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Framework for Improving Engineering Representational Literacy by Using Pen-based Computing*

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Representations such as free-body and circuit diagrams are central to engineering practice and proficiency. Developing and using representations is an essential skill that engineering students need to learn. In this paper we present a case study of the use of pen-based computing to improve representational literacy through dynamic knowledge construction and management activities among engineering students. We use case study data to develop a framework that explains how students can learn to construct and manage knowledge in a participatory learning environment that allows the creation, sharing, recording, and reflection of digital representations. Specifically, we propose that pen-based computing can enable efficient use of representational practices by providing a mechanism to externalize representations through visualization; by supporting awareness and feedback within lectures, and by allowing the co-construction of shared representations among faculty and students. Our framework emphasizes the contextually embedded role of technology in a learning environment and has implications for implementing technology in conjunction with curriculum development to provide meaningful learning experiences.

Keywords: representational literacy; participatory learning; pen-based computing

1. Introduction

Representations are cognitive artifacts that play an important role in facilitating complex problem solving by making humans more intelligible [1]. The engineering profession—including its teaching, learning, and practice—is centered on the creation and transformation of representations [2]. Proficiency with representations consists not only of the ability to create them, but to be able to convert them into other representations; in other words, it requires knowledge construction. Typically, a problem statement in a textual form is translated into a sketch that visually articulates the problem and these sketches are in turn translated into mathematical formulae [2]. We term proficiency with this aspect of knowledge construction in engineering as representational literacy. Within engineering, representational literacy is particularly valuable in relation to visual representations given their value in translation across text and numbers. Examples of the diverse range of visual representations in engineering include free body diagrams, digital logic gate figures, flowcharts, chemical process flow models, energy gradient lines, and hydraulic gradient lines. Since the ability to work with these representations is central to engineering practice, students start to take courses in sketching, flowcharting, drawing orthographic projections of objects, and using CAD drawings from their first year onwards.

The teaching of representational literacy has been a core challenge of engineering education and several teaching models have been appropriated. Yet, the common teaching method still consists of a teacher creating a representation while explaining her/his actions and then asking the students to repeat the process. Assessment of student work usually follows this exercise and students are made aware of their mistakes. Overall, repetitive practice is the primary solution to learning to use representations. Until recently this entire exercise was done using a whiteboard or on paper [3], but now engineering practice and education have turned to digital tools and infrastructure and therefore the digital creation and manipulation of representations has started to take roots in teaching practice. Yet, challenges with teaching representational literacy persist as the use of digital tools is similar to a pen-and-paper-based teaching culture. So, even though the drawing tools have changed, technology has not leveraged interactivity to improve the teaching process. The problem with the current teaching method is that although the creation of representations can be learned through repetitive practice it does not necessarily ensure the assimilation of the cognitive dimensions of representation and its translation across representational type. Therefore, representational literacy is not just fluency with the use of representations but their appropriate use within a specific distributed cognition or activity system. Among other things, the development of this proficiency requires externalization of representations and their sharing with knowledgeable others. It is this crux of the problem that can be

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addressed through the use of technology particularly through visual co-construction and management of representations. The visual externalization of representations helps people construct knowledge, organize information, and communicate learning with others

To develop proficiency through the use of technology though, it is important to view technology as a cognitive artifact which facilitates knowing by becoming a part of the overall cognitive system [4]. This understanding then provides a pathway into the study of representations which is to observe their role as part of a distributed cognitive system. The externalization of representations affords us the ability to observe them and to study how they influence the course of actions taken by participants in a cognitive system [5].

Participants generate and interact with multiple representations where the external representations are produced to express a solution and also to interpret the situation and these representations project meanings that are gradually revised and confirmed. It is in this representational ecosystem that the visualization plays a central role as they provide a mechanism to study both the social and the artifactual [6]. But even though the importance of externalization of representations is well established [7], it remains to be explored how representational activities should be structured for knowledge construction and management.

Guidance on this issue is provided by socio-cultural approaches to learning. Several decades of research on situated learning [8] and apprenticeship-based practices [9] has highlighted the role of social interaction and embedded nature of knowing in learning practices. This work has revealed the important role played by informal and peer learning, and by educational activities aligned with everyday life in the educational development of students. Socio-cultural learning theories, the learning in activity [10] perspective in particular, argue that guided participation in meaningful activities that entails engagement with a community of practice is critical for learning [11–12]. Enabling participation requires being attentive to the idea that "ability is part of the individual–environment transaction" [13]; in other words, students are and act intelligibly within a certain environment and, therefore, a primary aspect of supporting learning is to create environments that provide students with the ability to act and become learned. The specific theoretical underpinning for examining representations within the context of activities comes from the guided participation and participatory appropriation perspective proposed by Barbara Rogoff [12, 14] whose work focuses on informal learning settings to examine experiences, such as the progression of Girl Scouts as they become sophisticated cookie sales agents.

Rogoff [14] proposes three planes of socio-cultural activity: apprenticeship, guided participation, and participatory appropriation. Guided participation refers to a means of access to specific, community-valued practice that is organized by shared goals; most importantly, guided participation highlights the need to connect more knowledgeable members with novices and encourages members to adopt diverse roles, referents, and devices while developing an understanding for future contribution. Participatory appropriation refers to how individuals change through their participation. It is a personal process by which, through engagement in an activity, individuals change and handle a later situation in ways prepared by their own participation in the previous situation; that is, they construct new knowledge. Here, we use guided participation and participatory appropriation as the foundation for understanding the development of representational literacy through engaged knowledge construction and we use participatory learning to refer to both practices occurring in tandem. Given the paucity of research connecting knowledge construction and management within digital participatory learning environments the central research question guiding the study was how can information technology improve representational literacy among engineering students through knowledge construction and management activities in digital participatory environments? By exploring this research question we aimed to develop a guiding and explanatory framework.

2. Research study

2.1 Research setting

Data for this case study were collected at Virginia Tech, a large engineering school in Southeastern United States. The school offers one of the biggest engineering programs in the country and is recognized as a national leader in implementing technology enhanced learning into its curriculum. At the time of this study, all first-year engineering students (~1500 each year) were required to own a Tablet PC. A Tablet PC is a Windows-based laptop with pen-based computing capability built into the hardware. Tablets are used extensively in first-year engineering courses, particularly in an introductory course that presents an overview of engineering to students and also focuses on problem solving, introductory design concepts, engineering ethics, graphing and analysis of experimental data, and algorithm development supported by flowcharting. This course, Engineering Exploration, formed the setting where data were collected. The course is delivered as a combination of 50 minute lectures in a 150–300 seat classroom followed by a 90 minute hands-on workshop in a 32 seat classroom every week. Tablets were used in both lectures and workshops but with more regularity in the lectures. The choice of different settings allowed us to address their use across large and small group of users.

2.2 Technology used

As mentioned earlier, the primary technology used in the study setting was a pen-based technology, Tablet PC. Pen-based computing, of which tablet PCs are a currently popular form, has a long history in the computing field (since 1968). Tablet PCs are unique since they combine high computing power with direct pen-based input and unlike smaller devices, such as PDAs, they provide larger screen space as well. This combination provides users with the affordance to engage in several design activities such as sketching and ideation directly in digital medium, allowing them to easily store, manipulate, and share their creations. The ability to be able to manipulate and share creations digitally takes Tablets beyond what could be done with paper and pen, and people sitting around a table. Therefore, pen-based computing is increasingly being used in higher education and has been shown to have great potential for science and engineering subjects given the extensive use of representations in these areas [15–16].

To maximize the utility of a Tablet PC for teaching, we deployed an interactive software solution called DyKnow^{TM}. DyKnow^{TM} supports collaborative note taking and interaction among different stakeholders such as students and instructors. DyKnow^{TM} uses a client-server architecture where different computers are connected to a central server that 'serves' the software to the subscribers. Once a user logs into the software they have different options based on the privileges associated with the account. Once the students and faculty are logged into the same session, the faculty can share slides with them; these are referred to as panels in DyKnow^{TM}. Instructors have the permission to start and stop a session and can control many of the options such as sharing panels with students, collecting panels from students, looking at the list of participants, taking attendance, and being able to initiate chat. Student participants, on the other hand, have limited privileges to initiate interaction within DyKnow^{TM} but can participate by observing dynamic representations made by the instructor and making representations of their own. While the primary control of the interaction rests with the instructor, he/she has an option to grant control to students to encourage collaborative learning.

2.3 Methods and data collection

To understand the role of representations and their visual externalization within the engineering class, we collected data using several methods. The data come from several surveys that were conducted in-class (N=100 to 250) as well as online surveys conducted at the end of the course (class exit surveys, see Appendix A) (N=525). Furthermore, assessments of technology and course materials were also done through separate surveys and focus groups with students. Data were collected over two semesters Fall 2007 and Spring 2008. The survey consisted of 28 items that asked about overall experiences with the class and with the use of technology. Survey items are discussed in the findings section. In addition, archival data also consisted of instructor notes and digital artifacts that were collected from the students during the classes. These data formed a large corpus—hundreds of panels collected from students—and were analyzed to understand the nature of representations that were constructed and shared in the class.

The focus group data come from a single focus group conducted at the end of Spring 2008. The purpose of this focus group was to assess students' experiences with the technology in and outside the class. Focus groups are especially useful for collecting data that can lead to inductive models about behavior and functioning of tools since they allow participants to talk in depth about their own experiences and build on experiences of others by participating in a common discourse. To conduct the focus group, a protocol was designed with open-ended questions and messages meant to elicit responses from the participants [17]. Since the purpose of the focus group was to collect data in addition to large surveys and informal data collected throughout the semester, it was done with a small subset of students for a longer period. Four students from the Spring 2008 class participated for just over 75 minutes. Of this the moderator spent only five minutes directing the questions or the conversation and the participants spent the rest of the time talking about their experiences. The four students were planning to major in different disciplines including chemical engineering, aerospace engineering, and computer science. There were three men and one woman in the sample. The diversity of the group turned out to be particularly useful as students brought not only their common experiences to the table, but also their diverse perspectives, especially those related to the use of technology.

2.4 Data analysis

Given the mixed-method data collection, we analyzed the survey data first, followed by the analysis of archival data collected in the class. After this initial analysis a preliminary explanation of participatory learning using digital representations was developed and we used that understanding to create the focus group protocol as well as the next iteration of the survey. Subsequently, we analyzed the focus group data, survey data, and archival data to further develop the argument about participatory learning.

3. Findings

3.1 Student Use of technology

We first present findings about the attitude of students towards their use and acceptance of technology. When asked in an exit survey conducted at the end of the semester in Fall 2007 (N=525) if the use of technologies in the class "effectively contributed" to their learning, 148 (28%) students responded "Strongly agree" and 242 (45%) students said "Agree," indicating an overall positive response to the use of technology. The results to a question about their experience with using DyKnow^{TM} were similarly positive. When asked to respond to the survey item: "The DyKnow^{TM} software has been successful in making the classroom environment interactive and conducive to learning," student responses were as follows: Strongly Agree 70 (13%), Agree 251 (47%), Neutral 124 (23%), Disagree 62 (12%), and Strongly Disagree 28 (5%). In the same survey the students were asked for open-ended responses to "usefulness of Tablet PCs for in-class activities," and many responses pointed out the usefulness of DyKnow^{TM}, especially the ability to work with representations. Students enumerated different ways in which they found DyKnow^{TM} and pen-based computing useful and most of the responses were linked to the ability of the technology to support the creation and sharing of representations. For instance, students responded that:

- "I liked that we could make our own notes on the DyKnow^{TM} program during lecture."
- "Being interactive and allowing us to draw things that needed to be drawn and just give a different feel to the ordinary class lecture."
- "DyKnow^{TM}, being able to add my own input/ notes to the slides, having all my notes in one place, drawing designs."
- "DyKnow^{TM} was especially useful on the tablets because we could interact by writing our ideas and thoughts out on the tablet. It was easy to organize notes in class using OneNote, it helped to be able to write directly on the slides used in the lecture."
- "DyKnow^{TM} made it easier to follow a professor's lecture, draw right onto the program using your notes without all the paper mess."
- "The questions that we were to answer or illustrate an answer for & then were shown to the class—keeps people engaged during class."
- "I liked the ability to take notes on top of the lecture slides."
- "I thought the tablet was very useful when the instructor was trying to draw what his point was. The good part about having a tablet and DyKnow^{TM} was that we got to keep a copy and go back to it if we were confused."
- "Design, DyKnow^{TM} because I took my own notes as well as the notes written on the screen."
- "With DyKnow^{TM} it was useful for writing on the slides and taking notes for the lecture at the same time."
- "I think the tablet PC was very effective for the lecture class. Being able to use DyKnow^{TM} made the lecture class very effective and interesting."
- "Being able to draw diagrams, graphics, and representations of problems on my computer instead of having to use another source."

Overall, student responses indicated that the use of technology created a digital environment where students participated fluently and used digital representations extensively. The survey also indicated that although DyKnow^{TM} was conceived primarily as in-class software, students used the software while they were in other locations, which suggests that our approach is equally viable for teaching in non-class settings and can be easily transferred to an online setting. A course exit survey question indicated that ~15% of the students (N= 536) joined a lecture session from a remote location on one or more occasions. Students listed several reasons for using DyKnow^{TM} synchronously while they were not in the class, for instance, while they were sick or out of town for an emergency. The number of students across semesters increased with time and in a survey of students in Spring 2008, 30% of the students surveyed (N=49) responded that they had used DyKnow^{TM} from a remote location. Across the two semesters, Fall 2007 and Spring 2008, the percentage of students remotely logging in to the class doubled, indicating that the use of technology outside the class found quick acceptance.

To further explore students' use of technology, we analyzed the focus group data. Student responses regarding the use of technology were equally positive but students were more reflective in their assessment of the role of visualization of representations. All students reported that they found Tablet and DyKnow^{TM} software very useful and one participant elaborated, "I thought it was kind of cool when [the instructor] would go over something in class and break stuff down like he would draw arrows and be like this is what this is write an equation or something, that was good, or where he would put up stuff and derive something." He said that he wished that these occurrences were more common in the class but in a manner that they did not become a "crutch." He said this meant that technology should be embedded in a useful manner within the lecture and not used just for the sake of using it. Another participant said that he found the Tablet useful when he was stuck in the airport and he could use it to solve the problems using the writing feature and finish his homework and submit it. Students also suggested several changes to the technology as well as to the manner in which it was used in class. For instance, they suggested adding audio recording to DyKnow™ to make it more accessible; that is, they argued for additional forms of representations in addition to visuals. Overall, students emphasized that often when technology is used in classes, the pedagogic value of technology is often neglected.

The findings from the focus group highlighted the diverse nature of any large incoming class. Students had very different prior experiences with technology and this affected their use of technology within the class and for their homework and exam preparation. Given the diverse nature of the focus group it became clear to the moderator, and to the students, that they all came in with very different experiences and expectations with technology. Yet, all found the use of technology valuable to their learning experience. Having established the usefulness of technology from a student perspective and its range of uses in relation to digital representations, we now move towards a more analytical explanation of the role of digital representations and its relation to participatory learning and develop and present a framework.

3.2 Dynamic integration of knowledge construction and management with digital representations

As explained earlier, the term participatory learning combines Rogoff's [12, 14] conceptions of guided participation and participatory appropriation and represents the socio-cultural view of learning where students learn through participation in engaged environments with more knowledgeable others and this participation leads to changes in their identity as they become more expert. In figure 1, we provide our conception of the process by which representations enable participation in classes through the use of Tablet PCs and DyKnow™. This framework forms the basis of the discussion that follows. It is not meant to be exhaustive or represent a strict cyclical process. For instance, we recognize that sharing might often occur before creating and so on but the basic idea is that the four activities of creating, sharing, recording, and reflecting, are critical for learning within the activity system (Figure 1). These activities encapsulate both knowledge construction and knowledge management processes.

3.2.1 Creating representations (knowledge construction)

The primary advantage of using DyKnow™ on Tablet PCs is the ability to be able to create representations of different kinds on the panels (panels are slides or pages within DyKnow™). The ability to create representations that can be viewed dynamically by students helps eliminate the need of a whiteboard in the class and makes it easier

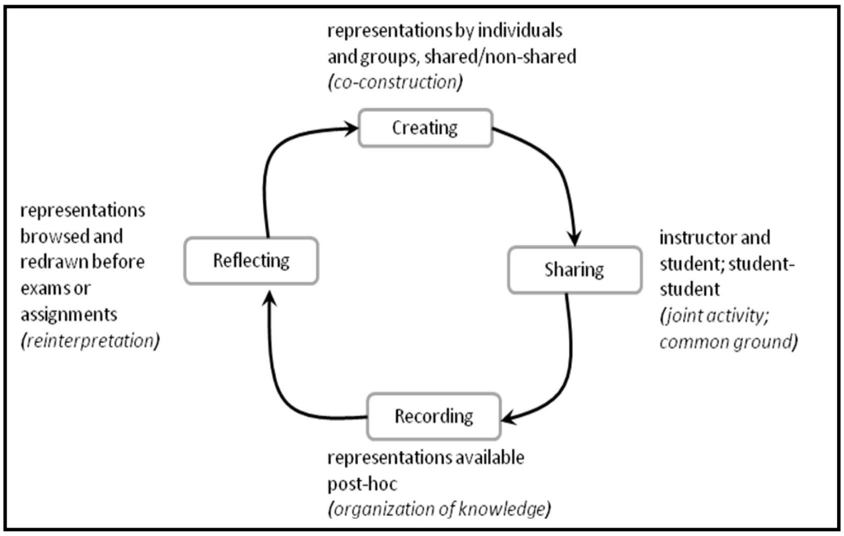

Fig. 1. Knowledge construction & management framework using digital representations.

to reach and interact with hundreds of students. Through this technology, students can get the representations directly on their computer and engage in knowledge construction [18]. In addition, DyKnow^{TM} allows students to add to the representation presented by the instructor by creating their own representations. Students can add text or graphics to comments made by their instructor on a particular panel. They can also take notes on a separate area about a panel. In this way the students become participants and co-creators in the knowledge construction process, creating a common foundation [19]. The ability for self-expression and co-creation of a representation is critical for student participation and learning [5]. "As individuals or groups work on problems, they may make drawings, write notes, or construct tables or equations. These representations help them keep track of ideas and inferences they have made and also serve to organize their continuing work" [20]. In the context of our class, representations were frequently in the form of creating problem solving diagrams, graphing numerical data, deriving equations, developing flowcharts for documenting algorithms, and highlighting block diagrams in a software called LabVIEW^{TM} to explain programming concepts.

The functionality to create representations was also supported in other ways through multiple kinds of annotation and pen tools. For instance, the instructors can prepare panels in advance by writing on them with a purple ink which is only visible to the instructor even when the panel is shared. By doing this the instructor can create elaborations on the panels but ask students to participate, by creating their representations and writing, rather than doing all the work for the students. Participants can use different colored inks for differentiating among the representations they are making. Instructors can use a flicker tool to highlight certain areas within the panels and draw the attention of the students. Of course, there is a functionality to highlight and erase the writing. Free hand annotation which allows for free hand sketching makes the creation of representations easier, flexible, similar to what students are used with pen and paper. Our in-class survey results show that the majority of students (70%, N=163) either "agree" or "strongly agree" with the statement that they like the ability to write on the panels. The students also like that the instructors can write on the panels (57%, N=75).

3.2.2 Sharing representations (knowledge construction and knowledge management)

In addition to creation, one of the primary participatory processes is the exchange or sharing of representations among the members of a group or community which not only lead to knowledge construction but also its communal management. Within DyKnow^{TM} the representations made by the instructor are of course shared with the students in real time. But more than that, the representations made by the students can be shared with the instructor and with other students as well. Through the "Panel Management" function, DyKnow^{TM} allows the instructor to pull panels from students. The instructor can pull the panels for a particular student (using their user-id as identification) or anonymously. In addition, the panels can be pulled randomly from among the class. These can be previewed and the instructor can then share them with the rest of the class (Fig. 2 & 3). This function creates visibility among the participants. In our class we used this functionality in several ways. We provided different kinds of panels— blank, partially filled—to the students and they were given the task to draw some representations on the panel. We then used the panel management functionality and shared the panels with the class. The answers or ideas provided by students ranged from nothing to very substantial representations. The students were engaged and we tried to do this as often as possi-

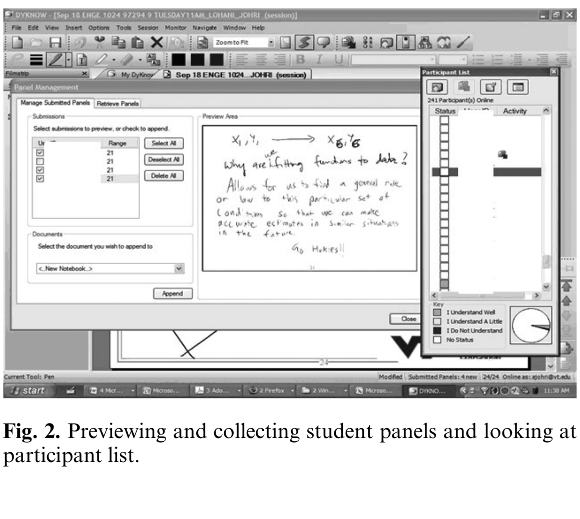

Fig. 2. Previewing and collecting student panels and looking at participant list.

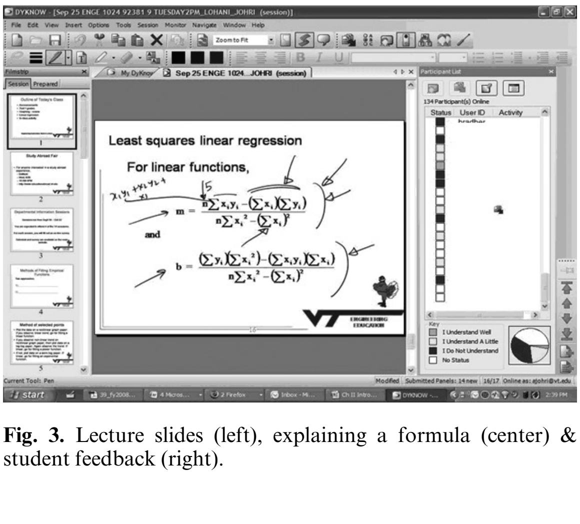

Fig. 3. Lecture slides (left), explaining a formula (center) & student feedback (right).

ble—every 10 minutes or so—to keep the students engaged.

In addition to the panels and representations on panels, DyKnow™ also supports additional representations that can be shared. DyKnow™ has a polling functionality where students can be polled and the results shared with them. In our class we used this in several different ways. One was to gauge students' prior knowledge, to get instant feedback about the class and the software, and to quiz them on multiple choice questions. Another representation allows the students to display to the instructor their status—how well they do or do not understand what is being taught. This shows up on the instructors screen as a pie chart with different colors and different colors for each student as well. This increases awareness and visibility within the activity system making it easier for the instructor to repeat a certain idea or example. One major limitation when technology is used for learning is that the use of gestures and facial expressions to advance communication and encourage joint activity is impeded [21] which makes it harder to create common ground. The use of DyKnow™ helped us overcome obstacle to a large extent by allowing for the formation of joint problem space [6] thereby facilitating representational learning.

Figure 4 shows an example of a panel that was shared with students (~180) to discuss a programming concept (i.e. Use of Case Structure) in LabVIEW™, the pie chart at the bottom right of this figure shows students' instant response about their understanding of the concepts being discussed by the instructor. One of the advantages of in-class exchanges is the number of responses, signifying interactions, which we can get from students. When we asked students to submit panels we got responses from all of them and then we could share back some of the panels with them. The ability to provide a public forum for individual effort is one of the advantages we are able to offer given the number of students in the class. This was also true for features such as "polling" and "voting." In our in-class survey, 50% (N=110) of the students either "agreed" or "strongly agreed" with the statement that they "like the sharing of panels in class."

3.2.3 Recording representations (knowledge management)

Another affordance of DyKnow™ is the ability to create a permanent record of the panels and representations thereby providing significant capability to manage knowledge. This works both statically and dynamically. As panels are passed from the instructor to the students they have the record of representations drawn by the instructor as well as what they drew themselves. They can later return to these panels and even 'play' them in the manner in which they were passed and drawn upon in the class. Recordings serve as organizational memory as well as provide a basis for building something on top of it. Unlike the process where something was written on the white board and then erased there are records here. Also, there is a transformation where rather than students copying what was on the board they get most of it and then can build on top of it. The presence of representations makes it possible for observational learning but also to be able to participate later on, more like a lurker. Representations can be used later to write upon and reinterpret. The

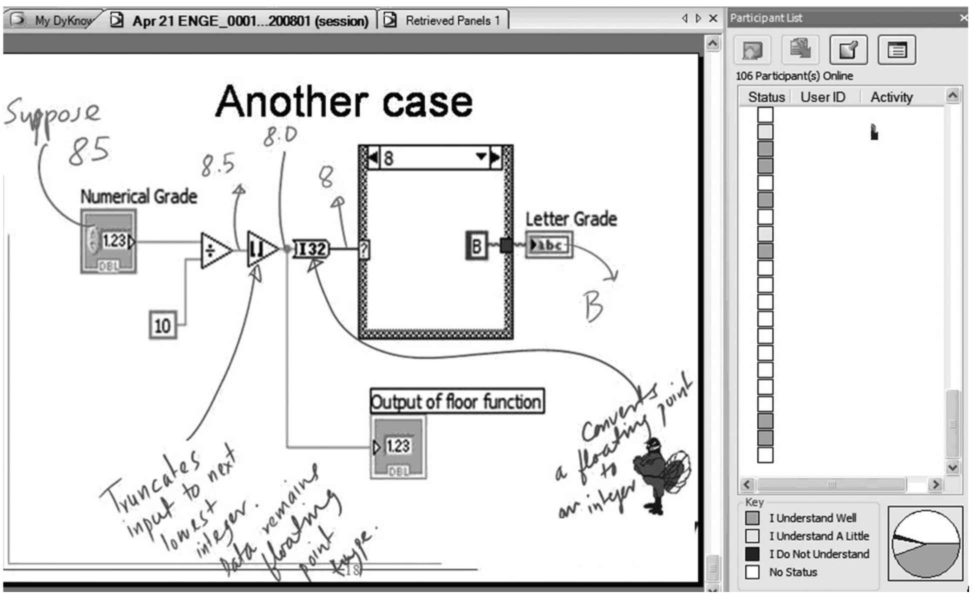

Fig. 4. Pie Chart displaying self-understanding by students.

recording of representations allows us to extend the learning environment beyond the lecture, as is usually the case. We forget that students' lives do not stop after the lecture and they participate in a number of networks of events and these representations often become a part of their conversation and interaction. Therefore, they are essential for organizing their knowledge and in the long term for building an organizational memory. In our survey students reported that they used the recordings of the lectures and the representations created therein to review for exams and for homework; the representations became meaningful through practice [18]. Although some students reported that they used the recordings frequently (11%, N=12), most of the students said that they used them on a "need to know" basis (41%, N=43).

3.2.4 Reflecting on representations (knowledge construction and knowledge management)

The recorded representations provide the opportunity to be able to reflect on the artifact, reinterpret, and review it, thereby constructing new knowledge but also managing it more efficiently by removing representations that are not needed anymore. The participatory environment created by the technology enables and supports reflection which leads to understanding, "People use representations to aid understanding when they are reflecting on an activity or working on a problem" [20]. This process sometimes occurs in the classroom when a previously produced artifact is reviewed in class in the following lecture. There is more writing and discussion around it and reflection on what it is. But the reflection occurs primarily outside of classroom. Students bring up the panels and review them before exams. Of course, the process of reflection is indirectly, or directly, present in the creation of artifacts that follow. Whether in exam, as part of an assignment, or as a design product, the understanding that students derive is reflected later on. In practice, as students take the follow-up courses that build on this course they use many of the concepts that they learn here. Therefore the process of reflection is the key to learning.

Another aspect of reflection is formative assessment in the class and in this process the role visual representations is vital. According to [22], classroom assessment is an ongoing process and by employing short and simple assessment techniques instructors can get feedback and in turn provide students with feedback on the results of the assessment and suggestions for improving learning. DyKnow^{TM} proved to be an efficient tool to incorporate formative assessment into instruction. An example is presented below from a lesson on flowcharting.

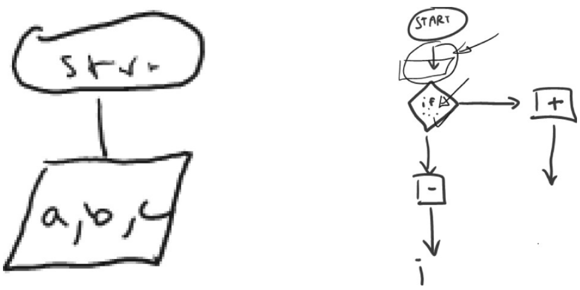

Fig. 5. Student panel showing flowchart submission.

Traditionally, the instructors used to describe the flowcharting process by developing an incomplete flowchart. This year due to incorporation of DyKnow^{TM}, we decided to share a blank panel with all students and asked them to draw the flowchart on their own for a given problem (Fig. 5). This problem was discussed before giving this in-class assignment and involved use of sequential and decision control structures. It may be noted that students were assigned to read a flowcharting document before coming to this lesson. We collected some panels randomly after about five minutes and started projecting collected panels on a large screen through a projector.

The first panel shared with the class did not show any significant amount of work. The instructor felt that this might embarrass the student who submitted the work even though s/he was anonymous to the class. The instructor quickly changed to another panel that showed a reasonable effort and discussed various elements of the flowchart that were right or wrong or missing. Next day a student stopped by the instructor's office and told him that the first panel (that had insignificant amount of flowcharting work) that the instructor had flashed momentarily in class made him feel good since he thought he wasn't the only one who was lost in drawing the required flowchart. Since then, we have decided to share all panels, irrespective of the amount of work shown, with students.

Students are thoroughly assured that the work is being collected anonymously and their submissions would in no way affect their course grade. Since students did not have the option to prevent their panel from collection, they are encouraged to participate in the class activity which was found very helpful in a large class. By collecting panels before the actual lesson instructors are able to gauge the prior knowledge of students which is useful in framing the lesson subsequently. Interestingly, in the focus group students suggested that for greater accountability panels could be collected non-anonymously making it essential for students to attend class, pay attention while they are in the class, and then submit panels that are of good quality.

4. Discussion

As technology has started to play a significant role in learning, the ability to visualize information throughout the learning process has become critical. Through visual representations and re-representation, and co-construction of visuals, representational literacy can be fostered among students in a more supportive manner. In this paper, through a case study, we have presented a framework that provides a dynamic perspective on the knowledge construction and management process through the use of digital representations. The framework we propose derives its strength in part from its theoretical basis in socio-cultural understanding of learning. We argue we can better understand the role of representations through a participatory learning approach where the creation, sharing, recording and reflecting on content are all supported. Furthermore, this environment must have the capability to provide guided support to learners and that this support should ideally come from a more knowledgeable other.

In particular, we outline the role of classroom technologies such as Tablet PCs and associated software in this process, although our model is applicable to any e-learning setting and even to large classes where it is particularly hard to engage students [23]. The software we used, DyKnow^{TM} provided support to engage students in a shared activity involving higher level thinking around representations created in class [24]. Through this process the technology transforms the practice of large classes by creating a discourse that is critical for appropriation of scientific and engineering practices [25]. Together, Tablets and DyKnow^{TM} have the ability to create, share, and collect different kinds of representations of engineering concepts and give students a chance to express themselves and engage in the lectures. As with any other research study, there are limitations to our approach. The data we use comes from the study of only one particular class, although we collected data over multiple semesters. The data is primarily qualitative supported by some quantitative measures but future work can improve the generalizability of our framework through comparative studies across courses and institutions.

5. Conclusions

In this paper we have developed and presented a model of how pen-based computing, and other digital mechanisms for developing representations, can be used to create a participatory learning environment in engineering classrooms. Although prior work on the role of representations in engineering exists, there is no literature that directly addresses the role of digital technology in representational practice. Given the exponential increase in the use of digital technology within engineering we believe the role of this capability in engineering representational learning is essential. The framework that we present is a new way of thinking about the role of technology and helps us move from thinking of technology as a means to improve the efficiency of delivering curriculum towards its role in improving student engagements by leveraging representations.

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Appendix A: Survey Items

The complete survey administered to the students contained 28 items. Here is a list of pertinent items (original item numbers):

Q7. Use of modern technology (e.g., Blackboard, Tablet PC, DyKnow software, etc.) effectively contributed to my learning in this course:

Q15. The DyKnow software has been successful in making the classroom environment interactive and conducive to learning:

- Q15 (a). I participated in EngE 1024 lecture session from a remote location with the help of DyKnow software on one or more occasions:
- Q15 (b). If you answered "yes" to question 15(a), then can you please cite some examples explaining the circumstances? (For example, I wasn't feeling well one day and I ended up logging in from my dorm room, etc.)

Q16. As you know, this is the second year that engineering freshmen were required to purchase a Tablet PC. What in-lecture or in-workshop activities did you think the Tablet PC was useful for?

Q17. Did your skills of using the Tablet PC in this course help you in any manner in other courses?

Q18.If you answered yes to Question 17, please provide some examples of how using the Tablet PC helped you in your other courses:

Q19.The most FRUSTRATING aspect of the use of the Tablet PC in this course was:

Q20.The most INTERESTING aspect of the use of the Tablet PC in this course was:

Q21. Manufacturer of Tablet PC:

Q22. Two primary issues I have with the design of Tablets are:

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