Assisting Education through Real-Time Learner Analytics

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***Abstract*—Learning analytics has been dominating the education arena for these last few years as the efficacy and applicability of big data in general has been recognized, appreciated and fruitfully employed. Such analytics can assist and support higher education learners to optimize their interaction with available resources, while providing crucial insights on their learning behaviour and study processes. In this paper, we present a case study of how we employ an online environment with mature students within an ambient intelligent classroom. The specifically designed learning space makes use of a number of strategically positioned sensors that provide explicit data to the underlying intelligent system that forms part of the associated online portal. Physically present and remotely connected learners have access to their personalised learning environment that depends on their academic needs, progress, position in class, and the other learners in their group or vicinity. The ambient intelligent system coordinates the interaction between all the students and teacher who is present in class. A real-time machine learning application to detect learners' levels of attention and participation makes use of sensory data generated together with other learning data collected from the portal that collectively assists in the learning analysis process that is looped back to the learners' learning environment, as well as to the educator, in an attempt to improve the delivery and the entire educational process. We report on several issues encountered together with accuracy and reliability concerns as we draw a number of conclusions and offer recommendations.**

Keywords—learning analytics; online education platform; e-learning; assessment visualisation; Aster plot

I. Introduction

Learning analytics has been dominating the education arena for these last few years as the efficacy and applicability of big data in general has been recognized, appreciated and fruitfully employed. Such analytics can assist and support higher education learners to optimize their interaction with available resources, while providing crucial insights on their learning behavior and study processes. The main advantage of learning analytics is their personalization capabilities that enables individual learners to gain specifically tailored knowledge, as well as adaptive academic support that supplements their own unique learning journey.

What if these learning analytics were provided in real-time to both the learner and the educator within a context that enables the optimization of the entire learning process? What if the environment itself was conducive to complement the acquired knowledge and inferred recommendations extracted from the same analytics? Furthermore, what if the other learners together with the online crowdsourcing community were to contribute and collaborate to share their knowledge and experiences in an academic attempt to enrich the learning process?

In this paper, we present a case study of how we attempt to answer the above research questions, as we engaged our undergraduate students within an Ambient Intelligent classroom. Apart from a number of strategically positioned sensors within the classroom, the learners had access to an associated online portal that interacted with the sensors as well as with the underlying virtual learning environment. The environment simulates the physical environment for remote learners who were not able to attend class in person, but also keeps track of the individual learners' academic profile once they had logged into the system. Those learners who made it to class were still required to login, but the system was aware of their attendance as they were physically identified within the real classroom from their electronic university cards. The system coordinates the interaction between all the students and teacher who is present in class, but also between learners themselves, as such interactions are considered paramount to the receptive and education acquisition processes. We take full advantage of the ambient intelligent environment to employ non-intrusive sensors, displays and cameras, in combination with a real-time machine learning application to detect learners' levels of attention and participation. This, combined with other learning data collected from the portal, assisted in the learning analysis process which looped back to the learners' learning environment, as well as to the educator, in an attempt to improve the delivery and the entire educational process. We report on several issues encountered together with accuracy and reliability concerns as we draw a number of conclusions and offer recommendations. The rest of the paper is organized as follows. The next section presents the details pertaining to the smart environment we employed, online and face-to-face. The ideological stance behind our online learning portal are then elaborated in some detail in the following section, giving details

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of e-learning affordances in the realisation of this study. Section IV tackles and presents all the issues related to real-time learning analytics as we present a number of results and outputs. Finally we close with an evaluation of our study as we draw conclusions and offer recommendations in the final section.

II. Ambient Intelligent Classrooms

The application of Ambient Intelligence (AmI) to education is not abundant, comprehensive and coherent even though it can be traced back to prior to the millennium. A number of research studies investigated the physical aspect of the classroom [1, 2, 3] that involves monitoring the occupants within the classroom, and automatically controlling the lights, air-conditioning, multi-media displays and acoustics. Shi et al., [4] employ two wall-sized projector screens together with a full-sized touch-sensitive smart whiteboard within a dedicated classroom, as well as with a number of cameras, microphones, light controllers and software capabilities to portray remote students within the same classroom. Other AmI researchers investigated how to create a smart educational environment through the development of some kind of piece of furniture that sits in the classroom. Antona, et al., [5] present an augmented school desk that incorporates a number of AmI educational applications. The authors aimed to support common learning activities in an effort to improve the overall performance and experience of the learner. The desk is technologically loaded with an integrated personal computer, two mini projectors behind a small screen that faces the student, two cameras and four infrared projectors behind the same screen, another camera on top of the screen and a smart pen together with its transmitting device. This setup made use of purposely developed software which kept track of the learner's movements when interacting with the screen. In a similar manner another project Tagawa, et al., [6] also integrated touch screens and cameras within the students' desks to enhance the teaching environment.

Other AmI projects within the educational domain made use of wireless technologies to be less intrusive and remain loyal to the covert nature of AmI. Shen, Wu, & Lee, [7] developed desktop interfaces for the educator and the students to interact with, but with the additional use of a wireless technology. The authors employ Near Field Communication (NFC) to automatically identify individual students and the educator and use the acquired information to record who attended, locate the exact position in class each student is occupying, as well as provide real-time feedback to each student. The use of another wireless technology, Radio Frequency Identification (RFID) was also employed in a number of projects [8, 9, 10] that mainly took advantage of the popularity of this wireless technology to provide a context-aware environment in their efforts to create an AmI learning environment. Ramadan [2] employs RFID extensively to track the educator and students and execute a number of processes including identification of all the persons, presenting class information, controlling the projector and uploads the learning materials to the target learners.

To some extent the above mentioned AmI research projects failed to focus directly on the academic content in a way that accommodates the unique learning needs of each unique student, which is what AmI in education should be focusing on. Leonidis, et al., [11] offer a better insight in the way they tackle the application of AmI to education as they present a theoretical framework that enables pervasive interactive and context aware instruction within a smart classroom. The authors highlight the fact that apart from the indispensable contextual awareness an AmI system within a technologically-enhanced classroom is the need of adaptive educational content coupled with the learning profile of each individual student. Their framework which is called ClassMATE has five core components that collectively constitute the main functionality proposed. The first four distinct components are the Security Service, the User Profile, the Device Manager, and the Data Space, which all have the fifth overlapping component, the context manager, that coordinates and orchestrates the entire operations of ClassMATE. The data space component itself is further subdivided into four subsections, namely, Application, User, Class and Lesson, as it gathers materials from a number of sources to perform its job. A typical scenario of how this framework is envisioned to work when a specific academic need occurs in class is when an educator attempts to make use of the interactive whiteboard. The context manager detects such an action and focusses all activities to the one at hand to dedicate all possible resources but also to ensure that all the learners have now converged to this particular activity. Worth noting the concept of a ClassMATE cloud is distinctive from the smart devices that are controlled by the same underlying system. Such a treatment of how AmI can be applied to education, even though at a theoretical and conceptual architecture, is the closest to the way we tackle the area. We adopt a similar classroom software architecture but combine a fully functional online portal that accompanies the AmI classroom and reflects all the individual specifics of each learner in real time. This online portal was purposely designed to offer a reflexive environment to the students irrespective if they are physically present in class or remotely and synchronously connected to all the other learners and educator in the class itself.

III. The Online Portal

New educational technologies have emerged since the introduction of computer-mediated and online learning. Some of these key educational technologies are related to Learning Management Systems, e-Textbooks, Flipped Classrooms. Intelligent Tutors, Games and Simulations, Discussion Boards, Web workspaces and e-Portfolios, Adaptive, Personalized and Differentiated Instruction and Machine Assessments [12]. Yet, none of these technologies is particularly new, since shifts in educational media have been a long time coming. In fact, digital media do not necessarily change anything fundamental in schools [13], and some of them have already been present for quite a long time in traditional schooling contexts and not rarely have been used to replicate old teaching and learning practices [14, 15, 16].

In a different direction, however, it is possible to use educational technologies to promote real changes in the education system from an e-learning ecologies perspective, which can impact learners' configurations of space, their relationships, the textual forms of knowledge to which they are exposed, the kinds of knowledge artefacts that they create, and the way the outcomes of their learning are measured. According to Cope and Kalantzis [13], e-learning ecologies would be a kind of 'metaphor' to understand the learning environment as an ecosystem, consisting of the complex interaction between human, textual, discursive and spatial dynamics. These e-learning ecologies are, therefore, pedagogical and epistemic forms that underlie reflexive/inclusive education [13]. In order to operationalize such e-learning ecologies, Cope and Kalantzis [16] heuristically segmented them into seven "new learning" affordances (e-Learning Affordances): ubiquitous learning, active knowledge production, multimodal knowledge representations, recursive feedback, collaborative intelligence, metacognitive reflection and differentiated learning. The authors also point out that, in the CGScholar environment, these affordances constitute an 'agenda for new learning and assessment' to reframe the relations of knowledge and learning, recalibrating traditional modes of pedagogy in order to create learning ecologies which are more appropriately attuned to our times. All the seven affordances constitute the grounds for the reflexive pedagogical rationale and the learning analytics with which CGScholar deals. The seven affordances are presented here is some more detail.

Ubiquitous Learning – Anywhere, anytime. Ubiquitous learning makes it easier for learners to access content from any computer or mobile device, online or offline, anywhere and anytime. Historically, knowledge and information has been restricted by class and privilege but creating a networked learning environment opens up access to validated knowledge and a plethora of facts.

Active knowledge making – Making new connections between pieces of information in order to create new meanings is part of the learning process. Learners build upon existing knowledge and/or on what they already know, so it helps if there are a variety of activities that are both process and product orientated.

Multimodal meaning – Text, media, sound, and data resources are easier to create more than ever. Multimodal resources add interest and break up the style of learning. If the content is presented in multiple ways it ensures that you not only can choose your preferred medium, but also have concepts reinforced along the way.

Recursive feedback – Recursive feedback is an important way for learners to check their progress. Receiving timely and relevant feedback has always been part of any course but now most obviously received as part of an online activity. It helps you think about what you are doing, your successes and failures, and how you can improve.

Collaborative intelligence – Whether it's to participate in a forum or to collaborate on a resource together, online social activities provide support and teamwork opportunities. Working with others in a collaboration space also stimulates more food for thought.

Metacognition – Thinking about thinking is a valuable activity for online learners. It helps you reflect on what you have learned and where you are going. It helps you determine areas of weakness as well as strengths and it helps you think about what questions to ask.

Differentiated learning – Differentiated learning is also more possible now than ever before. It refers to personalizing learning experiences or tailoring a course to a learner's needs and interests.

IV. The Empirical Study

An educational environment that was purposely designed to support multiple technologies in an attempt to render it intelligent and smart will inherently be subjected to a number of factors and variables that, not only need to be controlled, but whose collective effect needs to be investigated. A learner within a smart classroom is being shadowed over a connected network by the underlying system that is extracting information from a number of sources. The learner her/himself is a primary source of information as the activity perceived while performing activities online are indicative of what the interests, needs and requirements are. Secondly, the learner's social networks are also indicative of the learner's characteristics, but also a source of information where the other network members provide additional content and feedback. Finally, the academic programmes and the pedagogical methodologies employed will provide additional input to the system that will be required to rationally provide direction, advice, and academic assistance. The educational environment is ubiquitous as long as the learner is connected to the online classroom network in one way or another employing any kind of device. However, the learner will be acting with a social group that in itself brings about a number of social aspects that need to be taken into consideration. Research performed on classroom dynamics [17, 13] can shed some light on the social features occurring within such a scenario as the complexities involved are somewhat similar. The numerous activities happening within a social group, similar to a class, are multi-dimensional while at the same time they cater for all the needs, interests and academic benefits of each individual member or learner. While an educator takes control of a class and sequentially addresses the individual needs of each student, a personalised online portal sustained by an intelligent classroom addresses and services the individual needs of the specific learner. In such a way, the individual portals will be able to address the unique academic needs of each individual learner while successfully achieving the specific educational objectives. Another aspect that can be related from within a physical classroom is related to all the simultaneous activities happening. In a class the educator is required to multitask by retaining control, manage time and interruptions, follow the syllabus, attend to each student, and maintain continuity. The underlying software within the online portal is able to specifically cater to the academic needs of the individual learner by following a planned educational programme that has been customized for the needs of the same. Another important task performed by a teacher in class is related to the immediacy aspect. An educator is estimated to perform around five hundred fast and unplanned interventions with each individual student [18]. Within our empirical study the underlying software manages numerous swift responses in respect to the individual student without tire or inconsistency. Each online portal can assist the respective learner, while the collective classroom environment manages all the portals in a collaborative and information sharing way. However, the smart classroom is not planned to work in isolation without any assistance of a human educator. Our philosophical reasoning supports the indispensable necessity of a trained educational professional who can assist the learners while also ensuring to contribute to the overall functioning of the online learning portal. The educator is indispensable to moderate and facilitate the educational process, to resolve unpredictable situations, while also to establish and control the academic needs of the students.

The smart classroom's underlying system is meant to evolve over time as it refines its internal learner model to the dynamic realities reflected by the learner. However, the pedagogical model is reflected within seven imperatives or learning affordances that were introduced in the previous section. The first of these affordances, related to the ubiquitous nature of the smart classroom, continuously and uninterruptedly keeps track of the academic activity of the learner blurring the traditional institutional, spatial and temporal boundaries of education. It is now even more possible for education to occur outside the teaching hours and away from the school building. Learners have the possibility to access the online environment and interact indirectly with the smart classroom system through user-friendly interfaces, assistive systems, social media with a just-in-time and just-enough learning ideology that reflects a novel pervasive pedagogy. Secondly, learners are expected to create and produce content as much as they have been required to consume. Social media and Web2.0 technologies have engendered a new breed of active knowledge making learners that can also contribute to the educational needs of other learners. The smart classroom caters for such a shift whereby learners are required to actively discover, observe, author and curate knowledge beyond the teacher and formal content while contributing to others within a conceptual crowdsourcing network. This third affordance relates to differentiated learning whereby personalized services tend to be more effective and academically rational. A smart can definitely achieve this by enabling the learners to draw upon the resources of their own identities and apply their evolving knowledge to the ubiquitous intelligent environment around them in a way that is distinctive and unique to their perspective. The use of a variety of media enriches the educational process while motivating further the learner to creatively author new content and express oneself with the timbre of their own character. Through a smart environment it is possible to employ an array and mixture of representational models for students to express themselves as well as to learn. This will also facilitate the realization of the fifth affordance within the model whereby the online environment can assess and evaluate the learner's academic abilities over an extended period of time. Formative assessment in contrast to summative reflects a clearer and much realistic representation of the learner's academic abilities in a way that it provides ongoing feedback to the smart system that can be employed to further refine and improve the services rendered [19, 20]. This will be further discussed later on in this section and displayed in Figure 2. In this way learners are guided even better within the ubiquitous learning environment as their strengths and weaknesses are continuously being analysed in a way that allows the dynamic restructuring of the education process to address the unique learner needs. The sixth affordance enables the smart classroom system to tap into the collective intelligence of the social group as the learner is encourage to connect her/his own thinking not in recalling knowledge, but in the ability to find and identify knowledge over the same network. Learners with the ubiquitous learning environment harness new skills to think about thinking and behold knowledge for its face value rather than just for blinding passing an exam. Finally, learners through the same smart network around them are able to build collaborative knowledge cultures, whereby collaborative intelligence empowers the individual as much as the group. The smart model encourages learners to seek and uncover knowledge sources within their different social networks, while at the same time being sources themselves to assist other learners within the classroom.

An empirical study has been carefully and meticulously designed to study the combination of all three aspects as higher education students will be experiencing while attending class in the first semester of 2017/18 academic year. The educational aspect, that incorporates the e-learning affordances, will be represented through the Scholar platform (Figure 1) which has been purposely developed to embody these same affordances [16].

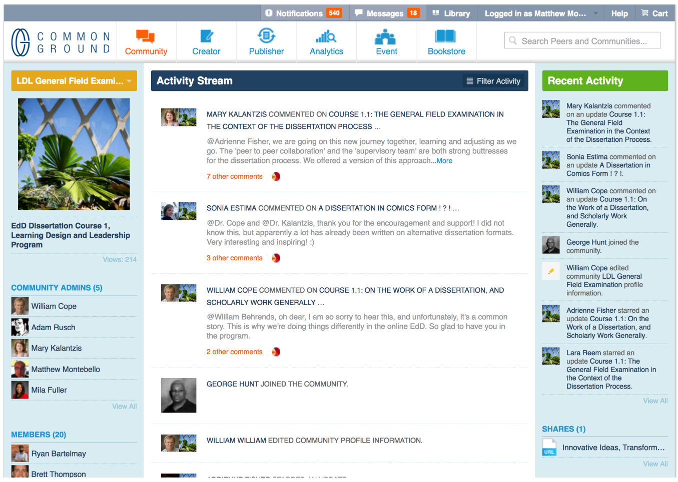

Figure 1 – Online Portal

Participants will enrol to the environment to follow their academic course while experiencing different functionalities that reflect the different affordances. The ubiquitous learning affordance is explicitly manifested in the fact that Scholar is a web-based platform accessible from anywhere over a Web browser at any time of the day. Time stamping and logs of users logging in together with a full trace of their activities while using the platform is saved and available for data analysis. Every course has a dedicated community with its specific activity stream that keeps track of all that is happening within that community, as well as, updates, recent activities, and publications that the other members within the same community have shared. Students will be required to have a Scholar account and log onto the platform to access the specific course community to which they would have been enrolled. Irrespective whether the students will be joining the course session within the physical classroom or from an alternate place like home, they still need to be logged in over Scholar and their presence recorded.

The technological aspect of the study is represented through the different devices being employed within a high-tech classroom at the university that provides an ideal infrastructure for fine-grained research using numerous technologies. This lab enables the capture of learner interactions with digital technologies in real-time, as the collection and storage of massive and varied data is possible. Cameras within the classroom, as well as cameras on learners' computers, if remotely connected, will be employed to project the person who will be speaking or making an intervention over the big screen within the classroom. This screen is also projected on the shared online environment that enables a collaborative learning amongst those within the classroom and those connected from a remote location. Finally, the social aspect is achieved through the physical presence of students and teacher within the physical classroom together with the students who are remotely connected, as they all will be virtually represented over the same shared collaborative learning platform. In this way all the students and the teacher, irrespective wherever they may be located, as long as they are logged into the platform and collaborative environment, they form part of the class. Once the session commences, the collaborative environments acts as a social forum for all participants to feel part of the class by sharing a common chat, potential to have private chat with a single or group of participants, a shared common whiteboard, as well as a shared common display screen to present one's own work or any other content. Additionally, similar to any social scenario, when a student or a teacher within the physical classroom starts to talk, sound-sensitive receptive cameras focus on that person and project the image on the communal screen within the collaborative environment. If on the other hand a remote student requests permission to talk and enables the functionality to address everyone, the personal camera on the remote computer will similarly project the image of that student on the communal screen. If a remote student decides to use a saved image, a graphic or an avatar instead of a real image, then this is also possible. All the data collected is analysed to perform a series of learning analytics together with an analysis of interactions, interventions, and other statistical analysis. Additionally, a pre and post survey will be administered to gauge the participants thoughts and opinions. A number of data capturing techniques have also been employed through the Scholar platform as the analytics section enables numerous functionalities related to the educational use of the same platform. Finally, additional logistical data is collected over the course of the entire semester to shed light on the social aspects of the virtual classroom in collaboration with the physical one. Attendance data, in person or virtual, can also shed some light on the research being performed.

In this approach, teachers are knowledge designers; they create different learning modes for learners to meet the objectives of an area of subject matter, while learners are more responsible of their own learning as they develop a reflexive and critical self-review of one's own [21, 17]. Similarly, through this Analytics tool, instructors develop a learning module to introduce the main ideas of the subject matter and prepare a set of collaborative and individual activities to guide learners into their learning. As progressing in the course, learners would have an immediate recursive feedback of all of their contributions. Through this new learning analytics tool, all of learners' interactions in a learning environment are being captured and analysed from posting updates, making comments, taking quizzes, peer reviews, instructors' feedback and annotation.

The overall goal of developing this new tool is to encourage learners to reach the mastery level of learning explained by Benjamin Bloom [22]. According to Bloom, every learner is capable to learn and advance if he/she has the right scaffolding and special attention to meet his/her needs. Indeed, this new learning analytics tool offers the possibility for learners to see where they are and where they need to be in order to succeed and master their learning with teachers' and peers' support.

CGScholar's Analytics is a learning visualization tool, where in any unit of work a student can see their progress towards mastery, and a teacher can see the comparative progress towards mastery of all members of the class, identifying which students may require more time or special attention to achieve mastery. As the students work, they will each see their progress towards mastery in an aster plot (Figure 2).

A learner is able to view their learning visualization at all times during a unit of work. The central image is an "aster plot," where each petal of the metaphorical flower represents one kind of learner activity. At the start of the unit, the plot is a white circle, but as study progresses towards mastery, the coloured petals in the aster plot grow using data continuously mined by the software during learning activities. The visualization is interpreted as follows:

- The width of the petal is the weighting given by the teacher to this aspect of the work. The length of the petal is the amount of achievement of the learner to this point
- θ is progress towards mastery. 100 learning credits represents mastery. All students can increase their learning credits and achieve mastery by doing more work, for instance revising their projects, adding more comments to the class discussions or re-taking the knowledge surveys. The teacher may set a target minimum mastery level, such as 75%
- Each petal in the aster plot is active, so clicking on it brings more detailed information about the data used to generate the conclusion about learning represented by each petal. The text displayed can be customized by the teacher to scaffold possible learner actions for improvement. Additionally, the learner is able to navigate all the way down to the work itself — an incorrectly answered quiz item, or a low score against a criterion in a rubric. This guides them to places where more work is required
- The visualization is divided into three major segments, each labelled by a learning aspect and a symbol representing that variable:
    - φ Focus, or Bloom's concept of "perseverance," measuring variables such as time on task and amount of work produced.
    - ε Knowledge, which measures knowledge via data elements such as quizzes or knowledge surveys and peer review ratings against rubrics.
    - β Help, which measures community contributions and collaborations, such as the extent and quality of comments on others' posts and peer reviews.

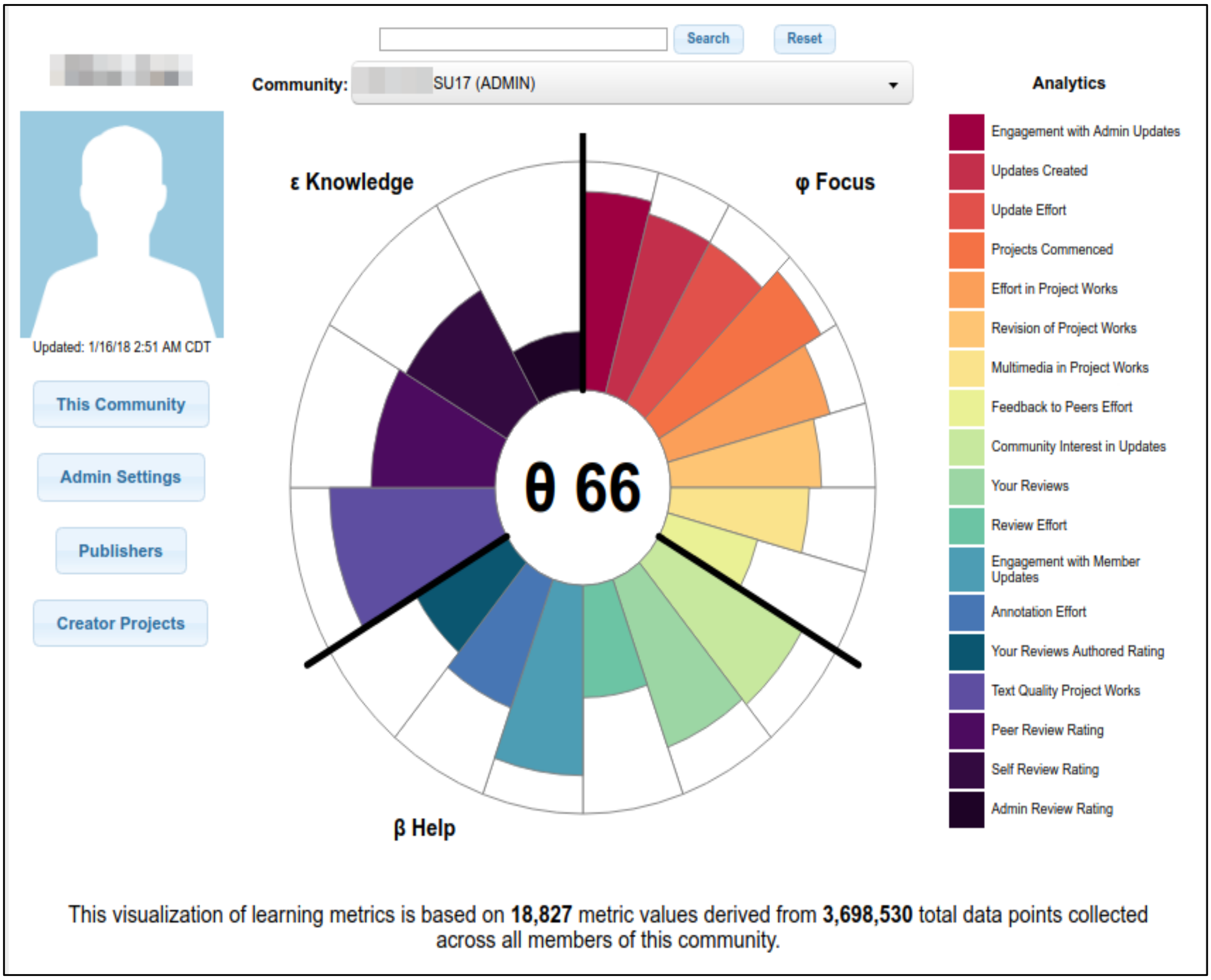

Figure 2 - The Learning Analytics Interface

Before the unit of work commences, the teacher has specified task expectations and the relative weighting of each task (represented by petal attributes). Petals can be deactivated if they are not relevant or desired for the work unit. Custom petals can also be created to accommodate data from other sources or manual entries. During the unit of work, the teacher is able to access each student's progress visualization, including the capacity to dig deep into areas requiring additional attention by an individual learner. This makes visible deficiencies which might otherwise pass unnoticed by the teacher. Figure 3 shows a snapshot of the real-time data collected through the portal and which acts as input data to the personalisation aspect of the portal. This information is not available to the individual learners but to the educator, together with the individual Aster plots for each learner that is available for inspection and encouragement. Participants reported great interest in their analytics interface that helped them identify lacunas in their tasks and assessment efforts. This increased learners' initiatives to enhance their activities as well as their responsibility towards their own education and knowledge. The online portal identified areas that require improvement or further work and informed the individual participants when the logged into the learning environment. Worth pointing out that the individual petal fields are adjustable and can be customised by the educator to highlight or accentuate one aspect more than other as part of the pedagogical process of the same subject matter.

Participant	Cmts Admin Upds	Num Upds	Avg Wrds Upd	Num Projs	Avg Len Wrk	Avg Edit %	Avg Num Media Embed	Avg Wrds in FB	Pre-Course Survey	Views Upds	Num Rev Auth	Avg Rev Auth Len	Num Cmts	Avg Annots Peers	Avg FB Score	Coded annotations	Avg Txt Qual	Avg Peer Revs	Avg Self Revs	Plot	Tot Score
1	2	3	295	2	2299.0	2.4	11	1	96.6	3	7	196	8	12	50	0	12	71.2	86.2		81.6
2	0	0	0	1	3878.0	4.7	19	74	0	0	2	336	0	10	100	0	11.8	79.8	0		53
3	7	7	548	2	3714.0	5.9	15.5	95	100	10	5	260	18	13	75	100	15.7	82.9	89.6		98.9
4	7	7	308	2	2952.0	30.4	8	1	100	13	6	332	21	15.8	100	100	12.2	78.8	92.5		96.3
5	7	7	281	2	2220.0	2.3	7.5	80	100	8	6	278	15	15.5	75	100	16.1	85	100		98.9
6	4	1	219	1	0.0	0	0	0	0	6	0	0	19	0	0	0	0	0	0		17.7
7	0	0	0	1	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		1.9
8	9	7	657	2	4504.0	47	26.5	115	100	9	6	492	34	20	50	100	10.1	79.2	85.4		98.2
9	7	7	308	2	2648.0	5.1	7	43	96.6	11	6	191	19	22	83.3	10	10.5	76.2	87.5		93.3
10	0	0	0	1	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		1.9
11	1	1	505	2	3884.0	43.8	11	100	89.7	0	7	291	3	10.6	81.2	100	13.5	75.6	90		83.3
12	7	7	367	2	2215.0	8.2	8.5	13	100	12	6	220	26	11.2	93.8	100	11.2	84.5	94.6		95.6
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Figure 3 - Statistical data employed in learning analytics

V. CONCLUSIONS AND RECOMMENDATIONS

Through the empirical study we were able to evaluate the effectiveness of combining a purposely designed and developed online learning environment with a smart classroom that promises to take advantage of the potential and capacity of Ambient Intelligence. We have seen that a combination of a number of aspects or dimensions have collectively contributed to an interesting outcome whereby individual learning data contributed to the required analytics to personalise the learning experience. The social aspect within the physical class, and those participants who were remotely connected, helped in creating a conducive learning environment whereby the learners were positively surprised and excited of having their physical presence and current activities effecting their online learning environment while enjoying the additional interaction with remote users. Our main recommendations are based on our adopted methodology of treating such a scenario as a multi-facetted and richly-factored research study without simplifying any of the issues involved. Each of the three conceptual dimensions are intrinsically and intricately complex entities that require respective research attention in their own right. We strongly recommend to ground any epistemological decision within established learning theories as the smart environment in intended specifically for educational purposes. We are convinced that this work has critical and appealing potential that could potentially enhance the effectiveness of e-learning environments as they merge with traditional physical settings that learners are much more used to and assimilate to the educational process. The real-time analytics tool represents a number of significant developments in the field of assessment and learning as it captures individual and whole cohort progress based on customisable contributing factors. This empowered the educator to highlight and accentuate what needs to be taken into consideration, while helped the learners recognise and act upon matters that really mattered. The visualisations of these analtics offered learners a clear view of their progress towards instructional objectives or "mastery", while the instructor could better rationalise whole cohort data that may prompt them to recalibrate their teaching. The shift in assessment from summative to formative taking into consideration every metric value represents a small piece of actionable feedback that can contribute to learning rendering summative assessment a retrospective view of learning progress based on datapoints that were in the first instance formative. Such an approach to real-time learning analytics can serve a number of important functions, supporting the assessment of higher level epistemic performances such as critical, creative or design thinking, and supporting learning which involves active knowledge making rather than traditional assessments based on memorization and the generation of correct answers.

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