Facilitating Human Interaction in an Online Programming Course

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ABSTRACT

Human/human interaction is a critical component of learning in many domains including introductory computer programming. For on-campus courses, lectures and problem sessions provide opportunities for students to interact with the instructor(s) and their peers. For online courses, opportunities for human/human interaction are more limited and usually correspond to activities like forum postings and online study groups. For online programming courses, the situation is potentially even worse since many of the computational tools designed to facilitate learning to program, such as unit testing, emphasize human/machine interaction and can be frustrating for beginning students.

In this paper, the authors describe their experience in teaching an introductory programming MOOC. The guiding philosophy for this course is that learning to program should be a social experience that emphasizes human/human interaction, not human/machine interaction. Both the tools and assessment methods deployed in this course were chosen to help achieve this goal. In particular, this paper discusses a key tool that supports human/human interaction and several aspects of the course that contributed to its success.

Categories and Subject Descriptors

K.3.1 [**Computers and Education**]: Computer Uses in Education—*Collaborative learning*
; K.3.2 [**Computers and Education**]: Computer and Information Science Education—*Computer science education*

Keywords

CS1, Python, MOOC

1. INTRODUCTION

The price of a higher education has outpaced the means of the vast majority of students to afford such an education. Massive open online courses (MOOCs), offered by providers such as Coursera, edX and Udacity, are one attempt to remedy this situation. These courses provide a mechanism for students, many with no access to traditional higher education, to learn advanced material from experts in the field. While MOOCs have been promoted as a solution to many of the ills of higher education, they face some key educational challenges if they are to deliver an educational experience that is on par with the typical classroom experience.

Perhaps the most common criticism of MOOCs is that, with their size and reliance on technology, they are unable to replicate the social experience (*i.e.*, human/human interaction) that is the linchpin of classroom education. (Of course, large on-campus classes are also often impersonal.) We set out to teach an introductory programming MOOC that would allow people to learn to program despite the challenges of online education at scale. We identified the following key issues that we felt needed to be addressed in order to be successful:

1. **Ease of use and consistency of the programming platform.** With tens of thousands of students, it is impossible to troubleshoot individual problems arising from multiple versions of a language and libraries, as well as different editors, all running under different operating systems. For beginning students, these issues can be a significant barrier to success when there is no one to help them get their system setup, let alone actually start programming.

2. **Instructor accessibility.** This is likely one of the greatest criticisms of large scale education. How can a student be successful if he/she can never interact with the instructor?

3. **Availability of timely and relevant feedback.** While a machine grader can instantly tell a student whether their code works or not, it cannot easily give advice on coding style or how to fix problems in the same way that human graders could. At scale, the staff can't possibly provide such individual feedback in a timely fashion (or at all).

4. **Peer interaction.** A significant element of an introductory programming class is the shared experience among the students. Seeing others struggle along with you, helping each other solve problems and sharing each others' successes are powerful motivators.

We went to significant effort to address each of these potential weaknesses of MOOCs. We have found that the mas-

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sive number of students in a MOOC combined with well-chosen technology makes the creation of a highly social online learning space possible. We have found that it is possible to provide human assistance to MOOC students in a number of innovative ways in such a space. At the core of our approach are tools that support easy creation and sharing of course material (generated by both student and instructor) with minimal effort.

Related work: Our social approach to teaching programming is grounded in previous work. [1] describes a community-based approach to the general problem of learning, while [6] observes that computer science and mathematics are social disciplines. A meta-analysis of studies on game-based learning [10] suggests that collaborative learning and instructional support positively influence learning outcomes.

One specific topic related to our work is the design of programming environments to enhance the social aspects of learning to program. [2] describes an environment that supports the computer language Logo and shows that (on a small scale) this environment facilitates peer interaction for social problem solving. Both Alice [5] and Scratchpad [8] are highly collaborative, social environment that are designed to engage students learning to program.

Contributions: In this paper, we relate our experience in teaching an online introductory programming class, in both on-campus and MOOC form. In particular, we describe a programming environment developed for these classes that was designed to promote human/human interaction. As our main contribution, we discuss the ways in which we leveraged this tool to create a social learning space for the MOOC students that did not exist for the on-campus students. This space, formed by students in the MOOC, compensated (at least partially) for the lack of an in-person component that benefitted on-campus students.

2. A TOOL FOR SHARING CODE

Our particular online course "An Introduction to Interactive Programming in Python"[1] (IIPP) focuses on teaching beginning students how to program in Python with the motivation of learning to build simple games. This course was designed to be offered both on-campus (supplemented by in-person lab work) and online as a MOOC. This class has been offered on-campus in Fall 2012 and Fall 2013 to 25 and 40 students, respectively. IIPP has also been offered online in MOOC form three times. Between the Fall 2012, Spring 2013 and Fall 2013 sessions, nearly 19,000 students have completed IIPP and received a Statement of Accomplishment.

In designing a class suitable for both on-campus and online delivery, one key issue is how students create and assess their work. In popular introductory programming courses such as Udacity's CS101[2] or MIT's 6.00x[3], students create their code in a stand-alone programming environment and submit this code to a server for automated assessment via a collection of unit tests. This arrangement has several advantages. Machine tests are typically very precise and provide students with fairly prompt feedback.

[1]`https://www.coursera.org/course/interactivepython`
[2]`https://www.udacity.com/course/cs101`
[3]`https://www.edx.org/course/mit/6-00x/introduction-computer-science/586`

However, this approach also has weaknesses. The very precision of machine tests can lead to student frustration in that code that is very close to working may be scored the same as code that is not even close to correct. The error message provided by a failed unit test may be cryptic and not provide a sufficient hint on how to correct the program.

This issue has prompted research into automated hint systems for MOOCs [9]. In that work, the authors report that their system can provide meaningful feedback on approximately 2/3 of all incorrect submissions for their class. However, for some types of programs such as interactive ones with visual output (the main type of programs created in our class), machine grading and automated hint-generation systems are beyond the scope of current technology.

Since many of the weaknesses with the human/machine approach to teaching introductory programming can be improved or eliminated via interaction with a human instead of a machine, we focused on creating a programming environment that is optimized to support human/human interaction and foster a social space for learning to program. To this end, we made a number of critical design decisions when creating this environment.

- The programming environment should be web-based, so that students do not need to download and install a stand-alone development environment. This choice allows us to deploy and update the environment for all students quickly and easily. This choice also ensures that all students work in an identical programming environment, making sharing of code much more reliable.

- Student code should run entirely in the web-browser, avoiding the need to upload and execute code on a remote server. This choice enables interactivity and avoids the possibility of server-lag during high demand periods before assignment submission.

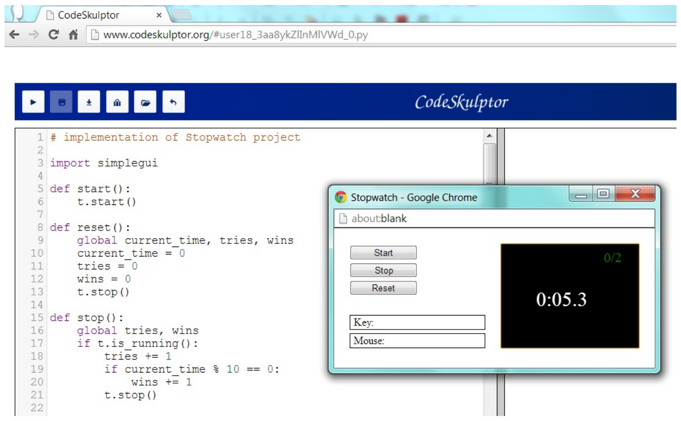
- Student code should be stored anonymously in a cloud-based file storage system. This choice avoids the need for accounts or authentication and removes another impediment to easy sharing of code.

- Finally, the environment should support download and execution of student or instructor code via a single URL. Any auxiliary assets such as custom Python modules, images and sound would load inside the program via specified auxiliary URLs.

Starting from the browser-based Python runtime system Skulpt[4],we developed a web-based programming environment for IIPP. This system, CodeSkulptor[5], allows students to create visual, interactive Python programs in their web browser, save these programs in the cloud with a single click, and share these programs via a single URL.

Figure 1 shows an image of a simple stopwatch program available for sharing via CodeSkulptor. The left code pane shows part of the body of the stopwatch program. The frame on the lower right shows a collection of buttons and a canvas displaying the stopwatch created by the program. This program can accessed and shared via the CodeSkulptor URL: `http://www.codeskulptor.org/#user18_3aa8ykZlInMlVWd_0.py`

[4]`http://www.skulpt.org`
[5]`http://www.codeskulptor.org`


CodeSkulptor
www.codeskulptor.org/#user18_3aa8ykZlInMlVWd_0.py
CodeSkulptor
Stopwatch - Google Chrome
about:blank
Start
Stop
Reset
Key:
Mouse:
0/2
0:05.3

```
# implementation of Stopwatch project

import simplegui

def start():
    t.start()

def reset():
    global current_time, tries, wins
    current_time = 0
    tries = 0
    wins = 0
    t.stop()

def stop():
    global tries, wins
    if t.is_running():
        tries += 1
        if current_time % 10 == 0:
            wins += 1
        t.stop()

```

Figure 1: A stopwatch program in CodeSkulptor

which is displayed in the address bar. A new random hash ("3aa8ykZlInMlVWd" in this example) is generated automatically by CodeSkulptor for each save.

With this design, the flow of saving, sharing and running a program requires at most seconds of work and entails four simple steps. A user saves the program generating a new CodeSkulptor URL (first step). This user can then transmit this link to a second user via email, a forum post or link submission (second step). This second user then clicks the received URL to open CodeSkulptor with the saved file preloaded (third step). Finally, the second user can run the program via a single click (fourth step). In our opinion, this ultra-streamlined work flow for sharing code is the key enabler for our social approach to teaching programming.

The design of CodeSkulptor was influenced by other web-based programming environments that employ web-based editing and cloud-based saving such as `jsfiddle.org`, `repl.it`, and `cloud9.io`. However, one key issue that distinguishes CodeSkulptor from these environments is its ability to run modestly complex, interactive Python programs entirely in the web-browser. These related environments either lacked the efficiency to run interactive programs with even moderate computational requirements in the web-browser (making them unsuitable for use in IIPP) or required the computational support of a back-end server (raising the issue of server cost and loading).

3. SOCIAL ASPECTS OF A CS MOOC

CodeSkulptor enabled the creation of a MOOC in which learning to program was a highly social endeavor. CodeSkulptor enables and facilitates human/human interaction in IIPP in ways that never manifested in the on-campus version of the class. In this section, we discuss the various social components of our introductory programming class and discuss how CodeSkulptor facilitated the success of some of these components.

3.1 The Code Clinic

One well-taken criticism of MOOCs is that they provide limited opportunities for personal interaction with a subject expert, compared to an on-campus class. Thus, one of our primary focuses when designing our online class was to provide mechanisms for students to receive timely, informative answers to their questions.

For massive online classes, the discussion forums are the standard mechanism for students to post questions and receive answers about class material. As we shall see in section 3.3, these forums were a tremendous resource for our class. However, the efficacy of the forums was clearly limited in certain situations.

For example, students often had bugs in their implementations of the weekly mini-projects. Posting a link to their erroneous code in the class forums when seeking help from their peers or course staff often represents an irresistible opportunity for other students to copy the posted code. Thus, posting partial or even incorrect solutions before the assignment due date violates the class Honor Code. As a result, forum posts requesting help in debugging code are often vague to avoid revealing potential solutions.

In IIPP, we have developed an additional social mechanism to allow students to receive knowledgeable assistance on coding questions. The *Code Clinic* is a class service that allows students to email a link to their code to the course staff and receive answers to specific questions related to their code. For example, a student might ask for help in debugging a part of their program that has a hard-to-locate error. The course staff member would then respond by explaining the error and even, perhaps, sending back a link to a corrected program. As opposed to the class forums, the student is able to share their code directly with a knowledgeable member of the course staff.

In the on-campus setting, standard email (or in-person office hours) are sufficient to support this type of service. However, in the MOOC setting, this type of service would most likely overwhelm a simple email account. To avoid this situation, we retained a professional help desk service (`helpscout.net`) to host the Code Clinic. This help desk service routes student email to a central web-site where course staff could then respond to these requests. This help desk service includes a number of helpful features that facilitate our handling of these requests: an auto-response on submission of a help request, a set of customizable stock responses to common questions, assignment and tracking of help requests, and automatic detection of simultaneous responses.

One potential objection to this private help desk approach is that feedback generated by answering student questions goes only to the questioner. As part of maintaining the Code Clinic, the staff noted common questions and problems and then posted sanitized examples back to the main class forums to alert the remainder of the class to these issues.

The Code Clinic has proven to be a very popular feature of IIPP. Figure 2 shows a plot of the number of help requests handled by the Code Clinic and the average response times for these requests for the Spring 2013 session. Overall, 1201 students (around 1/6 of the total finishers) made 2503 help requests. Each help request (and possible follow up questions) generated on average 1.87 replies from the course staff. The average response time for a help request was approximately 45 minutes with an average handle time (the time between viewing and responding to a request) of approximately 6 minutes. Note that this remarkably low handle time was due almost entirely to CodeSkulptor's ability to facilitate code sharing.

While this number of student help requests may seem daunting, the total amount of time dedicated to running the Code Clinic is sizeable, but tractable. The course staff sent

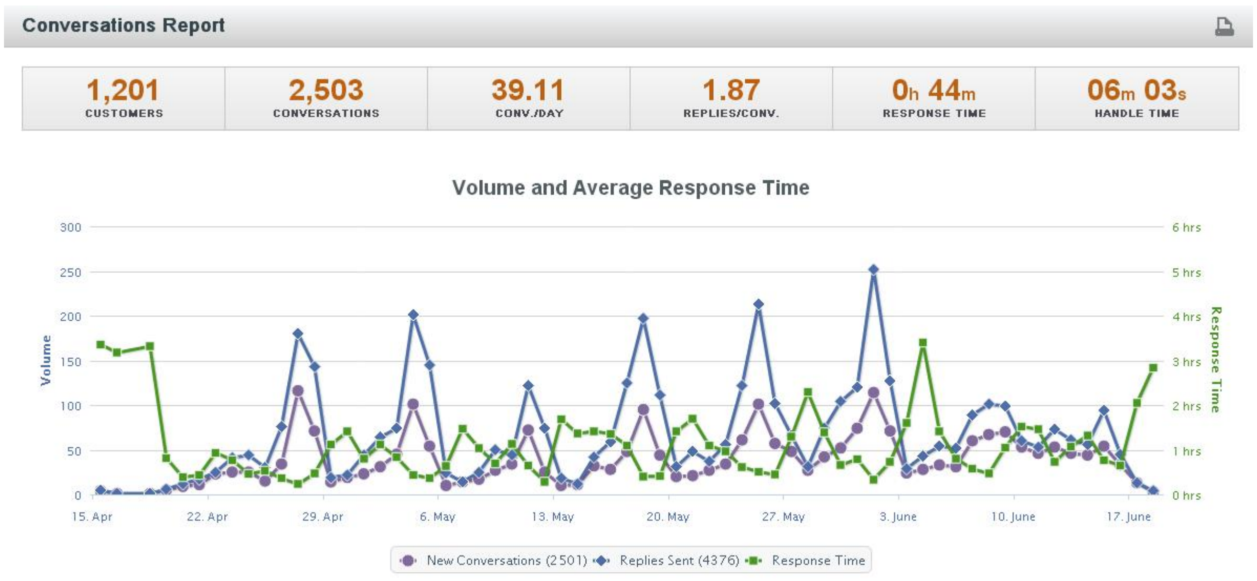


Figure 2: Help request statistics from Spring 2013

approximately 4800 replies to help requests and follow up questions. The key to replying to this number of requests is the 6 minute handle time per student email. In practice, 2/3 of the replies were generated by 3 course staff members (including one instructor) representing approximately 15 hours of work per week for each of these three people during the nine week course.

Figure 3 shows a typical weekly cycle of help requests for the Code Clinic. Help requests typically peaked on the weekend when mini-projects were due. On these days, the class would usually submit between 75–100 help requests. While this is a substantial number of requests, the peak demand (4–12 hours before the deadline) was easily handled by 3 staff members. As an interesting note, observe that the average response time on due days was approximately 15 minutes, much faster than the average response time overall. This phenomenon was due to the higher volume of help requests on due dates. On those days, at least one member of the course was staff was usually actively engaged in responding to help requests throughout the day. This engagement led to response times that are much faster than most on-campus classes could achieve.

These statistics lead us to the most important conclusion in this paper: **providing individual expert help to the students in a MOOC is absolutely possible**. In both the Fall 2012 and the Spring 2013 sessions, every email help request from our students was answered. Most of these requests (83%) were answered within an hour (or even more quickly on due days). In the Fall 2012 session, all the 1000+ help requests (sent to a custom Google Group) were personally answered by an instructor. In the Spring 2013, the help desk was used to prioritize help requests so that all "difficult" help requests were routed to an instructor while teaching assistants processed routine requests.

3.2 Assessments

The on-campus and MOOC versions of our class rely on two types of assessments: mini-projects (due weekly, 50–250 lines of Python) and quizzes (two per week with 8–10 questions). We next discuss some of the social aspects of each type of assessment.

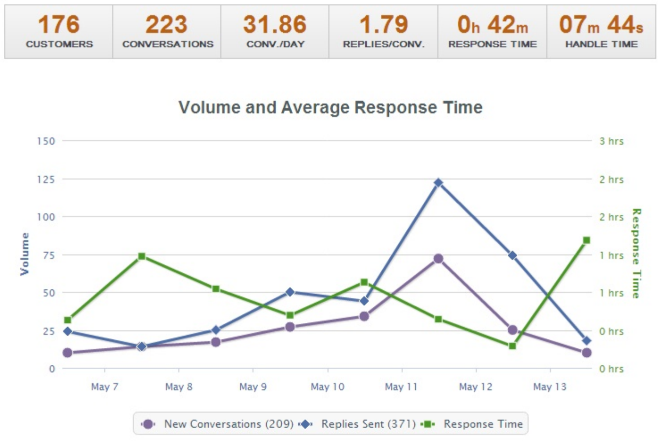


Figure 3: A typical week of help requests

Mini-projects: One of our motivational tools in teaching programming is the fact that many students love games. Our class focuses on building simple interactive games based on games such as Pong, Memory, Blackjack and Asteroids. Since machine-grading these types of programs is currently beyond the state of the art due to the interactive and visual nature of the programs, we choose a social method, peer assessment, to grade class mini-projects.

For smaller in-person classes, peer assessment has been used and studied extensively. [3] provides a meta-analysis of the effectiveness of peer assessment in higher education and concludes that peer assessment can be effective when grading rubrics are well designed. While [4] notes that peer assessment has been observed to enhance student perfor-

- 1 pt - The program successfully opens a frame with the stopwatch stopped.
- 1 pt - The program has a working "Start" button that starts the timer.
- 1 pt - The program has a working "Stop" button that stops the timer.
- 1 pt - The program has a working "Reset" button that stops the timer (if running) and resets the timer to 0.
- 4 pts - The time is formatted according to the description in step 4 above. Award partial credit corresponding to 1 pt per correct digit.
- 2 pts - The program correctly draws the number of successful stops at a whole second versus the total number of stops. Give one point for each number displayed.
- 2 pts - The "Stop" button correctly updates these success and attempts numbers. Give only one point if hitting the "Stop" button changes these numbers when the timer is already stopped.
- 1 pt - The "Reset" button clears the success and attempts numbers.

Figure 4: Grading rubric for stopwatch mini-project

mance, the study also raises questions about the accuracy of the resulting peer grades. In the last year, peer grading has been used in humanities MOOCs as well as more technically-oriented MOOCs [7] with similar questions.

With this issue in mind, we took special care in designing both the programming environment and the peer assessment component of the class. To facilitate consistent assessment of submitted programs, CodeSkulptor simplifies the process of sharing and running a peer's code and ensures a common shared environment for everyone executing this code. Second, we spent a large amount of time carefully designing the rubrics for class mini-projects. One factor in our favor compared to other MOOCs was that the work being graded, instead of being an essay, was an interactive computer program with a fairly precise behavior.

Figure 4 shows a rubric associated with an early mini-project. Note that the items in the rubric have a small point range and are very specific (*i.e.*, "The program has a working Stop button that stops the timer."). In essence, our approach was to design a rubric that mimicked the specificity of machine-based unit tests and restricted the scope of judgment for the human assessor. Rubrics for later, more complex projects consisted of 15–20 specific evaluation items, each valued discretely at 1 or 2 points.

Students were asked to assess five of their peer's mini-projects. To reduce the impact of outliers on the student's grade, the median score for the peers' assessment for each item in the rubric was used in computing the student's grade. Student were also required to provide written comments on items that did not receive full scores.

With this approach, we found that the vast majority of the students in both the on-campus version and the MOOC version of our class were very positive about the use of peer assessment. Students appreciated the flexibility of human evaluation versus machine evaluation and particularly appreciated the helpful written comments that many students included with their peer assessment. (These comments were mandatory if an assessor deducted points.)

In the Spring 2013 session of IIPP, the exit survey for the session asked the following question, "How helpful have you found your peers' evaluations and comments on your mini-project?" Out of 4429 responses, 71% found their peers' evaluations and comments helpful, 28% found them neither helpful nor unhelpful while 1% found them unhelpful.

In our class, most students also found the process of examining a peer's solution to a problem to be beneficial. In particular, they like the fact that peer assessment exposed them to the solutions, coding practices and errors of other students. On the exit survey for the Spring 2013 session, we asked "How helpful have you found examining your peers' code during peer assessment?" Out of 4429 responses, 81% found examining their peer's code to be helpful, 17% found this activity neither helpful nor unhelpful while 2% found this activity unhelpful.

Quizzes: Peer assessment is an inherently social mechanism. Our second assessment mechanism, the quiz, was machine-graded. As noted previously, this choice has the important advantage that student feedback on their performance is immediate. However, we observed instances of student frustration with the form or formatting of quiz answers that is common with the use of machine grading. In the on-campus version of our class, questions concerning this issue were resolved during in-person meetings. For the MOOC version, we augmented machine-grading with a social approach involving the class forums.

Our social approach to these quizzes was to allow multiple attempts at the quiz to encourage mastery of the material as well as to give students the opportunity to discuss the quiz problems in the class forums. In particular, we created a single sub-forum for each individual quiz. IIPP students were instructed to attempt the quiz at least once before visiting the specific quiz sub-forum. Inside the sub-forums, the rules for discussing quiz questions were very relaxed. Students were allowed to discuss the problems in substantial detail with the only restriction being that explicit answers should not be posted. This decision encourage substantial and detailed forum discussion (10–20 threads per quiz with 5–20 responses) of questions that were either difficult or perceived as ambiguous. As instructors, we rarely entered into these threads to avoid stifling discussion.

3.3 Class forums

Perhaps the most well-known social component of online classes are the discussion forums. For the on-campus version of our class (with 25 students), the class forums were essentially unused. On-campus students typically resolved questions concerning class material during either during in-person class meetings or via email exchanges with the instructor. Note that neither of these mechanisms provide particularly fast feedback for on-campus students.

However, in IIPP, the class forums were incredibly active, especially around class deadlines. For example, the forums for the Spring 2013 session included 8244 threads that generated more 65000 posts and comments. During peak forum times (4–12 hours before deadlines), new threads would be created at a rate of 10–20 per hour with each thread typically generating 3–5 responses within 20 minutes.

This highly active forum was a tremendous educational resource available to participants of the MOOC seeking timely answers to their questions. However, this social opportunity is not particularly unique to IIPP. Such forum activity should exist in any massive online class in which the level of activity reaches a critical threshold where it continually engages student attention and encourages active monitoring of forums. However, we leveraged CodeSkulptor and the forums in two ways that we believe are novel.

Peer feedback threads: While peer assessment was a popular component of IIPP, our students embraced the social nature of the class in a way that we did not fully anticipate. In the Fall 2012 session, approximately 13500 students submitted the first mini-project by the required deadline. After the deadline, we were besieged by requests from hundreds of students to extend the deadline and allow late submission. Due to the logistics of peer assessment, we could not allow extensions. As a way to provide these students with a feedback mechanism for their work, we created a "Peer feedback" thread in the sub-forum for the mini-project and encouraged students to anonymously post the URL for their mini-project in this thread. The directions for the thread asked that, if you posted in the feedback thread, you should review and comment on three of your peer's posted programs.

This idea proved to be highly popular with class participants. More than 700 students posted links to their mini-projects in this thread generating more than 2200 peer comments. Most of the posted code received comments that were helpful to the submitter. As was the case for traditional peer assessment, the open anonymous nature of these reviews also provided a valuable educational opportunity for students, allowing them to view a wide range of possible solutions as well as their peers' comments on these solutions.

The Hall of Fame: The knowledge level of the participants in IIPP was very diverse. Most of the students were either complete novices or had a very limited programming background. However, a significant minority of the class was relatively advanced and participating in the class to learn more about building games. As instructors, we viewed the participation of these students in the class as being beneficial since many of them actively participated in the class forums and answered novice questions.

To challenge and nurture this segment of the class, we create a special class forum known as "The Hall of Fame". This forum included two sub-forums, one for enhancements to existing class mini-projects and one for original game design ideas. The Hall of Fame allowed advanced students to challenge themselves beyond the basic mini-projects required in the class while motivating less advanced students to work hard at honing their skills so they could create a game for their peers. During the Spring 2013 session, approximately 250 enhanced versions of class mini-projects and 125 original games were developed by class participants.

Again, this activity was made possible due to the web- and cloud-based nature of CodeSkulptor. Students could share a project via a single URL with all assets (such as art and sound) hosted on the web. Several of the games were the results of collaborative development between multiple students in which one student would post an initial version and other students would then post enhanced versions with new features.

4. CONCLUSIONS

Our students' views of our class were extremely positive. Out of 4442 exit survey respondents for the Spring 2013 session, 66% rated the class as "Excellent", 28% "Very good", 5% "Good", 0.5% "Fair" and 0.0005% (2 responders) "Poor".

In our opinion, much of this popularity is due to the social environment that we created and helped foster in the class. Students actively engaged with each other to learn and teach themselves. The tools and format we provided, including CodeSkulptor, the Code Clinic, peer assessment, and the structure of the class forums made this possible.

In summary, we believe that a critical key to the success of massive online courses in the future will be the development of web-based environments that allow for fast, simple creation, saving and sharing of student assignments. In our case, the development of CodeSkulptor has also paid dividends for Rice's on-campus introductory CS classes by allowing students and instructors to create, share and assess code in a very streamlined manner. More generally, we see the advent of MOOCs as an opportunity to develop and test technology that will enhance the learning experience for both on-campus and online students.

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