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A Visual Analytics Tool for Personalized Competency Feedback

Completed Research

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Abstract

In this paper we report our study on the design and implementation of a visual analytics tool, Competency Analytics System (CAS), which provides feedback to instructors on both the cohort and individual student's competency acquisition rate, as well as provide personalized dashboard to each student on his or her competency acquisition for a specific course. We present the key functionalities of CAS and describe a case study on the implementation of CAS in a first-year programming course. Data from a student survey indicates that the personalized dashboard provided by CAS contributed to enhancing their ability to clearly identify the extent to which the students have acquired or not acquired the competencies tested in an assessment and motivated them to catch up on the competencies not yet acquired. Our approach is unique in the sense that we integrate the use of a competency framework with a visual analytics dashboard.

Keywords (Required)

Competency based learning, personalized feedback, competency framework, competency analytics, introductory programming course.

Introduction

Specification and continuous assessment of learning outcomes and competencies have become a central focus in undergraduate and postgraduate engineering and business education. In order for a program to be accredited, the Accreditation Board for Engineering and Technology (ABET), requires that it has defined student outcomes and an effective process for the periodic review and revision of these student outcomes. Furthermore, it requires that the program regularly uses appropriate, documented processes for assessing and evaluating the extent to which student outcomes are being attained (ABET 2019). In order to assess learning outcomes, institutions have defined program learning outcomes at different levels of granularity so that higher-level program learning outcomes can be refined into course-specific learning outcomes or competencies. The competencies are then measured in the individual course assessments. An aggregation of these measures provides valuable input for continuous improvement of a program. This approach has been adopted by a number of institutions (Larson et al. 2012; Wang et al. 2008) mainly for satisfying accreditation requirements such as for ABET (Anwar et al. 2012; Batterman et al. 2011; Burge et al. 2010).

Although these approaches provide a valuable mechanism for a program's continuous improvement, in many cases, the learning outcomes and competencies are not fully leveraged when designing and delivering content or when giving feedback to students in the context of a specific course within the program. One reason for this is the lack of a formal framework outlining how competencies can be used during the life cycle of a course. In order to address this, the authors developed a Course Life Cycle and Competency (CLCC) framework to show how competencies can be used during the various life cycle phases of a course (Shankararaman et al. 2015).

Researchers have addressed the importance of self-assessment of student performance and its benefits in enhancing student motivation and achievement (Mcmillan & Hearn 2008). An early implementation of the CLCC framework in an Information Systems core course (Ducrot et al. 2014) shows how the competencies can be used across the life-cycle of a course namely content design, assessment design, content delivery &

assessment, assessment feedback, and content review. However, this implementation lacked the capability to provide feedback to instructors on each individual students' competency acquisition and also did not provide any feedback to students on their competency acquisition. Based on this gap, we address the following research question (RQ):

How can we provide better visual feedback to both instructor and students in terms of competency acquisition through the use of data visualization techniques?

By addressing this research question, we make three contributions. First, we identify and analyse the main arguments for competency-based learning. To do so, we review relevant literature from different outlets and more specifically, address this need within the context of the CLCC framework. Second, we propose and discuss the architecture for a visual analytics tool, Competency Analytics Systems (CAS) that enhances the CLCC Framework and helps to provide feedback to instructors on both the cohort and individual student's competency acquisition rate as well as provide personalized dashboard to each student on his or her competency acquisition for a specific course. Finally, we discuss the lessons learnt through the implementation of CAS in an introductory programming course and also present the evaluation of CAS from both the instructor and student perspective.

We adopt the first five phases of design science methodology (DSRM) proposed by (Peffers et al. 2008). These are, define problem and motivation (Phase 1), define objectives of the solution (Phase 2), design the solution (Phase 3), demonstrate the solution (Phase 4), and evaluate the solution (Phase 5) (Venable et al. 2017). We apply this methodology with the key principle of producing an artefact to address the problem of providing competency feedback to instructors and students.

The paper is structured following the first five phases of DSRM. In the next section we address the first and second phases through conducting a review of other related works in the areas of competency-based learning and assessment, and briefly describe the CLCC Framework, its current drawbacks, and establish the need for a Competency Analytics System (CAS). In the subsequent sections, we address the third phase by describing the functionality of the Competency Analytics System (CAS), followed by fourth phase through demonstrating an implementation of CAS in a first-year programming course, and fifth phase through an evaluation of the effectiveness of CAS. The final section summarizes the conclusions from our work and proposes some future work.

Related Work

Competency Based Learning and Assessment

Many higher education institutions have clearly defined learning outcomes for the program, and competencies for specific courses within the program (Villalobos et al. 2011; Lister et al. 2012). For a detailed review of the use of the competency concept in various educational and professional development contexts, the reader may refer to (Heikki 2018). Some have also gone further and developed frameworks to successfully leverage the learning outcomes and competencies in a systematic way when designing, delivering or revising a course within the program (Shankararaman et al. 2015; Ducrot et al. 2014; Tovar et al. 2009; Baumgartner et al. 2013). The more recent curriculum frameworks such as the CC2020 (Computing Curricula 2020; see https://cc2020.nsparc.msstate.edu/) and IS2020 (Information Systems Curricula 2020; see https://is2020.org) projects have also chosen the competency-based approach as its underlying conceptual foundation for defining curriculum.

Assessment is a crucial component of learning. Hence having defined learning outcomes and competencies, the next step is to define assessments and then to map student performance in these assessments to competencies. For example, the Course Life-Cycle Competency (CLCC) framework developed at the School of Information Systems provides a systematic approach to assess competencies and then uses the results of this assessment to give valuable feedback to both students and instructors teaching the course (Shankararaman et al. 2015; Ducrot et al. 2014). Tovar and Soto provide a framework, where they assess basic competencies that high school students must have, before they can embark on a Computer Engineering program (Tovar et al. 2009). Here the emphasis is on identifying whether the students have the necessary pre-requisite competencies before starting the program. Bekki et al., propose a modified-mastery based learning approach that uses a finite cycle of formative assessments and feedback to demonstrate mastery of the competencies for the course (Bekki et al. 2012). This is achieved through the use of three types of assignments; "evidence assignments", which provide evidence of the students' attempt to learn the topics; "competency assignments", which assess the mastery of a competency; and "enrichment assignments", which present challenges beyond what is covered in the course material and help extend students' understanding of the related topics.

With more and more emphasis on online learning for higher education, e-assessment is also increasingly becoming important. Sitthisak et al., present a system for automatically generating questions from a competency framework, based on question templates, criteria for effective questions, and the instructional content and ability matrix (Sitthisak et al. 2008). Ilhai et al., show how a competency based assessment can be extended to online learning environments using assessment grid and feedback (Ilhai et al. 2013).

Course Life-Cycle Competency (CLCC) Framework

Although there has been a lot of work in developing competency frameworks for a program's continuous improvement, in many cases, the learning outcomes and competencies are not fully leveraged when designing and delivering content or when giving feedback to students in the context of a specific course within the program. In order to address this gap, at the School of Information Systems, the authors developed a Course Life Cycle and Competency (CLCC) framework to show how competencies can be used during the various life cycle phases of a course. This framework consists of five phases, namely content design, assessment design, content delivery & assessment, assessment feedback, and content review. In actual practice, many of these phases are highly iterative, involving a lot of small iterations. For a more detailed explanation and application of these phases, the reader may refer to (Shankararaman et al. 2015). The research work presented in this paper is related to the assessment feedback and content review phases of CLCC.

Need for a Competency Analytics System

Following are some of the shortcomings of the current CLCC Framework implementation (Shankararaman et al. 2015). During the Competency Feedback Phase:

- The faculty is unable to ascertain the competency acquisition for each student in terms of what competency have been acquired and those that have not been acquired
- The individual student has very little visibility regarding his or her competency acquisition other than marks he or she scored for a specific question

During the Content Review Phase:

- The instructor is only focused on content review and modifications to address competencies that were not acquired across the entire cohort. There is no visibility to fine tune and determine additional content that may be required for specific students based on their competency acquisition and thus "close the learning loop".

The current research work reported in this paper, through the development of the Competency Analytics System (CAS), aims to address these shortcomings. CAS is an online analytical tool that enables instructors to get clear insight on students' competency acquisition rate after each assessment and to provide targeted and timely feedback to students. CAS also enables students to visualise, after each assessment, a personalised competency dashboard that shows the extent to which the relevant course competencies have been acquired by an individual student and how it compares with respect to the cohort.

Competency Analytics System (CAS)

Functional Architecture of CAS

The system enables the instructor to get a clear insight on the student competency acquisition rate after each assessment or at the end of the course and to provide targeted and timely feedback to their students, which contributes to improving the teaching and learning experience of the students. The system enables individual students to visualize their competency acquisition for specific assessments and for the overall course.

CAS has two functionality modules:

- The Data Acquisition Module (DAC) that allows the instructor to enter all the necessary information related to a course, students and assessments.
- The Visualisation Module (VIS) that the CAS system computes and generates, to provide insights to instructor and students on competencies acquisition.

Data Acquisition Module (DAC)

The Data Acquisition Module helps to capture the following information that is needed to perform further analysis and to provide insightful visualizations.

Course Details: The instructor has to first enter data related to the course he/she is going to teach such as course code, course name, academic year and semester, etc.

Course Competencies: Once course details are captured, the instructor then has to enter the list of competencies that the students are required to acquire for the course. For efficiency, the system also accepts a pre-filled Microsoft Excel file which the instructor can upload. The required data is the competency code (such as C1, C2 etc.), the competency description (Ability to...), the week number when the related topic will be taught to students etc.

Student Data: The instructor next provides the list of students attending the course. A Microsoft Excel template file provides the format of the data required by the system. It includes the student name, student ID, section and school, which can be extracted directly from the school Learning Management System (LMS) and uploaded directly into CAS.

Assessment Details: The competencies are assessed through in-course assessments, the details of these assessments are entered into CAS such as the assessment name and the week where the assessment will be given to students (for example, Quiz 1 in week 4). The instructor can also upload the assessment paper into CAS as a pdf or Microsoft Word document that can be referred to later during the analysis of the reports generated by the system. Additionally, the instructor has to provide some details about the various questions of the assessment (such as questions name, total number of marks for the question as well as a threshold value). The threshold value will be used by the CAS system to decide if the competencies tested in that question have been acquired or not. For example, if a question is out of 5 marks, the instructor may decide, for example depending on the difficulty of the question, that students with a score above 3.5 have grasped most of the important concepts tested in the question whereas below 3.5 they have missed some of them. Thus 3.5 will be set as the competency threshold value for the question.

Assessment to Competencies Mapping: Each assessment is mapped to one or more competencies, which is referred to as “Competency Linkage” or “Competency Mapping”. This is achieved by mapping each question within the assessment to one or more competencies. This could be a laborious task, hence to simplify the entry process, CAS provides an instructor friendly interface, requiring the instructor to tick the cell which is at the intersection of a competency (horizontally) and a question (vertically) in the competency matrix generated by the CAS system.

Assessment Results: Finally, in order to calculate the competency acquisition rate, the instructor needs to enter in the CAS system the students’ scores for each assessment. The CAS system provides a Microsoft Excel template pre-populated with the data entered by the instructor such as students’ details, questions names and their respective total number of marks. The instructor needs only to fill-in the scores that each student got for each question.

Visualization Module (VIS)

The CAS system generates visualisations that can be very insightful for instructor as well as for students. For illustration purposes we will choose the data of the OOAD (Object Oriented Application Development) course that had 238 students (6 sections of about 40 students) and we will choose the first assessment that was a quiz given in class in week 4.

Visualisations for Instructor: The CAS system generates three competency reports for Instructor namely Questions Analysis, Cohort Competencies Analysis and Individual Student Competencies Analysis.

Questions Analysis: The first competency report is an analysis of the competency acquisition at questions level. For each question, the CAS system determines the percentage of students who passed that question meaning the percentage of students who scored above the threshold, set by the instructor for that question. If more than 50% of the students passed this question, the system places a green tick next to the question name, otherwise a red cross. So, at a glance, the instructor can detect all the questions with a red cross, meaning all the questions where students failed to acquire the corresponding competencies.

In Figure 1, the question Q1 C is marked with a green tick because 63% of the students passed this question whereas the question Q2 A is marked with a red cross because only 12% of the students passed this question. The instructor can then refer back to the question paper in class and walk through the solution for the question Q2 A to clarify the mistakes made in the quiz.

At this stage, the instructor knows which competencies are involved in each question but does not know how well the individual competencies have been acquired by students. For example, Q2A tests competencies C12 and C17 and 88% of the students failed this question. But one does not know if it is because of C12 or C17 or both. Similarly, if we look at Q1C (testing C3 and C17), 63% of the students passed this question, therefore acquired C3 and C17. However, when comparing Q2A and Q1C one is unable to say much about the acquisition of C17.

So, this view is very useful for the instructor in getting a good insight on the success or failure of each question asked in the test but not on the extent to which each individual competency is acquired by students. In order to answer this, the instructor has to look at the second and third views generated by CAS and which are called the Cohort Competencies view and Student Competencies view respectively.

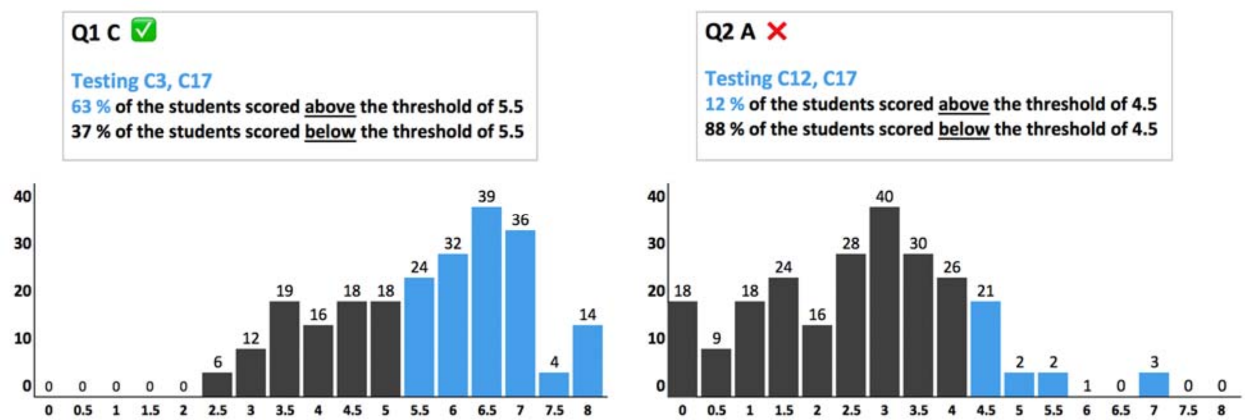

Figure 1 Question Analysis Visualization

Cohort Competencies Analysis: The second view generated by the CAS system is a Cohort Competency Heatmap allowing the instructor to visualise the competencies acquisition rate at the cohort level. A mathematical model has been developed in the CAS system to calculate the percentage of students who have acquired a particular competency.

The Cohort Competency Heatmap is a two-dimension table where the cells represent the competencies that the students are supposed to acquire at the end of the course, namely C1 to C27.

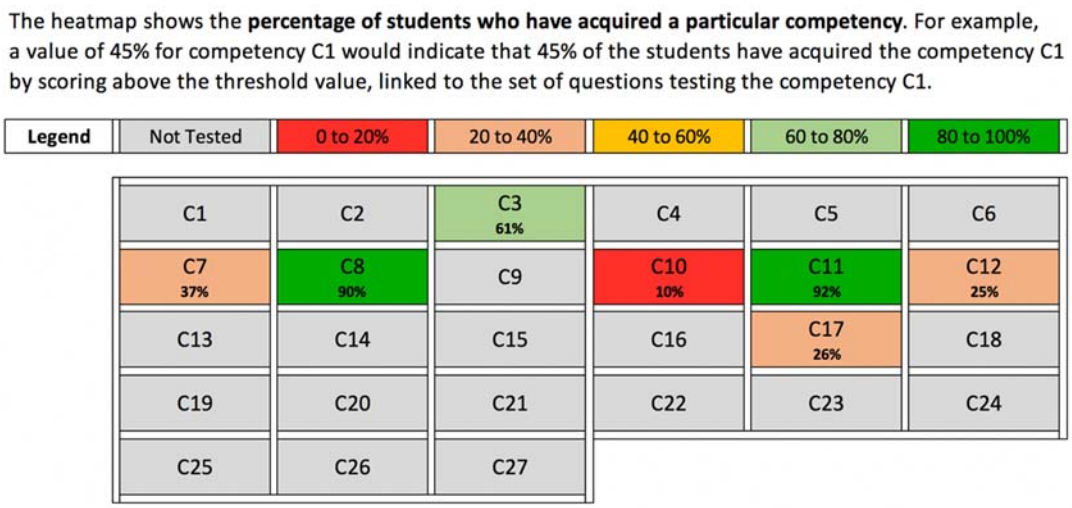

Figure 2 Cohort Competency Analysis Visualization

The cells in colour are the cells related to the competencies tested in this assessment (Quiz 1).

Each colour of the cell has a meaning related to competency acquisition, as shown below:

Red: Between 0 and 20% of the students acquired that competency; Maroon: Between 20 and 40% of the students acquired that competency; Orange: Between 40 and 60% of the students acquired that competency; Light green: Between 60 and 80% of the students acquired that competency; Dark Green: Between 80 and 100% of the students acquired that competency.

The percentage in each cell represents the percentage of the students in the cohort who have acquired the corresponding competency.

Individual Student Competencies Analysis: The third view generated by the CAS system is a Student Competency Heatmap allowing the instructor to visualise the competencies acquisition rate for each student. The mathematical model, developed in the CAS system, calculates for each student and each competency tested in the assessment, the corresponding competency acquisition rate.

Section	Student	ID	C3	C7	C8	C10	C11	C12	C17	Average Competency
MAR (Minimum Average Ratio for acquiring competency)			69%	75%	68%	67%	75%	63%	65%	
SAR (Score Average Ratio) performed by the cohort			70%	59%	83%	17%	90%	47%	54%	
G3	Student 13	student_13.2018	79%	38%	36%	0%	50%	19%	59%	**40%**
G1	Student 2	student_2.2018	87%	75%	82%	0%	75%	19%	62%	**57%**
G1	Student 85	student_85.2018	51%	50%	68%	0%	75%	39%	39%	**46%**
G1	Student 8	student_8.2018	76%	75%	86%	50%	100%	43%	52%	**69%**
G1	Student 53	student_53.2018	40%	63%	86%	0%	100%	50%	45%	**55%**
G1	Student 67	student_67.2017	64%	63%	86%	0%	100%	67%	61%	**63%**
G1	Student 98	student_98.2018	82%	50%	100%	100%	100%	56%	62%	**79%**
G1	Student 125	student_125.2017	53%	75%	100%	0%	100%	29%	39%	**57%**
G1	Student 35	student_35.2018	76%	0%	86%	0%	100%	43%	56%	**51%**
G1	Student 42	student_42.2018	87%	63%	82%	50%	75%	39%	59%	**65%**
G1	Student 88	student_88.2018	81%	75%	68%	0%	75%	47%	62%	**58%**

Figure 3 Individual Student Competency Analysis Visualization

Using Figure 3, the instructor can get a clear sense of the strengths and weaknesses of each student. For example, student 98 is very strong in competency C8, C10 and C11 because the corresponding acquisition rate is 100% whereas the competencies C7, C12 and C17 are respectively acquired at a rate of 50%, 56% and 62%. In average that student acquired 79% of the competencies tested in this assessment (which is shown in the last column).

Visualisations for Students: This view shown in Figure 4, generated by the CAS system, is a personalised dashboard allowing each student to visualise his/her own competency acquisition rate. The personalised dashboard comprises a set of horizontal bars and each bar is linked to the acquisition of a particular competency. Each horizontal bar is divided into four quarters corresponding from left to right and refers to the competency levels: Not Acquired, Partially Acquired, Acquired and Mastered.

Each colour of the bar has a meaning related to competency acquisition as below:

Red: The bar extends up to the first quarter indicating the competency is Not Acquired; Orange: The bar extends up to the second quarter indicating the competency is Partially Acquired; Light Green: The bar extends up to the third quarter indicating the competency is Acquired; Dark Green: The bar extends up to the fourth quarter indicating the competency is Mastered; Grey: Represents the competency acquisition rate by the cohort.

Additionally, if the length of the bar is either red or orange, the competency is marked with a red cross and is deemed as not acquired. Otherwise if the colour of the bar is either light green or dark green, then the competency is marked with a green tick, and is deemed as acquired.

This dashboard, allows each student to visualise three important aspects related to competency acquisition:

Whether a competency is considered as acquired or not by checking respectively the "green tick" or the "red cross" located next to the competency name.

The extent to which each competency tested in the assessment is acquired by the student by checking the length and the colour of bar (full bar means fully acquired).

Where the student stands with respect to the cohort, by comparing, for each competency his or her own colour bar with the grey bar.

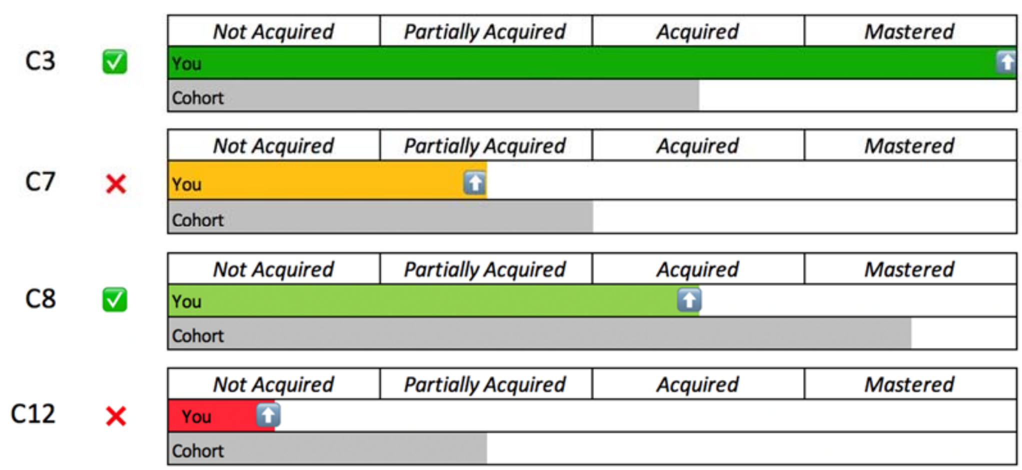

Figure 4 Personalized Student Dashboard

Case Study on Implementing CAS

In this section, we describe the implementation of CAS for one of the Introduction to Programming courses within the BSc (Information Systems) Program.

Course Details

Following are some of the shortcomings of the current CLCC Framework implementation (Shankararaman et al. 2015). During the Competency Feedback Phase:

Introduction to Programming (IS111) is a core course delivered in the first semester of the first academic year at the School of Information Systems. This course focuses on the fundamental building blocks of a software application. Students learn programming fundamentals. As a part of the course, students are required to design, code, and test software applications using the Python programming language.

Each year, around 400 students take the Introduction to Programming course and are divided into ten sections of about 40 students each. However, the pilot implementation of CAS system was used only in four sections, around 172 students. The course extends over a 14 weeks term and each week there is a 3-hour session which includes lectures and labs. Each section is managed by two instructors and two teaching assistants (TAs). The entire teaching team is present in all classes allowing efficient support during class exercises and lab sessions as well as consultations. Following is a sample competency (C3) for this course.

- C3: Perform efficient string manipulation (concatenation, slicing, traversing a string using for-loop and range function etc.).

CAS Implementation Process

For the sake of brevity, without going through every phase of the Course Life-Cycle Competency Framework, we will briefly describe the use of CAS in this course, focusing on the Content Delivery & Assessment, and Assessment Feedback phases.

During Week 1, the explanation of the CAS system and its role in the student learning experience along with emphasis on the importance of competencies and their relationship to assessments helps to create a "competency oriented" mind-set amongst the students and they begin to see the value of doing the course in terms of "what they can do on completing the course" rather than just learning few topics.

A few weeks before an assessment, the general practice in the past, is to inform the students about the list of topics that will be tested in the assessment.

With competency-based learning, the emphasis in the assessment is shifted from topics to testing students on "specific competencies", which is applying what they learnt. For example, in topic-based approach, the student is asked to learn a topic such as "handling strings", whereas using competencies the emphasis is on acquiring specific competencies such as "Perform efficient string manipulation (concatenation, slicing, traversing a string using for-loop and range function)". This creates a sharper focus on what the student needs to know before taking the assessment. This helps the students prepare for the assessment by ensuring "what they can do with the knowledge and skills acquired" rather than attempting to merely learn the different topics taught in the course.

For learning through assessments to be effective, prompt feedback needs to be given. This means that during the week of assessment the instructors have to mark the student answers by the end of the week and also conduct a competency acquisition analysis. CAS provides very useful insights through the Question and Heatmap analysis visualizations to help accelerate this process. Additionally, CAS also helps the course team to target remedial content based on this analysis. It is also very important to give immediate feedback to students through mailing their personalized competency dashboard a few days after the assessment. This will help students to focus on their areas of weakness.

During the session after the assessment, the Questions and Heatmap analysis walkthrough conducted by the instructor helps the students to gain a better understanding of their weaknesses and strengths. Conducting a walkthrough of the remedial materials that focuses on competencies that majority of the cohort failed to acquire, will help the students re-learn those specific competencies. During this session, the students can also compare their personal dashboard and raise questions related to weak competencies identified in their dashboard.

Evaluation of CAS

In order to ascertain the effectiveness of the CAS and the competency-based learning approach, student evaluation survey was conducted along with focused group discussion with the instructors.

Student Evaluation Survey: The evaluation survey comprised six quantitative questions and one qualitative question. Out of the 172 students who participated in the pilot implementation, 161 completed the evaluation survey. Some conclusions from the survey data follow:

- About 85% of the students "strongly agreed" and "agreed" that the Question Analysis allowed them to efficiently pinpoint the questions where the cohort did not perform well and also helped to provide timely feedback by instructors to the entire cohort for those questions.
- About 80% of the students "strongly agreed" and "agreed" that the Competency Heat Map helped them to identify at a glance the competencies that were not yet acquired by the entire cohort in the given the assessment.
- About 75% of the students "strongly agreed" and "agreed" that the Personalised Dashboard helped them to clearly identify the extent to which they have acquired or not acquired the competencies tested in the assessment.
- About 70% of the students "strongly agreed" and "agreed" that the Personalized Dashboard motivated them to catch up on the competencies not yet acquired by them because they are clearly highlighted in the visualization and additionally can be compared with the rest of the cohort.
- About 72% of the students "strongly agreed" and "agreed" that the different reports generated by CAS were very useful in supporting their learning as they helped them to identify at a glance those competencies not yet acquired and to focus attention on clarifying misconceptions by referring back to the corresponding questions.

Instructor Feedback: Following is the comment based on a focused interview session with one of the instructors: "Overall, I found the CAS system very effective in helping faculty understand students' progress, strengths and weaknesses. This helps us adjust our teaching method and revise our teaching materials to better suit the students' needs. I'd recommend the system to other colleagues, both within and outside of School of Information Systems, to use".

A key limitation of our work is that the CAS system was used only within one course. To have a more holistic understanding of its effectiveness and drawbacks, it has to be used across multiple courses in the curriculum.

Conclusion and Future Work

In this paper, we presented the functional design and implementation of a visual analytics tool, Competency Analytics System (CAS) that uses a competency framework, for supporting the analysis of assessment results and providing personalized feedback to students. Through this tool, we enhanced the "Assessment Feedback" phase of the Course Life-Cycle and Competency Framework which we had developed in an earlier research work. The evaluation of CAS through its implementation in the "Introduction to Programming" course identified a number of benefits including enhancing a student's ability to clearly identify the extent to which he or she has acquired or not acquired the competencies tested in an assessment; motivating students to catch up on the competencies not yet acquired; and, enhancing the instructor's ability to more effectively pinpoint questions not well performed by the students and provide timely feedback to the class on those questions. In its present form, CAS only highlights the competency that are acquired not acquired but does not provide any advice to students on how this competency acquisition can be achieved. Hence, further work will be focused on providing personalized remedial content for each individual student based on his/her competency acquisition map.

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REFERENCES

ABET. 2019. Accreditation policy and procedure manual (https://www.abet.org/accreditation/).

Anwar, M. A., Ahmed, N., & Ameen, A. M. A. 2012. An outcome-based assessment and improvement system. Contemporary issues. Education Research, 5(4), pp. 279–293.

Villalobos, J., Gonzalez, O., Jimenez, C and Rueda, F. 2011. Curricula design model for designing and evaluating systems and computing engineering programs, 41st ASEE/IEEE Frontiers in Education Conference, pp. S4E-1-S4E-7.

Batterman, S. A., Martins, A. G., Antunes, C. H., Freire, F., & Da Silva, M. G. 2011. Development and application of competencies for graduate programs in energy and sustainability. Journal of Professional Issues in Engineering Education & Practice. 137(4), pp. 198–207.

Baumgartner, I. and Shankararaman, Venky. 2013. Actively linking learning outcomes and competencies to course design and delivery: experiences from an undergraduate Information Systems program in Singapore. Proceedings of IEEE Global Engineering Education Conference (EDUCON), Berlin, Germany, pp. 238-246.

Bekki, J.M., Dalrymple, O. and Butler, C.S. 2012. A mastery-based learning approach for undergraduate engineering programs. Proceedings of the IEEE Frontiers in Education Conference (FIE).

Burge, L.L. and Leach, R.J. 2010. An advanced assessment tool and process. *Proceedings of the 41st ACM technical symposium on computer science education (SIGCSE'10)*, Milwaukee, Wisconsin, USA.

Ducrot, J and Shankararaman, Venky. 2014. Measuring student performance and providing feedback using competency framework. IEEE 6th International Conference on Engineering Education, Kuala Lumpur, Malaysia.

Ilahi, M., Belcadhi, L.C. and Braham, R. 2013. Competence web-based assessment for lifelong learning. Proceedings of the First International Conference on Technological Ecosystem for Enhancing Multiculturality (TEEM '13), Francisco José García-Peñalvo (Ed.). ACM, New York, NY, USA, pp. 541-5.

Larson, S., and Harrington, M.C.R. 2012. BA survey of ABET accredited information systems undergraduate programs in the USA. Proceedings of the Information Systems Educators Conference. Vol.29, No 1961, New Orleans Louisiana, USA.

Lister, R., et al. 2012. Toward a shared understanding of competency in programming: An invitation to the BABELnot project. Proceedings of the Fourteenth Australasian Computing Education Conference (ACE2012), Melbourne, Australia, pp. 53-60.

Mcmillan, James H. and Jessica M. Hearn. 2008. Student Self-Assessment: The Key to Stronger Student Motivation and Higher Achievement. Educational Horizons. Vol. 87, No 1, pp. 40-49.

Peffers, K., Tuunanen, T., Rothenberger, M.A. and Chatterjee, S. (2008). A Design Science Research Methodology for Information Systems Research. Journal of Management Information Systems, vol. 24 no. 3, pp. 45–77.

Shankararaman, Venky and Ducrot, J. 2015. Leveraging Competency Framework to Improve Teaching and Learning: A Methodological Approach. Journal of Education and Information Technologies. Springer, Vol. 20, No 1, March 2015, pp. 1-29.

Sitthisak, O., Gilbert, L. and Davis, H.C. 2008. Deriving E-Assessment from a Competency Model. IEEE International Conference on Advanced Learning Technologies (ICALT 2008), pp. 327-329.

Topi, Heikki, 2018. "Using Competencies for Specifying Outcome Expectations for Degree Programs in Computing: Lessons Learned from other Disciplines. Proceedings of the 2018 AIS SIGED International Conference on Information Systems Education and Research.

Tovar, E and Soto, O. 2009. Are new coming computer engineering students well prepared to begin future studies programs based on competences in the European Higher Education Area? Proceedings of the 39th IEEE Frontiers in Education Conference.

Venable, John R., Pries-Heje, Jan., and Baskerville, Richard L. 2017. "Choosing a Design Science Research Methodology" (2017). ACIS 2017 Proceedings.

Wang, T., Schwartz, D., & Lingard, R. 2008. Assessing student learning in software engineering. Journal of Computing Sciences in Colleges. Vol. 6, pp. 239–248.