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Bridging engineering practice and learning through cyber-environments

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Abstract: nanoHUB.org is a major engineering cyber-environment that serves over 110,000 annually. Engineering cyber-environments such as the nanoHUB play a critical role in enabling practice within their respective disciplines. They feature a variety of professional grade cyber-tools that are designed for the expert users. However, these very cyber-environments play a fundamental role in enabling learning by allowing the easy use of industrial strength research modeling and simulation tools within the engineering curricula. We argue that cyber-environments, by providing avenues for learners to utilize tools and services designed for professionals, could offer an extremely authentic learning experience. The literature on engineering learning repeatedly calls for authentic learning experiences that offer learners a natural pathway to engineering practice and vice-versa. In this paper, using nanoHUB.org as a case study, we argue for the use of cyber-environments as a bridge between engineering practice and learning.

Introduction to Cyber-environments and the nanoHUB

Cyber-environments play an increasingly critical role in engineering as platforms for enabling scientific discovery, industrial progress, and learning. We define cyber-environments as a collection of computational, visualization, collaboration, and data management resources presented to an engineering community through an easy-to-access and easy-to-use online portal. The primary audiences for engineering cyber-environments are, in general, professional engineers, scientists, and researchers. However, cyber-environments due to their ease-of-use and ease-of-access are heavily used for facilitating learning in the engineering curricula. The nanoHUB (1) is widely believed to be one of the most successful engineering cyber-environments (Klimeck, 2008; Wilkins-Diehr, 2008).

nanoHUB.org currently serves over 110,000 users who have run about 369,557 simulations using interactive online simulation tools just within the last 12 months. In essence, nanoHUB has provided users with an equivalent of 25,485 hours of compute time [technically, wall clock time] in the last year alone. About 77% of nanoHUB users are researchers, educators, and students at institutions of higher education, 4% are from the industry, 2% from governmental organizations, and 16% are from other sectors. Although, nanoHUB.org is designed primarily for scientists and professional engineers, it offers a range of tools and other content that cater to a wide range of ability levels.

Figure 1. Global usage of the nanoHUB and current usage numbers

nanoHUB.org now delivers 170 online simulation tools and accesses national computing resources such as the Teragrid and the Open Science Grid. Forty-three (or 25%) of these tools are heavily supported by the nanoHUB team and are used by 76% of the users, providing them a higher quality experience. nanoHUB provides 1,792 educational resources, such as tutorials, and courses – 360 (20%) new added within the last year – that are freely offered for self-study, to augment traditional courses, and to serve as models for new ways of cyberlearning. In November 2009, NCN became the newest of 68 organizations allowed to provide content in the Beyond Campus section of iTunes U (3). nanoHUB has also contributed high quality animations to Wikipedia to enable a larger community to reach the cyber-environment (4).

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Any major cyber-environment needs significant participation from the expert segment of the community it is attempting to reach. To this end, the nanoHUB currently has content contributed by 659 experts in nanotechnology and associated fields such as chemistry and physics. In calendar year 2009, 116 graduate and undergraduate classes at 97 universities made use of nanoHUB, 50 for the first time. 575 papers in the scholarly literature cite nanoHUB.org (up 145 from the prior year). In turn these 575 papers are cited on average 6.1 times to a total of 3521. These citations give nanoHUB an h-index of 27. Experimental data is reported alongside simulations results in 142 (30%) of the 469 nano research papers. These data show that the nanoHUB is primarily aimed at practicing engineers and researchers. However, it forms a natural bridge for use in educational activities.

Use of nanoHUB resources is truly global, with 35% of our total users coming from the United States, 33% from Asia, and 23% from Europe. In the past year, data indicates substantial growth in South America and Europe, as well as some growth in Africa, Australia, and Asia. About 91% of nanoHUB users are affiliated with an academic institution. The use of simulation tools shows a slightly different picture: 60% of simulation users are in the US running 70% of all nanoHUB simulations. This may be in part due to the effect of network delay on the user experience with interactive simulations.

In the US, nanoHUB users represent about 18% of all 7,073 US .edu domains. Considering the very broad spectrum of institutions represented by the set of organizations with a .edu domain, we believe that 18% represents a very strong presence for the quite specialized nanotechnology research area.

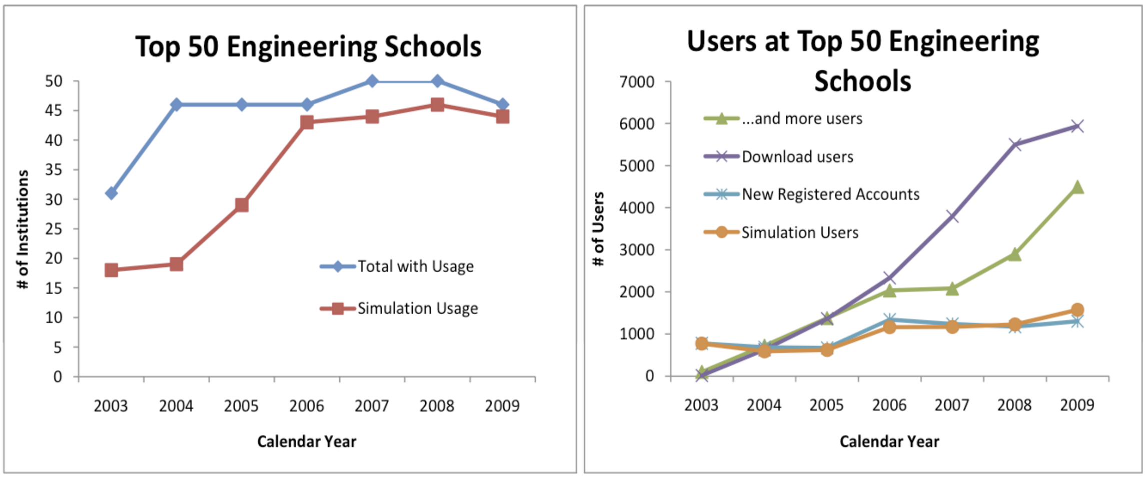

Figure 2. nanoHUB simulation and content usage in engineering schools

We have been tracking nanoHUB use at universities that are members of *U.S. News and World Report*’s list of Top 50 Engineering Schools. In the past four years nanoHUB has delivered a large range of educational content to users in at least 45 of the top 50 Engineering Schools. Almost all of these schools run simulations on nanoHUB, accounting for over 1,200 of our total 7,100 simulation users. The Top 50 Engineering Schools account for about 30% of US-based nanoHUB simulation users.

Bridging engineering practice and learning

The impetus for using cyber-tools and cyber-environments for teaching and learning in engineering disciplines comes from the need to provide students with real-world, hands-on experiences that utilize a network of practice (Brown and Duguid, 2000) as the basis for knowledge-creation activities. Edelson (1998) points out that “the most fertile use of technology in adapting scientific practice for the purpose of science learning has been in the adaptation of scientific tools, techniques, and resources” (p. 326). Cyber-environments by positioning learners within the larger network of practioneers and researchers allow learners to act as part of an established network or community. Wenger (1999) identifies the role of “social practice” (p. 47) as not only something that is derived from participating in a community, but also as something that provides “structure and meaning” (p. 46) to the activities. By allowing learners to follow workflows of practicing engineers and researchers, cyber-environments allow learners to associate meaning to the modeling and simulation practices that are embedded within these tools. Therefore, the use of a cyber-environment essentially provides learners with access to the culture of the profession they intend to enter.

It must be noted here that in the context of cyber-environments, while students can observe experts at work through various tele-presence tools and tool-sharing, well designed environments such as the nanoHUB make it easier for users to interact with the tools directly – thereby, moving learners to the role of user as opposed to observer. Lave and Wenger (1991) argue that learners need to be placed within the larger context of practice in any domain so that they may learn from multiple experts not only the content, but also the culture of that discipline. Also, according to situated learning theory (Lave, 1991; Cognition & Technology Group, 1993; Brown, Collins, and Duguid, 1989), learners need to be placed within authentic contexts while simultaneously setting appropriate ability levels that can facilitate learning within these environments. The key theme to notice here is that of "real-world engineering experiences" and "authentic learning activities." Other pedagogical theories – such as inquiry-based learning, problem-based learning, and cognitive apprenticeship (Wood et. al, 1976; Cole, 1985; Spiro et. al, 1991) – also emphasize that students need to be provided with authentic learning experiences in social settings. Cyber-tools and cyber-environments can provide authentic contexts to learners through the process of "harnessing collective intelligence" (O'Reilly, 2006). In essence, cyber-environments have great potential to function as "innovation communities" (Newstetter, 2004) that allow students to form cognitive partnerships with professional engineers and researchers.

Defining the Problem and Focus of this Study

The goal of using cyber-environments for bridging engineering and science practice with the classroom curriculum is not new. There are numerous cyber-environments funded by various national and international agencies that attempt to achieve this – however, with varying levels of success. It is not clear how most cyber-environments operationalize this link between practioneers and pedagogy. In this paper, we argue that cyber-environments, by providing avenues for learners to utilize tools and services designed for professionals, could offer an extremely authentic learning experience. Furthermore, we make the case that it is not sufficient for cyber-environments to claim that just by virtue of providing a set of resources to a community of users they achieve the goal of linking engineering and science practice with learners. It is critical to identify a framework and concrete data that cyber-environments can base these claims on. We pose the question – *what characteristics do cyber-environments need to manifest to make them conducive for providing authentic learning experiences so as to link engineering practice and learning?* In the next sections, we present our methodology and the resulting framework.

Methodology and Data Collection

Our methodology utilizes a combination of analyses of system informatics, social network analyses, and traditional educational research methods (focus groups and surveys). This integrated approach is needed to translate the theoretical frameworks described in the education literature into concrete design parameters of a cyber-environment. nanoHUB is very unique in its ability to capture a large range of user data. Since the nanoHUB provides access to the national cyberinfrastructure, it requires users to have an account (which is free to users) on the nanoHUB to run simulations. However, users do not need accounts (nor do they need to login) to view a large range of educational content. All data collected directly through the nanoHUB remain strictly confidential and individual identity of users is never revealed. This method of gathering system informatics pertains mainly to the usage statistics and related analyses provided in this paper. There are currently no standard tools for analyzing this type of data.

Establishing baseline data about the type of community enabled by a cyber-environment is significantly more complex activitiy due to the highly distributed and fragmented nature of this data. For the social network analyses presented in this paper, data was gathered using publicly available sources such as Google Scholar, Web of Science, and other similar avenues to identify all papers that cite the nanoHUB or resources published through the nanoHUB. The nanoHUB provides users with guidance on how to cite resources – however, this does not lower the barriers to collecting and analyzing publication data. Once this data is collected, members of the nanoHUB team, read each paper to identify if the citations contained in each paper are indeed valid. This is a cumbersome process – but guarantees a very high level of reliability in our analyses. The data is then formatted into forms appropriate for input into social network analyses tools such as UCINet (Borgatti et al., 2002) and Pajek (Batagelj and Mrvar, 1998). The resulting output is then arranged to make visual sense to the reader – which in itself is an extremely time consuming process.

The last aspect of the data used in this paper pertains to results related to the pedagogical outcomes and usage experiences of the individual users. Surveys were administered to our users using the online survey tool surveymonkey.com. Multiple such surveys focusing on various aspects of nanoHUB use were conducted over the last year. Respondents are usually students using the tools, faculty adopting nanoHUB for curricular use, and in some cases researchers not necessarily involved in teaching and learning. Additionally, a series of focus groups were conducted at a west coast public university where a total of 40 undergraduate engineering students participated. They were primarily from communities that are traditionally underserved. Students were either at the junior or senior level. 95% of participants in the focus groups were males. Results from the surveys were analyzed using standard descriptive statistics. The responses during the focus groups were analyzed to find large thematic patterns that were of relevance to this study. We use all the various pieces of data collected to triangulate findings and identify insights into how cyber-environments such as the nanoHUB facilitate learning.

Emerging Evidence Framework for Cyber-environments

In this section, we attempt to outline three major criteria that a cyber-environment must satisfy for it to successfully bridge engineering practice and learning. These criteria are based on the argument of community formation identified in the previous section and also on tenets of authenticity identified in Herrington et al. (2003) and Herrington and Herrington (2006). In identifying these criteria, we would like to point out that much has been written in the learning literature about the characteristics of authentic learning experiences. Our goal is not so much to expand on those, but rather leverage the most relevant criteria effectively in the design of cyber-environments.

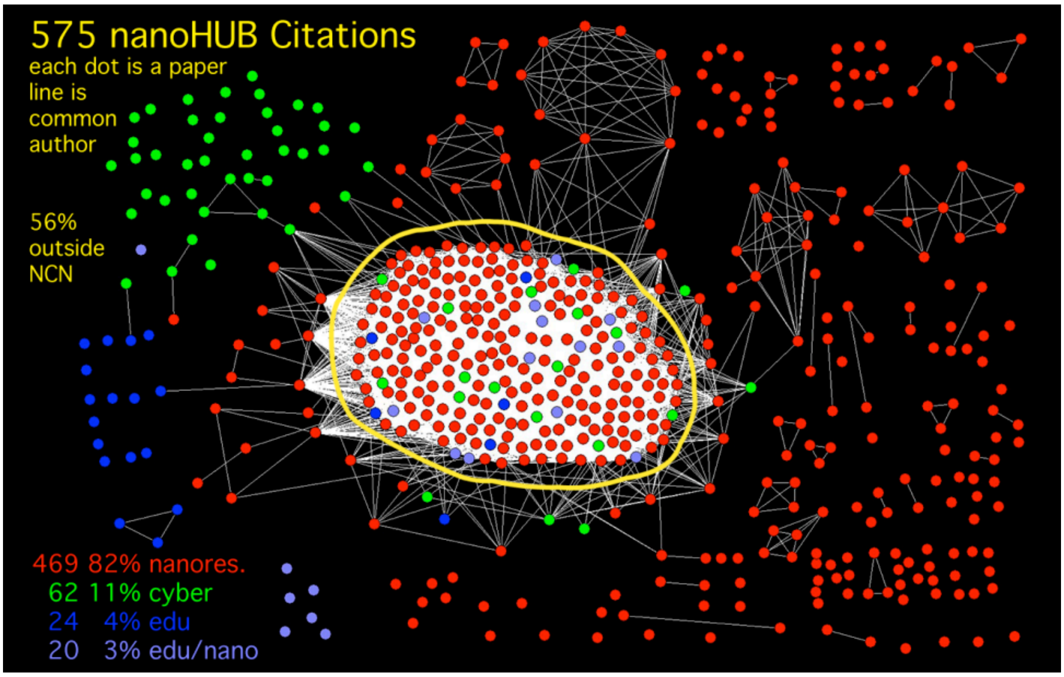

Figure 3. nanoHUB citation map (Klimeck and Perigo, 2010).

1. **Evidence of participation from a real community of experts and access to real-world workflows**: Herrington and Herrington (2006) point out that providing "an authentic context that reflects the way the knowledge will be used in real life" (p. 4) and "access to expert performances and the modeling of processes" (p. 5) are critical in establishing authentic learning environments. While most cyber-environments do offer services that are designed and used by a wide range of experts, they very rarely include significant evidence that explicitly points learners or learning facilitators to this data. Part of the problem with providing such data and insights is the critical lack of instrumentation in the design of the cyber-environment itself. For example, seemingly simple questions such as "who are the users?", "where do they come from?", and "what do they do when they use the cyber-environment?" are generally very difficult to answer at the present time. The success of nanoHUB as a cyber-environment is in part because it is heavily instrumented to collect this type of information and as a result provide extensive insights into how the environment is used. These are presented readily to the users – therefore, going beyond the normal in providing extensive evidence for authenticity. Figure 3 provides a citation map based on 575 citations (Klimeck and Perigo, 2010) derived from the community usage of nanoHUB for real scientific work. It must be noted here that 82% or 469 of the citations considered for this analysis deal with nanotechnology research.

   In addition to providing such evidence based on social network analyses, every nanoHUB-supported tool also includes information about the author(s) of a specific resource, usage of the resource, any associated citations, tips to get help when using these tools. While such information may seem simple and easy to provide – they go a long way in establishing the credibility of a tool. Data collected through surveys of users indicates that the faculty members play a critical role in selecting the tools that are used in the curricula. Furthermore, most students get introduced to the nanoHUB for the first time during a course. In this context, the ratings of individual resources and all background data about the tool play a critical role. Based on individual ratings, resources either bubble up or down. This is also a critical piece to show that there is a broader community involved in the cyber-environment.

   The second aspect of this discussion focuses on access to real-world workflows. Users who have significant experience building simulation tools for real-world research and practice create all nanoHUB tools. Quality assurance processes in combination with the feedback from a large community of users provide guidance on the quality of a specific resource or simulation tools. Since most of the tools are initially designed with expert users in mind, they innately reflect expert workflows. When students use these tools, regardless of their ability levels they are automatically provided access to expert workflows. This has a negative effect also. Repeatedly in user surveys, students seem to want easier methods for finding content that are appropriate for their expertise levels. Faculty members using the nanoHUB in their curriculum reflect these sentiments also regularly. To alleviate this problem, nanoHUB has adopted an easy to use taxonomy of user content. These taxonomical classifications are done in collaboration between content experts and experts in pedagogy – providing a significant pathway for bridging various expertise levels. Collins et al. (1989) make a case for how an apprenticeship system provides access to the workflow process of experts and provide learners a model to follow. In the context of a cyber-environment, these types of taxonomies created by experts allow users to track their progression without limiting users to traditional disciplinary boundaries. Relan and Gillani (1997) point to the risks of limiting learning along departmental or disciplinary boundaries. However, a properly conceived taxonomy can provide the necessary scaffolding without dividing learning along disciplinary boundaries. Figure 4 provides a screenshot of the taxonomy system implemented in the nanoHUB. The horizontal lines on either sides of the dots and the size of the halo around each dot indicate the depth and breadth of the content element. These are designed to cross disciplinary boundaries and expertise boundaries.

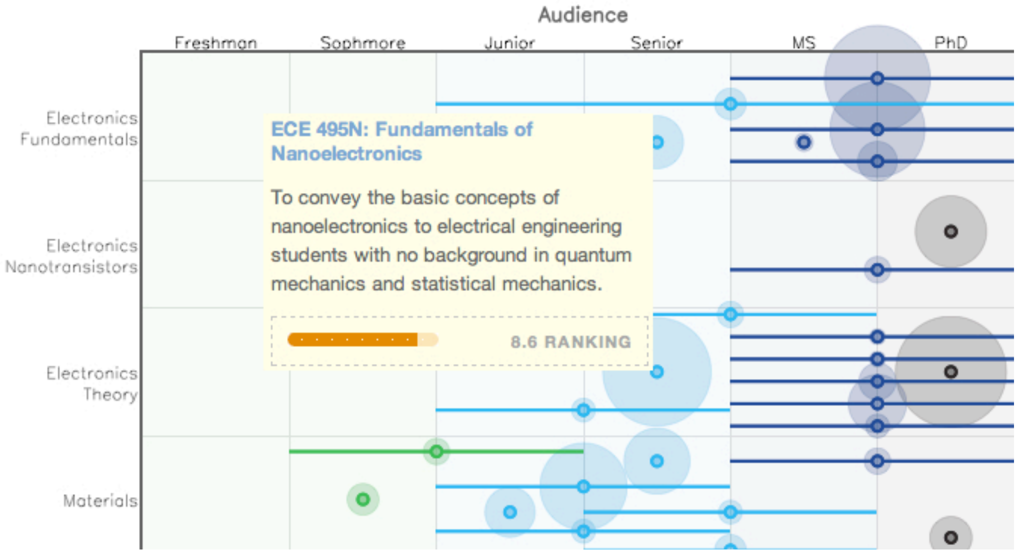

Figure 4. Taxonomy adopted by the nanoHUB to bridge expertise levels

2. **Evidence that cyber-environment allows for collaboratively scaffolding the learning experience:** One of the most significant motives behind establishing a cyber-environment is to facilitate collaboration among researchers, scientists, and industrial partners. Most engineering cyber-environments include a number of collaboration tools. However, what is not clear is if these tools are readily leveraged for enabling scaffolded learning experiences. Jonassen (1999) points out that while "modeling is focused on the expert's performance […] scaffolding is a more systematic approach to supporting the learner, focusing on the task, the environment, the teacher, and the learner" (p. 224). Engineering cyber-environments should indeed allow users to not only model the workflows and practices of experts, but also allow appropriate scaffolding as the learner uses the environment. Any cyber-environment used for facilitating learning must allow instructors to manage and customize not only the content that is being used within their curricula, but also provide avenues for seamless use of collaboration services within that environment to scaffold learner experiences.

nanoHUB provides learners and faculty members with numerous avenues to collaborate and customize learning experiences. nanoHUB users can create groups, create tools that they can share with collaborators, and also use a full-fledged commercial collaboration environment such as Adobe Connect™. In observing the usage patterns of users, we notice that users create custom groups for individual courses where students participating in that course have exclusive access to materials associated with that course. For example, when tackling homework assignments, particularly using the nanoHUB simulation tools, students commonly run into issues with setting appropriate parameters. The process of running a simulation tool can be frustrating to students particularly when learning to use a certain tools. During the focus groups that were conducted, students indicated problems with getting started using a simulation tool. In order to help with these learning situations, nanoHUB includes the ability to share a tool with an instructor or another group member by using a simple share option below the tool window. This allows the instructor or another student to see the tool from the viewpoint of the other user using the tool and interact freely with it. Figure 5 provides a quick view of the number of methods available to users for collaborating. It also shows a simulation tool with the ability to share the tool right below the tool window highlighted in an orange box. This ability to collaborate coupled with the data gathering and capabilities of the nanoHUB are significant assets in providing appropriate scaffolding to the learners. We are currently exploring ways for leveraging these collaboration tools better in a pedagogical context and studying their impact.

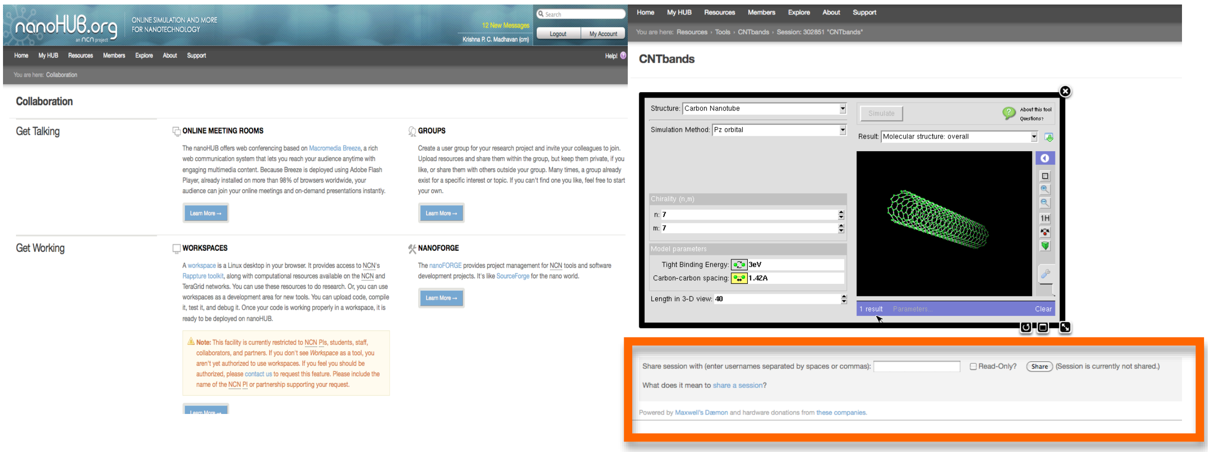

Figure 5. Collaboration options within the nanoHUB. Image on right shows ability to share screen in orange.

3. **Evidence that the cyber-environment goes beyond providing resources to incorporating a sound pedagogical strategy:** As we previously stated, just because a cyber-environment is able to provide a community of users with some resources does not mean that it is effective at facilitating learning. In order to truly form a bridge between engineering practice and learning, a cyber-environment must clearly demonstrate that it includes a clear pedagogical approach to creating, organizing, and deploying materials. Very few engineering and science cyber-environments today clearly identify and provide data to indicate an evidence-based approach to learning. nanoHUB has adopted and promotes an evidence-based approach to teaching and learning using cyber-environments. Our approach is informed by the How People Learn (Bransford et al., 2000) framework. Furthermore, nanoHUB includes resources and guidance for faculty members on how to design high impact courses while leveraging current knowledge about facilitating authentic learning experiences. Figure 6 shows the pedagogy deployed on the nanoHUB and the resources available to both faculty and students to facilitate learning.

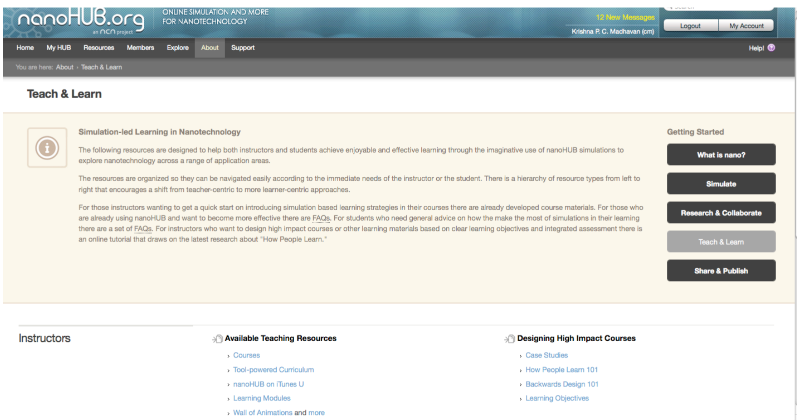

Figure 6. nanoHUB page showing the pedagogy employed and teaching and learning resources

A large number of cyber-environments undertake an incremental strategy to adopting tools within the learning curriculum. For example, it is common for faculty members to try out a tool or a content material as part of a course homework assignment. Eventually, this usage may increase or sometimes faculty members choose to not use the cyber-environment at all subsequently. However, data collected by the nanoHUB from our focus groups indicate that students prefer a more systematic and end-to-end incorporation of cyber-environments. Students repeatedly stated that learning an environment once and continuing to use it multiple times - as opposed to a one-time use - better utilized their time. This essentially is opposed to the incremental strategy that many cyber-environments promote. While the incremental strategy may be the best approach from the instructor's perspective, from the student's perspective it lacks the coherence and continuity needed for learning. To tackle such issues, nanoHUB is also developing a series of case studies (Magana, 2010) to illustrate a variety of approaches to incorporating nanoHUB (and by extension other cyber-environments) into the curriculum. Furthermore, the nanoHUB team conducts workshops to help instructors and faculty members understand various pedagogical approaches needed to implement sound pedagogical practices.

From a content perspective, it is critical to understand that nanoHUB features completely new and innovative approaches to a number of content domains. These approaches are driven by new research insights and capabilities on the research end. While sound pedagogy can enable better deployment of these resources for instructional purposes, the innovation fostered in pedagogy itself is a result of cutting-edge work by engineers and scientists working collaborative over a long period of time. Any cyber-environment must act as a vehicle for domain specific instructional transformations and this must be evidence-driven. For example, nanoHUB has pioneered a completely new approach to teaching nanoelectronics entitled "Electronics from the Bottom Up" (5).

Reverse Learning Trends – From Learning to Engineering Practice

nanoHUB user data suggests that learners continue to explore and use professional grade simulation tools for their learning activities. However, it is important to point out that the pathways provided by cyber-environments do not always flow from engineering practice to learning, but also from learning to engineering practice. In the nanoHUB context, it is important to note that applications that would be considered "educational" are used in research work, and the results are published in high quality journals. For example, the tool *CNTbands* found on the nanoHUB was originally envisioned as an educational tool for classroom usage. It is however also cited 14 times in the engineering research literature. Similarly, *Schred* is a particularly interesting nanoHUB tool because of its dual-use: 1) it is used for education at the graduate and undergraduate level in classroom demonstrations and for homework or project assignments and 2) it is the most-cited nanoHUB tool with 97 citations in the scientific literature. Schred does not embody the most sophisticated theory; rather, it is exactly what is needed by experimentalists to calibrate their experiments. As such, the deployment of Schred on nanoHUB is itself designed to build the nanoHUB community. Another critical element is that Schred is relatively easy to use and requires about 1 minute to execute on a recent Intel CPU. 464 users ran 8,107 Schred simulations (including classroom use) resulting in 16 publications in 2007 alone.

Conclusion

In this study, we outline some of the fundamental characteristics of cyber-environments that potentially enable them to act as a bridge between engineering practice and learning. Clearly, there are numerous other factors that need to be considered that have not been highlighted here due to logistical and space constraints. However, in this paper, we begin by addressing the ability of the cyber-environment to provide an authentic learning experience in combination with its innate capability to allow access to an "innovation community". In essence, we have argued that cyber-environments by their very design and purpose are at the cusp of delivering transformative capabilities in terms of bridging engineering practice and learning. However, a large majority of the cyber-environments do not currently provide the capability to demonstrate this – an essential component to promote curricular adoption. Further, we have made the case that the collaboration services built into cyber-environments are ideally suited for providing a scaffolded learning experience that allows novice learners to model expert behaviors. Finally, a cyber-environment needs to provide a viable pedagogical approach accompanied with a research program to refine this approach on a continuous basis.

Endnotes

(1) nanoHUB is a National Science Foundation funded effort and can be accessed at http://nanohub.org.
(2) Refer to http://nanohub.org/resources/fettoy/citations for citations of FETtoy and MolCtoy - originally designed as a toy model for educational use.
(3) nanoHUB on iTunes U can be accessed from http://nanohub.org/itunes/.
(4) Wikipedia content related to the nanoHUB is available at http://en.wikipedia.org/wiki/Nanohub.
(5) Electronics from the bottom up: a new approach to nanoelectronic devices and materials. Available online at http://nanohub.org/topics/ElectronicsFromTheBottomUp.

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