelligent Tutors, college admission estimation, student retention estimation, and equivalence of transfer courses. In addition, our work will contribute to the explainability and interpretability of machine learning algorithms beyond AI in education research. Our proposed models will be especially helpful for applications where parameters need to be updated regularly due to a dynamic system.

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